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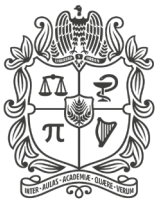

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## CONTENTS

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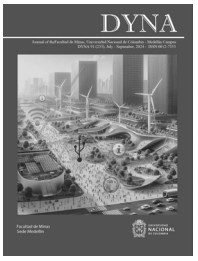

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## CONTENIDO

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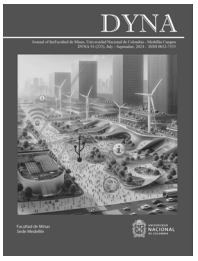

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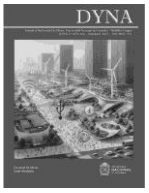

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# Optimization of the enzymatic clarification process of glucose syrups derived from agro-industrial residues

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**Abstract**
In this work, the application of pectinase enzymes to clarify glucose syrups produced from corn fiber was studied. The enzymatic activity and kinetic parameters of the pectinase enzyme used were quantified. A specific activity of 5,528 U/mg protein, a maximum rate of 19151 U/mL, and a Michaelis-Menten constant of 1,656 mg/mL were obtained. The syrup was prepared by hydrolyzing corn fiber at 50°C and 180 rpm, and a central composite design was performed for the clarification step to find the optimal conditions of enzyme-substrate ratio and agitation. The syrup was heated to a temperature of 50°C, and an enzyme substrate ratio between 2.5 to 4.5 U/mL of syrup and agitation, varying between 215 to 285 rpm, was applied. The conditions to maximize the clarification of corn fiber syrup were determined to be an enzyme substrate ratio of 3.716 U/mL syrup and agitation of 267 rpm. These conditions were validated by taking the syrup from clarity of 65.8% to 88.1%, demonstrating that the methodology used presents advantages in the syrup clarification process. A physicochemical characterization of the corn fiber used to prepare the syrups was carried out, which presented a content of 12.90%, 23.33%, 13.4%, and 0.36% of cellulose, hemicellulose, lignin and pectin, respectively.

*Keywords*: enzymatic hydrolysis; glucose syrup; pectin; polygalacturonase; enzymatic clarification.

# Optimización del proceso de clarificación enzimática de jarabes glucosados a partir de residuos agroindustriales

**Resumen**
En este trabajo se estudió la aplicación de enzimas pectinasas para clarificar jarabes de glucosa producidos a partir de fibra de maíz. Se cuantificó la actividad enzimática y los parámetros cinéticos de la enzima utilizada. Se obtuvo una actividad específica de 5.528 U/mg de proteína, una velocidad máxima de 19151 U/mL y una constante de Michaelis-Menten de 1.656 mg/mL. El jarabe se preparó hidrolizando fibra de maíz a 50°C y 180 rpm, y se realizó un diseño compuesto central para la etapa de clarificación con el fin de encontrar las condiciones óptimas de relación enzima-sustrato y agitación. El jarabe se calentó a una temperatura de 50°C, y se aplicó una proporción enzima-sustrato entre 2,5 y 4,5 U/mL de jarabe y una agitación que varió entre 215 y 285 rpm. Se determinó que las condiciones para maximizar la clarificación del jarabe de fibra de maíz eran una proporción de sustrato enzimático de 3,716 U/mL de jarabe y una agitación de 267 rpm. Estas condiciones se validaron llevando el jarabe de una claridad del 65,8% al 88,1%, demostrando que la metodología empleada presenta ventajas en el proceso de clarificación del jarabe. Se realizó una caracterización fisicoquímica de la fibra de maíz utilizada para preparar los jarabes, que presentó un contenido de 12,90%, 23,33%, 13,4% y 0,36% de celulosa, hemicelulosa, lignina y pectina, respectivamente.

*Palabras clave*: hidrólisis enzimática; jarabe glucosado; pectina; poligalacturonasa; clarificación enzimática.

## 1 Introduction

Currently, industries such as agriculture, sugar refineries, fruit juice, and coffee production present challenges in the disposal of their residues, such as peels, seeds, leaves, and stems. In Colombia, approximately $72\times10^6$ tons of these wastes are produced annually, taken to landfills, or incinerated [1].

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Researchers have studied strategies to transform these wastes into products of industrial interest, such as fertilizers, food additives, chemical compounds, and furfural used to manufacture plastics, solvents, oil, or the production of liquid and gaseous fuels [2-4].

One of those strategies is the transformation of amylaceous and lignocellulosic residues by enzymatic hydrolysis to produce glucose syrups as a value-added product. These syrups are glucose-rich solutions with the capacity to sweeten and produce energy and with the ability to bring brightness to the manufacture of transparent beverages. They are ideal for animal nutrition or as ingredients for the preparation of medicines [5-8].

The first stage in the production of glucose syrups is the pretreatment. In this stage, compounds such as lignin and hemicellulose are degraded, leading to more access to cellulose or starch by the enzymes used in the subsequent stages. This pretreatment can occur by milling, acids, or high temperature and pressure in the presence of water. The next stage is the application of amylase or cellulase, enzymes that can hydrolyze the bonds of starch and cellulose, obtaining an opaque solution rich in glucose. This solution is then subjected to clarification and discoloration processes to reduce turbidity and color and a concentration process to eliminate part of the water that composes it, obtaining more concentrated solutions with a higher level of sweetness [5-8].

This clarification and discoloration stage is commonly performed by decantation, centrifugation, filtration, or adsorption with activated carbon or ion exchange membranes [9-11]. In the decantation process, the mixture that needs to be separated is left undisturbed until the solids dispersed into the liquid settle at the bottom of the recipient thanks to the action of gravity and their difference in density, which then can be separated by pouring the clarified liquid gently. The centrifugation process is quite similar to the decantation process, but instead of gravity, centrifugal force is used to force the solids into the bottom of the recipient. In filtration, the liquid is forced to pass through a porous filter, trapping the solids bigger than the pores on one side while the clarified liquid passes through the filter. Activated carbon and ion exchange membranes are used to remove non-charged and charged particles, respectively, that may impair unwanted colors, flavors, and smells to the clarified product, thanks to the action of intermolecular (van der Waals forces for the Activated carbon) and intramolecular forces (Ionic bonds for the ion exchange membranes) that bond those molecules to the solid media.

These stages' objective is to remove dissolved substances such as cell wall debris, proteins, and fats not degraded during hydrolysis, which scatter the light that enters these products, contributing color and turbidity to the syrups [12-17]. Nevertheless, most of the clarification methods have drawbacks: more viscous fluids need longer clarification times and faster speeds or more pressure to have an efficient process, decantation, and centrifugation, despite being simple, present material losses of around 50%; filtration, despite the good results, requires the use of a stepwise process with expensive equipment; and adsorption, even with a high capacity to remove colored compounds, also absorbs around 14.4% of the total reducing sugars in the syrups and the syrup may end with a darker coloration if the carbon cannot be removed entirely [15-19].

Among the residues that affect turbidity is pectin, a complex polysaccharide presents in the cell wall of higher plants, composed of long linear chains of polygalacturonic acid linked by α-bonds (1-4) and branched regions of various sugars linked by up to 20 different types of bonds [20-23].

The removal or degradation of pectin is a process of industrial interest due to the ability of pectin to form gels. The linear regions of pectin interact, forming three-dimensional networks where other solid particles are trapped, increasing the turbidity and viscosity of the solutions, giving a less desirable appearance for the consumers of the final product, and hindering processes dependent on fluid viscosity [24-27].

A clarification method studied in the fruit juice and wine industry is the use of pectolytic enzymes for clarification because these enzymes could modify and degrade pectin, obtaining a more significant amount of a more precise product during the extraction processes, in addition to facilitating the transport and processing of these products by reducing their viscosity [28-36]. This work proposed a strategy for clarifying glucose syrups using pectic enzymes. An experimental design utilizing response surface methodology was developed to determine the optimal agitation and enzyme-substrate (E/S) ratio for the clarification stage. Before this, the raw material was characterized, and the enzymatic activity was measured along with the estimation of kinetic parameters of the pectic enzyme.

## 2 Materials and methods

### *2.1 Materials*

Corn fiber was used as a substrate to produce glucose syrups, consisting of the remains of the endosperm of corn kernels resulting from corn maceration and starch extraction [32-36]. The enzyme pectinase/polygalacturonase (EC 3.2.1.15) produced from *Aspergillus niger* was used in the enzymatic hydrolysis. The enzyme preparation consists of a brown, clear solution with glycerol as a base, stored at temperatures between 2 and 8°$C$ for preservation. According to the supplier, the enzyme solution reported an enzymatic activity $> 5\ U/mg$ of enzyme units per milligram of protein. One enzyme unit corresponds to the amount of enzyme that produces one µmol of galacturonic acid per minute at a pH of 4.0 and a temperature of 45°$C$.

### *2.2 Characterization of the raw material*

To determine the chemical composition of the corn fiber, it was subjected to a characterization following the protocols proposed by the National Renewable Energy Laboratory (NREL) [37-41] modified by the laboratory of processes and reactive flows of the Universidad Nacional de Colombia-Medellín (BIOFRUN). Moisture content and total solids were determined by drying the samples in a Binder convection oven at 105°$C$ (NREL TP-510-42621), ash content by calcining the samples in a muffle with a temperature ramp up to 575°$C$ (NREL TP-510-42622), and extractives in water, ethanol, and hexane by heating the solvent to boiling point, (NREL TP-510-42619). Then, their

structural carbohydrate, cellulose, hemicellulose, and lignin content was determined by acid hydrolysis (NREL TP-510-42618 and TP-510-42617) and their starch content using amylase enzymes to degrade this compound (NREL TP-510-42624), measuring the amount of sugar produced to calculate the proportion of these polysaccharides in the sample.

For the determination of pectin content, the procedure described by the Mexican Official Standard F-347-S-1980 [42] was used: boiling $50g$ of the material in $400mL$ of distilled water, precipitating the pectin with $1N$ sodium hydroxide, $1N$ calcium chloride, and $1N$ acetic acid, and filtering the sample through a Whatman No. 41 filter paper, to measure the change in weight that this filter undergoes after this process.

### *2.3 Production of syrup from corn fiber*

The methodology proposed in the BIOFRUN laboratory patents produced syrups [7,8]. It starts with a thermal pretreatment of the raw material, adding distilled water and corn fiber until a percentage of solids of 15% is obtained. The solution then was autoclaved, subjecting it to high pressure (15-20 PSI) and temperature ($121°C$) conditions for 40 minutes. The solids obtained were washed with distilled water and dried following the NREL TP-510-42620 protocol [43].

Once the drying process was completed, enzymatic hydrolysis was performed by adding $28g$ of the material and $375g$ of 0.1 $M$ acetate buffer with a pH of 5.0. Subsequently, $3.6\% v/v$ cellulase was added. The resulting solution was incubated at a temperature of $50°C$ and $180rpm$ agitation for 48. Finally, the glucose-rich solution was subjected to a boiling water bath to denature the enzyme.

To verify the degradation of the corn fiber, the dissolved solids ($°Brix$) present in the solution were monitored by taking $1mL$ of the solution and depositing it in a PAL-BX/RI pocket refractometer for $48h$. The final pectin content of the syrup was also measured using the procedure mentioned in section 2.2 above.

### *2.4 Determination of the enzymatic activity of pectinases.*

For the determination of the enzymatic activity of the pectinase, the methodology proposed by Li et al. [44] was followed. Initially, a calibration curve was constructed with 1/6000, 1/9000 and 1/12000 dilutions of the enzyme, which were incubated at $50°C$ for $30min$, in a $5g/L$ solution of apple pectin, allowing to determine the amount of galacturonic acid released using the 3,5-dinitrosalicylic acid (DNS) method. The curve generated by these points was used to determine the enzyme concentration that releases 0.4 $g/L$ of galacturonic acid, which can be used in Eq (1) to find the activity of the original enzyme solution.

$$Activity_{Enzime} = Dilution\ Factor \frac{0.687\ U}{mL} \quad (1)$$

Where 0.687 $U/mL$ corresponds to the theoretical amount of enzyme that releases 0.4 $g/L$ of galacturonic acid. According to the assays of Li et al. [53], the product release curve presents a linear region between 0.2 and 0.6. This central point was selected.

To determine the amount of protein in the enzymatic solution, the method proposed by Bradford [45] was used, measuring the absorbance at 595 $nm$ by mixing the solution with a dye prepared from Coomassie Brilliant Blue G-250 and comparing the absorbance of the samples against a calibration curve prepared from bovine serum albumin in an interval of 0.2 to 2.0 $g/L$.

### *2.5 Modified DNS method*

A modified version of the DNS method proposed by Li et al. [44] was used. The DNS reagent was prepared by diluting $1g$ of 3,5-dinitrosalicylic acid and $1.6g$ sodium hydroxide in $100mL$ distilled water. $3mL$ of these reagents were added to 1 ml of the studied solutions in $25mL$ test tubes, which were heated in a boiling water bath for $5min$ and cooled in an ice bath for $10min$ to develop the color. Finally, 16 $mL$ distilled water was added to make an initial dilution.

To obtain a standard against which the amount of sugar in the above samples could be compared, a calibration curve was prepared using galacturonic acid solutions from 0.125 to $20.0g/L$. Finally, the absorbance of the samples was measured at 540 nm in a Thermo Scientific™ Evolution 60S UV-visible spectrophotometer, performing a second dilution of the samples if the measured absorbance exceeded a value of 0.8.

### *2.6 Optimization of the clarification process by statistical analysis*

To find the optimal conditions of agitation and E/S ratio, a composite central design generated with the Minitab® 2015 program was performed, the intervals and axial points ($\alpha$) for E/S ratio and agitation used in this central design are reported in Table 1.

While the temperature is an important factor in enzymatic reactions, this parameter was discarded as an option because the temperature interval recommended by the enzyme manufacturer and used by the different researchers that studied this kind of enzyme was only from 40 to 50 °C. This short work interval may not show any appreciable improvement in the clarification, so the other two not studied were chosen to reduce the number of experiments needed for this study.

The design obtained corresponds to 4 experiments using the axial points, 4 experiments combining the ends of the intervals, and 6 central points, for a total of 14 experiments.

During these trials, $100mL$ syrup centrifuged at 4500 $rpm$ was used, and clarification was performed at $50°C$ for two hours using the studied parameters. Once this period was over, syrup clarity was measured, expressed as the percentage transmittance

Table 1.
Central composite design.

| Variable | Value | | | | |
|---|---|---|---|---|---|
| | $\alpha$- | -1 | 0 | +1 | $\alpha$+ |
| E/S ratio ($U/mL$) | 2,08 | 2,50 | 3.50 | 4,50 | 4,91 |
| Agitation ($rpm$) | 200,5 | 215,0 | 250,0 | 285,0 | 299,5 |

Source: The authors.

at 600$nm$ (%T 600) using a Thermo Scientific™ Evolution 60S UV-Visible spectrophotometer, pH with a pH-meter Titulador 848 Titrino plus, total solids ($°Brix$) with a PAL-BX/RI pocket refractometer and reducing sugars using the DNS method. These data were analyzed by analysis of variance (ANOVA) using the R program (version 4.2.0).

There are other methodologies to evaluate the efficiency of clarification like: measuring the change in the turbidity of the syrup [13], comparing the absorbance at certain wavelengths [14] or checking how much solids were removed from the syrup [15]. %T 600 was chosen as the measuring method since it was the most common method to measure the clarification of fruit juices using pectinases.

### *2.7 Determination of the kinetic parameters of the enzyme*

To determine the kinetic parameters of the pectinase, maximum velocity ($V_{max}$), and the Michaelis-Menten constant ($K_m$), a Lineweaver-Burk diagram was used, preparing 300$mL$ apple pectin solutions with concentration between 0.01-0.15%$w/w$, which were treated with the optimum E/S ratio and stirring determined in the design of experiments. The kinetics of the process were determined by taking a 5$mL$ sample every 5$min$, and inactivating the enzyme in a boiling water bath. The amount of galacturonic acid released was then measured using the DNS method.

Subsequently, the amount of sugar released in moles was plotted against time, and the slope generated by the first 5 experimental data was taken to determine the initial velocity ($V$) of the process. These velocity values are used to create a Lineweaver-Burk plot, plotting the inverse of the velocity ($1/V$) against the inverse of the substrate concentration ($1/S$), which allows the determination of $V_{max}$ and $K_m$.

### *2.8 Kinetics of the clarification process*

The change in clarity and concentration of reducing sugars over time of enzymatic hydrolysis treated syrups were monitored by subjecting 300$mL$ of syrup to the clarification process, using the optimum enzyme concentration and agitation at 50°$C$. Every 20$min$ 10$mL$ of solution were removed, inactivating the enzyme in a boiling water bath at 95°$C$ for 5$min$ and cooling in an ice bath, then centrifuged at 4500$rpm$ for 5$min$. Employing the DNS method, the amount of galacturonic acid released and the transmittance at 600$nm$ was measured to determine the clarity in the syrups produced.

## 3 Results and Discussion

### *3.1 Characterization of the raw material*

Due to the complexity of the lignocellulosic materials, the NREL characterization methodologies have a total composition range from 90 to 110%. Table 2 presents the results of the characterization of the corn fiber; with these tests, it was determined that 12.90% of the material was cellulose, which cellulases can hydrolyze, and 0.36% was pectin, which ends up in the syrups by the processes of heating and hydrolysis of cellulose.

Comparing the results obtained with those presented by Gáspár et al., Kálmán et al., Kaur et al., and Zhang et al. [32-36], similar values for cellulose and ash can be seen in the work of Kálmán et al [34]. which reports a value of 15% for cellulose and 1% for ash. The value of hemicellulose was lower compared to this work, where they report a value of 37.1%, closer to the value reported by Kaur et al. [35] where a value of 22.4% is presented. The article by Gáspár et al. [33] is the only one that reports a lignin value, obtaining a value of 12.2%, quite similar to that obtained in this study. A possible source of variation is the presence of starch reported by these authors; the residue used in this test has undergone several processes to remove the starch and other valuable compounds, while the literature reports corn fiber in nature from which the starch has not yet been removed or has only undergone the starch removal process.

Table 2.
Characterization of corn fiber

| Compounds | Percentage (%) |
|---|---|
| Humidity | 8.5 ± 0.1 |
| Total Solids | 91.5 ± 0.1 |
| Cellulose | 16.3 ± 0.1 |
| Hemicellulose | 27.5 ± 0.1 |
| Lignin | 13.4 ± 0.1 |
| Pectin | 0.4 ± 0.3 |
| Starch | 0.0 ± 0.1 |
| Protein | 18.5 ± 0.1 |
| Ash content | 0.6 ± 0.1 |
| Total extractives | 32.4 ± 0.1 |
| Total | 109.2 ± 0.1 |

Source: The authors.

### *3.2 Production of syrup from corn fiber*

Table 3 shows the characteristics of the syrups produced for the clarification tests. Observing the development of dissolved solids, this was very similar in all the trials, doubling during the first 24$h$ after the enzyme was added but remaining approximately constant until 48$h$ were reached. These five solutions were centrifuged at 4500 $rpm$ for 5 $min$ to eliminate the larger solids and combined, obtaining a syrup with 4.8 °$Brix$ and a pectin concentration of 0.13 ± 0.02 %.

Table 3.
Characteristics of the syrups

| Vessel | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Solids ($\pm 0.0001\ g$) | 28.29 | 29.20 | 28.25 | 28.05 | 28.02 |
| Buffer ($\pm 5g$) | 375 | 375 | 375 | 375 | 375 |
| %Solids (%$w/w$) | 7.01 | 7.22 | 7.01 | 6.96 | 6.95 |
| %Enzyme (%$v/v$) | 3.70 | 3.70 | 3.70 | 3.70 | 3.70 |
| Initial Brix($\pm 0.1°Brix$) | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| Enzyme Brix ($\pm 0.1°Brix$) | 2.3 | 2.4 | 2.6 | 2.6 | 2.6 |
| Brix 24$h$ ($\pm 0.1°Brix$) | 5,2 | 5,0 | 5,0 | 5,1 | 4,9 |
| Brix 48$h$ ($\pm 0.1°Brix$) | 5,4 | 5,1 | 5,0 | 5,0 | 5,0 |

Source: The authors.

### *3.3 Determination of the enzymatic activity of the pectinase.*

The amount of galacturonic acid released by the enzymatic solutions with a dilution factor of 6000, 9000, and 12000 was 0.472, 0.385, and 0.314,$g/L$ respectively, plotting these results against their corresponding dilution factor yielded a line with a coefficient of determination $R^2$ of 0.996 and Equation (2):

$$Dilution\ factor = -37830\ Gal.Acid + 23759 \qquad (2)$$

Replacing the value of $0.4g/L$ in this equation shows that the enzyme concentration that releases $0.4g/L$ of galacturonic acid has a dilution factor of 8627; using this data in Equation (1) it was determined that the original enzyme solution has an activity of 5.926 $U/\mu L$.

The albumin calibration curve between 0.2 to 2.0 $g/L$ used for protein determination has a coefficient of determination $R^2$ of 0.968 and is represented by Equation (3):

$$Concentration\ (g/L) = 40.5826Abs - 0.0439 \qquad (3)$$

Where $Abs$ is the absorbance of the sample, and concentration ($g/L$) is the amount of protein present in the sample. Measuring the absorbance at 595$nm$ of 1$\mu L$ of enzyme solution dissolved in 0.999$mL$ of distilled water, we found an absorbance of 0.027 ± 0.001, which corresponds to a concentration of 1.072 $mg/\mu L$ protein in the enzyme solution, which allows us to find that the specific activity of the enzyme has a value of 5.528 $U/mg$ protein, which agrees with the value reported by the supplier of > 5 $U/mg$ protein.

### *3.4 Optimization of the clarification process by statistical analysis*

The results of clarity, pH, galacturonic acid released and dissolved solids for the 14 trials, a blank without enzymatic treatment, and uncentrifuged syrup are shown in Table 4.

Table 4.
Design of experiments for the clarification step.

| Test | E/S ratio | Agitation | Clarity (%T 600) | pH | Released sugars ($g/L$) | Solids ($°Brix$) |
|---|---|---|---|---|---|---|
| 1 | $\alpha$+ | 0 | 74.4 | 4.85 | 25.26 | 4.7 |
| 2 | 0 | 0 | 79.7 | 4.84 | 24.55 | 4.6 |
| 3 | 0 | 0 | 78.5 | 4.83 | 24.51 | 4.6 |
| 4 | -1 | +1 | 77.2 | 4.82 | 24.70 | 4.5 |
| 5 | +1 | -1 | 77.7 | 4.85 | 25.31 | 4.6 |
| 6 | 0 | $\alpha$- | 71.4 | 4.83 | 23.18 | 4.6 |
| 7 | 0 | 0 | 79.1 | 4.83 | 24.65 | 4.6 |
| 8 | -1 | -1 | 69.7 | 4.86 | 24.22 | 4.6 |
| 9 | 0 | 0 | 80.1 | 4.83 | 24.41 | 4.6 |
| 10 | 0 | 0 | 79.3 | 4.84 | 24.32 | 4.6 |
| 11 | $\alpha$- | 0 | 67.5 | 4.87 | 23.94 | 4.5 |
| 12 | +1 | +1 | 77.8 | 4.85 | 25.12 | 4.6 |
| 13 | 0 | 0 | 76.9 | 4.84 | 24.51 | 4.6 |
| 14 | 0 | $\alpha$+ | 77.1 | 4.75 | 24.70 | 4.6 |
| Control | - | - | 62.6 | 4.89 | 22.66 | 4.5 |
| Raw syrup | - | - | 11.8 | 4.91 | 22.37 | 4.5 |

Source: The authors.

Table 5.
ANOVA for clarity.

| Coefficients | Values | *p* Values |
|---|---|---|
| $R^2$ | 0.878 | 0.001707 |
| $R^2_{adjusted}$ | 0.802 | 0.001707 |
| Constant term | 78,933 | 5.138e-14 |
| E/S ratio | 2.29476 | 0.006049 |
| Agitation | 1.95763 | 0.013480 |
| (E/S ratio)$^2$ | -3.24167 | 0.001026 |
| Agitation$^2$ | -1.59167 | 0.039002 |
| (E/S ratio) (Agitation) | -1.85000 | 0.068000 |
| Lack of fit | - | 0.064043 |

Source: The authors.

An analysis of the results shows that a higher enzyme ratio releases more galacturonic acid, which leads to a reduction in pH, and also shows a slight increase in dissolved solids as more enzyme is applied, but when studying the interaction between the enzyme ratio and agitation, and the effect that these variables have on clarity, it is difficult to find a clear result, so these data were processed with R (version 4.2.0). Table 5 displays the ANOVA results.

The second-order model generated by the ANOVA analysis shows that the first and second-order coefficients for the enzyme ratio and agitation are significant, with a confidence level higher than 95%, presenting a p-value lower than 0.05. Still, the interaction of these two coefficients shows a *p*-value higher than 0.05, which cannot be assumed to be significant at this confidence level. The following polynomial expression can express this empirical model:

$$\begin{aligned} Clarity\ (\%T600) = {} & 78.933 + 2.295\ E/S\ ratio \\ & + 1.958 Agitation \\ & - 3.242\ (E/S\ ratio)^2 \\ & - 1.59167 (Agitation)^2 \end{aligned} \qquad (4)$$

The performance of this model can be verified with the values of the coefficient of determination ($R^2$), adjusted coefficient of determination ($R^2_{adjusted}$), and the p-value of the lack of fit. The data used to generate the model are adjusted to this, so the value of R2 and adjusted $R^2$ are close to 1 and present a p-value (0.001) less than 0.05. On the other hand, the lack of fit to the model has a value of 0.06, greater than 0.05, showing that this model is acceptable for representing these points and predicting new values. Plotting these results (Fig. 1), the clarity presents a maximum when applying 3.716 units of enzyme per ml of syrup (0.627 $\mu L$ of enzyme solution per mL of syrup) and a stirring of 267 $rpm$. When using a lower amount of enzyme, the pectin residues are not entirely removed, and a lower clarity is obtained. In comparison, if a higher amount of enzyme is used, the presence of these dissolved compounds causes the light transmittance to be lower, resulting in fewer clear syrups.

To validate the results of this model, clarification tests were performed in triplicate at the optimum point (3.7143 $U/mL$ and 267.4991$rpm$), one with high agitation and high enzyme (4.9142$U/mL$ and 299.4975$rpm$), and one with low agitation and low enzyme (2.0858 $U/mL$ and 200.5025$rpm$), comparing the results obtained with those predicted. Table 6 shows the results.

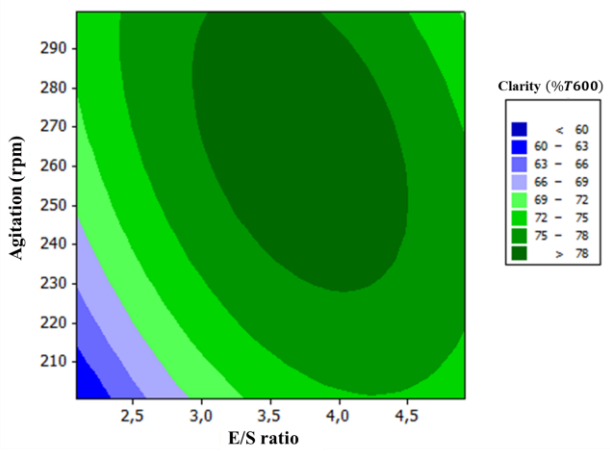


Figure 1. Contour plot, clarity concerning agitation and E/S ratio.
Source: Author made

Table 6.
Validation of the central composite design.

| Test | Predicted value | Expected value | %Error |
|---|---|---|---|
| High | 74.9 ± 2.9 | 74.9 | 0.1 |
| Maximum | 78.6 ± 0.6 | 79.7 | 1.4 |
| Low | 70.3 ± 1.7 | 71.1 | 1.1 |

Source: The authors.

Table 7.
Initial velocities and concentration.

| Substrate concentration (% $w/w$) | Initial velocity ($g/L/min$) |
|---|---|
| 0.010 | 0.012 |
| 0.015 | 0.017 |
| 0.030 | 0.035 |
| 0.090 | 0.112 |
| 0.150 | 0.186 |

Source: The authors.

Low error values (<2%) indicate that the model obtained can be used and that the optimum is around 3.7143$U/mL$ and 267.4991 *rpm*.

### *3.5 Determination of enzyme kinetic parameters.*

The apple pectin solutions used for this determination were 0.010, 0.015, 0.030, 0.090, and 0.150% w/w, the initial velocity obtained by plotting the amount of galacturonic acid released against time, taking the slope obtained in the first 25 minutes can be seen in Table 7. Plotting the inverse of these initial velocity values and the inverse of the pectin concentration in moles, the Lineweaver-Burk diagram is obtained, which has a coefficient of determination of 0.998 and is explained by the equation:

$$I/V_i = 6.68E - 0.4/[pectin] + 0.0522 \quad (5)$$

This diagram found that the enzyme is 2439.7 $mg/mL/min$ and an $K_m$ of 1.656 $mg/mL$, similar to that obtained by Dalagnol et al. [46]. A comparison between these results can be made because, in this study, the activity of pectin enzymes produced by the fungus Aspergillus niger, using apple pectin as substrate, is also sought. The presence of polymorphisms in the enzymes of the pectinase family and the use of other factors at the time of finding the parameters, such as the use of ultrasound or the application of other methods of obtaining and purification, are possible reasons to explain the difference obtained in the work of Dalagnol et al. [46] and the current work.

### *3.6 Kinetics of the clarification process*

A new syrup sample was prepared for these tests following the same steps as in the previous experiments. This solution initially presented a clarity of 65.8 %T 600 nm, 0.051 ± 0.002 % pectin, and a reducing sugars concentration of 17.636 g/L. After two hours of treatment, the increase in clarity reached a value of 88.1 %T 600 nm, following a curved line with a determination coefficient $R^2$ of 0.993, which is described by the polynomial equation:

$$Clarity\ (\%T\ 600nm) = 66 + 0.15t + 2.66E - 4t2 \quad (6)$$

Reducing sugars reached a value of 20.901$g/L$, and this property also followed a curved line, which can be described by the following equation, presenting a value $R^2$ of 0.987.

$$Sugar\ (g/L) = 17.5 + 0.0445t - 1.28E - 4t^2 \quad (7)$$

Comparing these results with those obtained during the previous clarification tests shown in Table 4, a greater clarity of the syrup was obtained. Still, a lower amount of galacturonic acid was released. One possible explanation for these results is the lower initial amount of pectin, which allowed the enzyme to remove most of this compound, resulting in a final syrup with less pectin that is clearer and, as less pectin is degraded, less galacturonic acid is released. As the tridimensional net of galacturonic acid is degraded by the enzyme, the solids trapped by it get released. Since both the pectin and the trapped solids contribute to the haziness of the syrup, the clarification process starts fast and then begins to slow down as pectin becomes scarce.

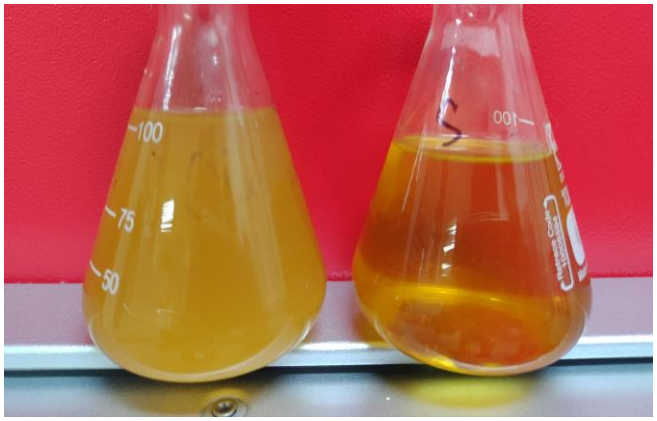


Figure 2. Untreated and treated syrup.
Source: The authors.

## 4 Conclusions

In this work, a methodology for clarifying glucose syrups using pectolytic enzymes was proposed. The characterization of the corn fiber used for syrup preparation determined the presence of 16.51% cellulose, 27.83% hemicellulose, 13.4% lignin, 0.36% pectin, 0.6% ash, and 32.45% extractives. An ANOVA analysis determined that the amount of enzyme and agitation that generated the highest response in the clarity of the syrup were around 3.716 $U/mL$ and an agitation of 267 $rpm$, obtaining a syrup with a notably more transparent appearance and a lighter color (as shown in Fig. 2), which may be more desirable for consumption. Additionally, a characterization of the enzyme from *Aspergillus niger* was carried out, which presents an activity of 5.528$U/mg$ and a $V_{max}$ of 19151$U/mL$ and $K_m$ of 1,656 $mg/mL$, when corn fiber is used as a substrate of the process. From the different results, we will seek to study the modeling of the clarification process by simulating the pectin degradation process and see how this affects the clarity of the syrup over time.

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# FinTech and its relationship to SMEs financing: a systematic literature review and future research agenda

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**Abstract**
This paper presents a systematic review of the literature, the state of the art and a future research agenda on the relationship between FinTech and the financing of small and medium-sized enterprises (SMEs). Digitalization and technological evolution have transformed access to financial resources, challenging SMEs in obtaining adequate financing. The emergence of FinTech offers new perspectives and opportunities, potentially revolutionizing how SMEs access and use financial services. Against this backdrop, 26 papers were extensively examined to analyze the relationship between the FinTech industry and its relationship with SMEs financing, possibilities, difficulties, and expectations in the current market in different parts of the world. Exploratory Research was found to be the most applied perspective to analyze the relationship between FinTech and SMEs.

*Keywords*: financing; fintech; small and medium-sized enterprises.

# Fintech y su relación con el financiamiento de Pymes: una revisión sistemática de literatura y una agenda de investigación futura

**Resumen**
Este artículo presenta una revisión sistemática de la literatura, el estado del arte y una futura agenda de investigación sobre la relación entre Fintech y el financiamiento de Pequeñas y Medianas Empresas (Pymes). La digitalización y la evolución tecnológica han transformado el acceso a los recursos financieros, desafiando a las Pymes a obtener financiación adecuada. El surgimiento de Fintech ofrece nuevas perspectivas y oportunidades, revolucionando potencialmente la forma en que las Pymes acceden y utilizan los servicios financieros. En este contexto, se examinaron exhaustivamente 26 artículos para analizar la relación entre la industria Fintech y su relación con el financiamiento de las Pymes, las posibilidades, dificultades y expectativas en el mercado actual en diferentes partes del mundo. Se descubrió que la investigación exploratoria es la perspectiva más comúnmente aplicada para analizar la relación entre Fintech y las Pymes.

*Palabras clave*: financiación; fintech; pequeñas y medianas empresas.

## 1 Introduction

The acronym FinTech is a compound term, which literally means Financial Technology. In a broader context, it is a company or part of a company that combines modern financial services with innovative technology, characterized by their focus on user experience, the use of advanced technologies such as Machine Learning (ML) and Artificial Intelligence (AI), as well as their ability to adapt quickly to changing market demands [1]. They represent a group of companies that provide financial services using digital platforms, merging innovative business models with advanced technology to provide a diversity of products and services [2]. This term not only encompasses technological advances, but also reflects transformations in banking and finance. Among the new technologies are applications for mobile devices, while innovations such as exclusive online banking and crowdsourcing allow people to manage their

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finances differently from traditional banking [3].

The FinTech revolution is driven by a wave of startups that adopt innovative business models, transforming existing services to meet the demands of contemporary customers [4]. Financial innovation known as FinTech is characterized by generating new business models, applications, processes, or products that have a substantial impact on markets, financial institutions, and the provision of financial services [5]. Innovation in the financial sector that results in the creation of new services more aligned with customer needs plays a significant and positive role in fostering Financial Inclusion [6]. This concept entails the availability of useful and affordable products and services to individuals and businesses, satisfying their requirements through secure and effective transactions, which in turn are delivered in a responsible and sustainable manner [6,7]. The concept of financial inclusion translates into access to and use of high-quality financial services by various sectors of the population, thus laying the foundations for a more equitable and accessible financial system [8]. The application of information and communication technologies has boosted financial innovation, streamlining processes, reducing costs, and making it possible to reach new users [9].

Banks, by staying at the forefront of these technological trends, have managed to explore and adopt these business models [10]. Thus, the definition of FinTech has evolved over the years. The concept has expanded to include a variety of companies that offer innovative financial solutions [11]. Thus, innovation has become an increasingly important part of FinTech, where innovation is a means to improve financial services [12]. Finally, in recent years, the user experience and how these companies can offer more accessible and personalized financial solutions has occupied the central role [13].

Two major trends are emerging in this context. The first relates to the acceleration of change brought about by Big Data, Machine Learning, the commoditization of technology and AI. The second trend is the fact that non-financial companies have entered and invested in financial services, in key areas in the development of Industry 4.0 [14]. Following this line, significant growth is observed worldwide. In 2020, global FinTech investments reached a record $105 billion, up 10.9% compared to 2019 [15].

Within the business world, one of the most important players in the economic market, globally, are SMEs; a survey conducted by the World Bank reveals that SMEs represent on average around 96% of all registered businesses in the world and approximately 50% of the workforce [16]. Thus, SMEs tend to dominate the business community in all countries and cover more than 96% of all enterprises in developed countries. They also provide around 75% of jobs in these types of regions [17]. By 2030, it is projected that around 600 million jobs will be required to meet the needs of the global workforce. Consequently, the growth and nurturing of SMEs becomes essential, as they will play a key role in providing most of these job opportunities [18].

The adoption of FinTech solutions by SMEs has been significant due to the accessibility to a wide range of digital services and the presence of an established entrepreneurial and investment ecosystem [19]. In Europe, the adoption of FinTech by SMEs has been variable across countries and the maturity of the regional FinTech ecosystem. In countries such as the UK and Sweden, SMEs have widely embraced FinTech solutions to access finance and improve the efficiency of their operations [20]. Asia has witnessed rapid growth in FinTech adoption in recent years. In countries such as China, India, and Singapore, SMEs have been favored by online financing platforms and digital payments, which have facilitated access to capital and the conduct of business transactions [21]. In Africa, the process has been slower compared to other regions. However, efforts to foster financial inclusion and access to FinTech services are underway in countries such as Kenya and Nigeria, where mobile payment platforms have had a significant impact on local SMEs [22].

Latin America has experienced an increase in the development of FinTech solutions aimed at SMEs. In countries such as Mexico, Brazil, and Colombia, SMEs are adopting digital payment solutions and online financing platforms to boost their growth and competitiveness in the market [23]. These companies, which contribute to the economic development of countries, face numerous obstacles related to their activity and access to sources of financing [24]. In general, one of the central challenges facing this type of enterprise is financing. The main sources of financing are their own or those provided by suppliers, with bank financing or other less conventional sources being relegated and limited [25]. This significant mismatch between the economic impact of SMEs and their access to financing is observed, for example, in Asian SMEs, which receive only 18.7% of total bank credit [26].

The limited involvement of SMEs in obtaining credit from the private sector, as well as their difficulty in accessing appropriate financial conditions, is a challenge that impacts various economies globally, regardless of their level of development. It has been shown that, as the size of companies decreases, the complexity of accessing financial resources increases [27]. In other words, it is potentially riskier and more expensive to provide credit to SMEs [28]. One of the limitations for access to credit for this type of companies is the different criteria for the selection of debtors by the entities [29]. Over time, it is observed that the owner-manager experiences a change in his attitude towards risk and in his goals in relation to the company. These goals evolve from growth or profitability-oriented approaches to more personal goals, such as securing the family's standard of living and income [30]. SMEs face constraints due to high interest rates, resulting in increased financial expenses and the need to provide greater guarantees to financial institutions to obtain approval on their loan applications [31]. Although the SMEs sector is a crucial contributor to employment, diversification, and productivity in any country in the world and especially in developing countries, they still face significant credit constraints through traditional lending institutions. However, the trend is changing and modern digital technologies in the FinTech area are providing new alternatives [32]. Despite advances in research on FinTech and SMEs finance, it is imperative to chart a future research agenda that is based on a bibliometric approach. This involves identifying promising research areas and formulating unresolved questions by

analyzing the existing literature. Bibliometric sources reveal the need to explore the following areas:

Regional and Sectoral Case Studies. Using a bibliometric approach, gaps in specific case studies have been identified in various regions and industry sectors. Further analysis of these areas may shed light on the effects of FinTech on SMEs.

Regulatory and Legal Challenges. The bibliometric review points to the paucity of research on the regulatory and legal challenges faced by SMEs when adopting financial technologies. A detailed exploration of this topic is suggested to better understand its impact.

Risk Assessment and Management Strategies. According to bibliometric trends, there is a gap in the assessment of risk associated with the use of FinTech in SMEs financing. Further bibliometric research is proposed to develop effective risk management strategies.

Innovative and Sustainable Business Models. Based on the bibliometric analysis, the need to explore the integration of innovative and sustainable business models that combine FinTech with traditional financial services is highlighted. This area can offer valuable insights for the benefit of SMEs.

This research agenda proposal is based on the bibliometric review, which provides a comprehensive view of current trends and gaps in knowledge related to FinTech and SMEs. Finally, it is necessary to mention that the work will be approached by applying the Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement methodology, which provides a systematic and transparent approach for conducting systematic reviews and meta-analyses [33]. In the context of this bibliometrics on FinTech using the PRISMA methodology, it is expected to achieve a comprehensive and rigorous review of the scientific and academic literature related to the topic. Key steps in the application of the PRISMA methodology will include identifying relevant literature, selecting studies in a systematic manner, extracting data in a standardized way, and transparently presenting the results [34]. The use of the PRISMA Methodology will allow obtaining a complete and structured view of the current state of research in the FinTech field, identifying trends, gaps, and areas of focus [35]. It will also facilitate the comparison and synthesis of the results of different studies, thus contributing to the advancement of knowledge in this specific area. In summary, this bibliometrics will serve as an essential tool for assessing the current state of knowledge in a specific field, highlighting areas of opportunity, defining research directions, and providing a solid basis for decision making.

## 2 Method

The methodology was approached through documentary research using the Systematic Literature Review technique [36-44], following guidelines established in previous studies. This involved the formulation of a review protocol and research questions, based on the PICOC (Problem, Intervention, Comparison, Outcome, and Context) format. These questions were designed to address critical aspects of the functioning of FinTech Companies that provide services to SMEs, their differentials, future challenges, and the current landscape of the FinTech Industry as a provider of financing solutions for SMEs. The following questions are considered relevant, as they focus on key aspects of the phenomenon studied, such as how FinTech companies operate, how they differ from other financial alternatives, the challenges they face and the role they play in SMEs financing. By addressing these questions, a comprehensive understanding of the dynamics between FinTech and SMEs can be obtained, which contributes to the development of more effective financial solutions tailored to the specific needs of this business sector.

1. How do FinTech companies that provide services to SMEs work? Are there determinants? Are there limiting factors?
2. What are the differentials that FinTech companies provide SMEs?
3. What are the future challenges for FinTech to continue growing and establishing themselves as a source of financing for SMEs?
4. What is the current outlook of the FinTech industry and how does it affect its role as a provider of financing solutions for SMEs, considering aspects such as financial inclusion, digitalization, and access to capital?

In the context of bibliometrics, it was crucial to conduct exhaustive searches in recognized academic databases such as Scopus and Web of Science. These platforms offer broad coverage of the academic literature, allowing a comprehensive collection of relevant studies around interest. In addition, by employing specific search equations, accuracy, and completeness in the identification of relevant documents is guaranteed. Consulting the thesaurus in databases such as STW Thesaurus for Economics helped refine the search terms and ensured the inclusion of relevant vocabulary in the literature search. This rigorous approach was essential to obtain a complete and up-to-date picture of the state of research in the field of study, which in turn allows for the identification of trends, knowledge gaps, and promising areas of research. The search equations used in each are included in Table 1. The observation window covered the initial term of the report in the databases until April 2023.

Table 1.
Utilized search equations.

| Resource | Equation | Results |
|---|---|---|
| Scopus | (TITLE-ABS-KEY (sme OR startup OR entrepreneur*) AND TITLE (financ* OR insurance OR payment OR bank* OR credit) AND TITLE (technology OR fintech OR digital OR embeddedness OR bigdata OR {big data} OR crowfunding OR {sharing economy} OR mobile OR ai OR {artificial intelligence} OR blockchain)) | 355 |
| Web of Science | sme OR startup OR entrepreneur* (Topic) AND financ* OR insurance OR payment OR bank* OR credit (Title) AND technology OR fintech OR digital OR embeddedness OR bigdata OR "big data" OR crowfunding OR "sharing economy" OR mobile OR ai OR "artificial intelligence" OR blockchain (Title) | 261 |

Source: Own elaboration.

The refinement criteria initially applied were based on the guiding questions, the researchers' experience on the subject matter and the articles containing the key interrelated concepts, among which the following stand out: FinTech, SMEs, Financing, Innovation, Financial Inclusion and Technology. Documents that did not have a direct relationship with the guiding questions were excluded to ensure the research focus. Above all, those that mentioned specific problems of certain regional economies or that were exclusively related to topics such as crowdfunding, entrepreneurs, blockchain or venture capital.

It is important to indicate that the systematic review protocol reported here was the one that was executed, its previous versions were tested by 3 professionals, whose profile was selected for meeting at least two of the following conditions: researcher with experience in literature reviews, academic in the area of Economics, Finance and Administration, and professional experience in FinTech and SMEs; the review performed by these experts included the structure of the PICOC question, keywords, syntagms, thesauri, prototype equations and selection criteria (inclusion and exclusion). This stage of the exercise allowed fine-tuning the protocol with the intention of not losing sight of any relevant detail for a successful execution of the review.

Subsequently, the execution of the final equations in both databases resulted in 616 documents, of which, eliminating duplicates, a total of 373 were submitted to the article selection process. At this stage, the titles, and abstracts of the 373 articles were reviewed independently by two reviewers to avoid selection bias, differences were resolved by consensus. The Flowchart (Fig. 1) was illustrated using the methodology Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement [32]. The supporting tool for this process was the Rayyan web application for systematic review [45].

Consequently, the full text of 86 documents was reviewed with the same inclusion and exclusion criteria of the initial selection by title and abstract, this process was also supported by two reviewers who evaluated the documents independently; the information was extracted using a Matrix for RSL in Excel, which involved the review of aspects such as article identification (title, year of publication, journal, authors, language and abstract); in addition, aspects such as: scope, objectives, methodological strategy, results, conclusions, managerial implications, limitations of the study and future research, as suggested by [37].

It is worth mentioning that, in the 86 documents, a deeper analysis of them was carried out again, taking as central variables: the relationship between the FinTech industry and its relationship with SMEs financing, possibilities, difficulties and expectations in the current market in different parts of the world. The number of documents that were related to the central topics to be studied, and complied with the initial agreement, was 26. Within these selected files, the key variables they contained were analyzed and classified according to 3 specific categories. Table 2 presents the categories and key variables in the articles analyzed in relation to quantity.

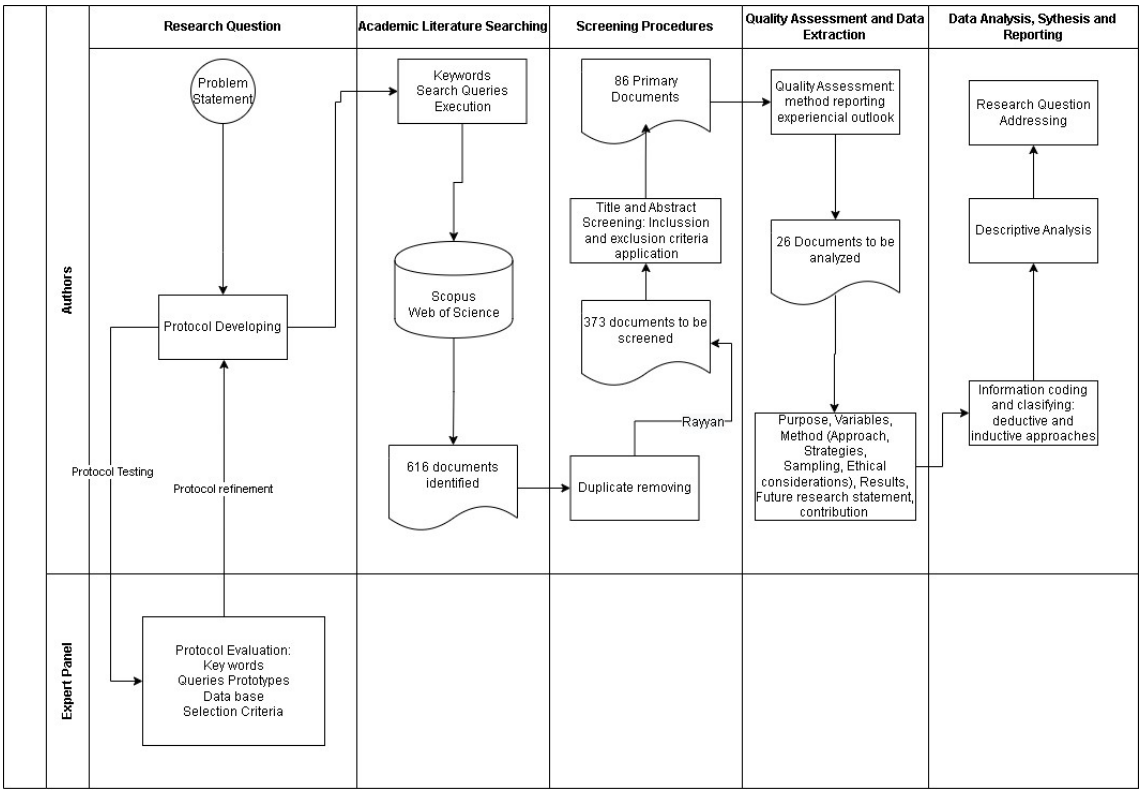


Figure 1. Selection process of the studies included.
Source: Own elaboration.

## 1 Results

Bibliometrics revealed a growing trend in research on the relationship between FinTech and SMEs finance. The main topics of study were found to include access to finance, financial inclusion, the adoption of financial technology by SMEs and the impact of FinTech on business innovation.

### *3.1 Primary articles overview*

To provide a descriptive overview of the articles reviewed, it is crucial to highlight the growing academic interest in addressing the issue of alternative financing for SMEs. This interest has gained remarkable momentum in recent years, reflected in a significant increase in the number of publications on this topic. Specifically, there has been a marked increase in the number of articles published in the most recent years, with the highest publication rate recorded in 2022 (12 papers), followed by 2021 (5 papers) and 2020 (3 papers). This pattern reveals an emerging trend toward exploring and understanding the evolution of alternative financing for SMEs in academia. This approach reflects the growing recognition of the importance of this area of research and its relevance in the current economic context.

Table 3 summarizes titles, authors, years of publication, main characteristics of the scope and methodological approach that are evidenced as predominant in the designs used at the time of approaching the research fieldwork.

Within the 26 texts chosen and analyzed, the variety of topics related to the impact of financial technology on SMEs is wide. As central axes, the following can be highlighted:

Table 2.
Key variables in the articles analyzed.

| Categories | Key variables | Quantity |
|---|---|---|
| Financing and SMEs | Financial Instruments, SMEs Financing, Financing, Constraints, Digital Financing, SMEs, Economic Growth, Entrepreneurship, Sources of Financing, Startup Growth, Startup Life Cycle, Technology Startups, Credit Rationing, Information Asymmetry, Mobile Payments, Big Data, Financial Industry, Financial Disintermediation, Online Credit. | 16 |
| Technology and Digital Finance | Crowdfunding, Platforms, Inclusive Finance, Digital Marketing, Local Banks, Digital Financial Inclusion, Use of Technology, Use of Technology, Financial Technology, Online Internet Banking, Mobile Internet Banking, Debt, Credit, Inclusive Finance. | 19 |
| Innovation and Vision for the Future | Business Innovation, Mediation Effect, Artificial Intelligence, SMEs Credit Rating, Solvency, Digital Lending, Developing Countries, Corporate Entrepreneurship, Business Performance, Structural Equation Modelling, Information Quality, Service Quality, System Quality, Perceived Usefulness, Perceived Ease of Use, Actual Use of Services, Financial Performance, Risk Management, Utilization of Financial Services, Use of Technology. | 11 |

Source: Own elaboration.

Table 3.
Main characteristics of the research articles.

| Authors | Year | Scope of Research | Methodological Strategy |
|---|---|---|---|
| [46] | 2021 | Exploratory Research | Quantitative |
| [47] | 2022 | Exploratory Research | Mixed |
| [48] | 2018 | Exploratory Research | Qualitative |
| [49] | 2019 | Exploratory Research | Qualitative |
| [50] | 2022 | Exploratory Research | Mixed |
| [51] | 2022 | Exploratory Research | Qualitative |
| [52] | 2022 | Correlational Research | Quantitative |
| [53] | 2021 | Correlational Research | Quantitative |
| [54] | 2022 | Exploratory Research | Quantitative |
| [55] | 2022 | Correlational Research | Quantitative |
| [56] | 2007 | Exploratory Research | Qualitative |
| [57] | 2020 | Literary Research | Qualitative |
| [58] | 2021 | Exploratory Research | Mixed |
| [59] | 2020 | Exploratory and Descriptive | Qualitative |
| [60] | 2022 | Exploratory Research | Quantitative |
| [61] | 2022 | Exploratory and Correlational | Qualitative |
| [62] | 2021 | Exploratory Research | Qualitative |
| [63] | 2022 | Correlational Research | Qualitative |
| [64] | 2022 | Exploratory Research | Quantitative |
| [65] | 2020 | Correlational Research | Mixed |
| [66] | 2022 | Exploratory Research | Qualitative |
| [67] | 2023 | Exploratory Research | Qualitative |
| [68] | 2021 | Exploratory Research | Quantitative |
| [69] | 2019 | Exploratory Research | Qualitative |
| [70] | 2022 | Literary Research | Qualitative |
| [71] | 2018 | Exploratory Research | Quantitative |

Source: Own elaboration.

*The role of FinTech finance in supporting SMEs during the COVID-19 pandemic.*

*The relationship between access to digital financial services and entrepreneurship in East Africa.*

*The process of SMEs financing in technology-based business incubators.*

*The impact of digital finance on SMEs innovation, especially in companies listed on the Chinese GEM exchange.*

*The influence of blockchain technology on startup financing.*

*The relationship between FinTech financing, crowdfunding, and customer retention in Islamic banks.*

*The role of FinTech in the democratization of entrepreneurial financing.*

*The bibliometric review of digital financing for SMEs turnaround in the Post COVID-19 Era.*

*The adoption of Financial Technology in the manufacturing industry and the impact on access to financial services for SMEs.*

*The influence of digital financial inclusion on business creation in a Chinese province.*

*The effects of financial digitization and literacy on SMEs performance.*

*The role of AI in access to finance for SMEs.*

*The impact of digital financial inclusion on China's economic development.*

*The use of Big Data and analytics in SMEs credit risk assessment.*

*The adoption of digital payment technology by SMEs and its effect on financial performance.*

*The relationship between access to digital finance and SMEs innovation.*

As can be seen, although the sphere of analysis is predominantly focused on the relationship between FinTech and SMEs finance, some approaches diverge in the type of assessment and characteristics. In summary, research in this area has approached the relationship between FinTech and SMEs finance from multiple perspectives, including financial technology adoption, digital financial inclusion, and financial entrepreneurship practices. These approaches have contributed to a deeper understanding of how FinTech can influence SMEs access to finance and innovation in an ever-changing economic environment.

To systematically organize and present the relevant information extracted from the articles reviewed during the research, the following table is constructed to summarize in a concise and structured manner the topics covered in each article, the purposes of the research conducted, the results obtained and the authors responsible for each study. By organizing the information in this way, it facilitates the comparison and analysis of the different approaches, findings and contributions of the different works reviewed. In addition, it provides an overview of areas of interest and recurring themes within the field of study, which helps to identify trends, knowledge gaps and possible directions for future research. In summary, Table 4 serves as a useful tool to synthesize and visualize the diversity and richness of the literature reviewed in relation to the topic of study.

Table 4.
Research topics in the research FinTech and SMEs.

| Topic | Purposes | Authors |
|---|---|---|
| Financing and SMEs | Explore and analyze various aspects related to access to finance for Small and Medium Enterprises (SMEs). These articles investigate how SMEs obtain and manage the capital needed to operate, grow, and innovate in a constantly changing business environment. | [46] [50] [51] [54] [55] [56] [57] [60] [61] [62] [63] [53] [64] [67] [68] [70] |
| Technology and Digital Finance, SMEs | To investigate and explore the intersection between Information Technology and finance, particularly in the context of Digital Transformation in the financial industry. These articles analyze how technology is reshaping and revolutionizing the way financial services are delivered and consumed, as well as its impact on individuals, businesses, and society at large. | [47] [48] [49] [51] [52] [55] [58] [59] [60] [61] [62] [64] [65] [66] [67] [68] [69] [70] [71] |
| Innovation and Vision for the Future | Explore the future challenges faced by FinTech to continue growing and strengthening their position in the SMEs finance business. Address topics such as the impact of artificial intelligence, information quality, data security and sustainability of financial practices. In addition, examine how to measure, evaluate, and improve the quality of financial services to ensure that they meet the needs and expectations of customers and users. | [50] [52] [57] [59] [64] [65] [66] [67] [70] [71] [69] |

Source: Own elaboration.

### 1.1.1 Key trends and knowledge gaps

The objective is to analyze key trends in the relationship between FinTech and SMEs finance, highlighting areas of research that require further attention and exploring potential future directions for academic inquiry and policy formulation. Through a comprehensive analysis of the relevant scientific literature, this study seeks to shed light on the most recent developments in the field and provide a solid basis for identifying opportunities and challenges at the intersection between FinTech and SMEs finance support.

The Financial inclusion is a crucial issue today, and its impact on SMEs has been the subject of research by several experts. [46] suggests that digital financial inclusion can promote innovation in SMEs, alleviating the financial constraints they face. This idea is supported by findings from [50], who examine GEM-listed Chinese firms and find evidence that digital finance can boost innovation by reducing financing constraints.

However, despite these advances, there are significant knowledge gaps in current research. One challenge is to understand in depth how specific FinTech solutions, such as blockchain-based finance [49], can drive creativity and technology adoption in SMEs. This area needs further research to identify the precise mechanisms through which these solutions affect innovation in SMEs.

In addition, the acceptance of financial technology in the SMEs manufacturing sector, as addressed by [47], raises additional questions about how these firms adopt financial technologies and how this adoption may affect their market performance. Differences across industries and regions in terms of FinTech uptake and usage are not yet fully understood and are an area requiring further research.

Taken together, these studies underscore the importance of financial inclusion and financial technologies for the development and growth of SMEs. The availability of big data, blockchain technology and digital finance have become key tools to ease financial constraints, drive innovation and improve access to finance for these companies, which in turn has a positive impact on economic growth at the regional and national level.

Access to Finance is another key aspect. The uptake of financial technologies in SMEs [47] shows a potential to improve access to finance. However, there is a need to investigate in depth FinTech solutions, such as financing through digital lending [46], can overcome traditional constraints and provide access to SMEs that would otherwise be excluded.

Digitization of financial services can influence the development of SMEs, as illustrated in the study by [54] on local start-ups. However, more research is needed to explore how FinTech solutions can optimize the growth and expansion processes of SMEs.

The integration of AI in the field of financial inclusion and its relationship with SMEs has emerged as a topic of growing interest and research. Advances in financial technology, supported by studies such as [46,50], have shown that financial digitization can play a key role in promoting innovation and alleviating the financial constraints faced by SMEs.

AI has emerged as a powerful tool in this context. As [62] points out, AI is becoming a magic pill that improves SMEs' access to financing. The ability of AI to analyze large volumes of

data, identify patterns, and make automated decisions has proven to be instrumental in assessing credit risks [53] and improving the accuracy of financing decision making [48].

Nevertheless, despite promising developments, there are still knowledge gaps that require further research. One critical area is to understand how AI can be more accessible and adaptable for SMEs, especially in rural or disadvantaged regions, as suggested by [69]. Furthermore, the relationship between the growth of FinTech and the adoption of AI by SMEs is an area that needs further research to identify the precise mechanisms of this interaction.

In summary, AI is proving to be a valuable tool for driving financial inclusion and improving SMEs' access to finance. However, understanding how to maximize its potential and overcome barriers to its adoption in diverse contexts is an area that deserves continued attention in future research.

Equity Crowdfunding and Collaborative Finance as noted by [61] are also important areas that require more attention. Studies are needed to understand how crowdfunding platforms can influence SMEs investment and how regulatory and security challenges can be addressed.

Risk Assessment and Security remain key concerns for SMEs, despite advances in FinTech. Future research could explore how FinTech solutions address these challenges and how effective security measures can be implemented [52]. In addition, it is important to understand the broader Socioeconomic Impact of digital financial inclusion on SMEs and how these solutions can overcome geographic barriers to provide access to finance in rural and remote areas [63,69].

Despite the potential of FinTech solutions, there is still a lack of complete understanding of the optimal business models for providing financial services to SMEs. Research is needed to analyze how these solutions can be designed and tailored to meet the specific needs of SMEs. In summary, research on FinTech and SMEs finance is constantly evolving and presents numerous opportunities to explore. It is crucial to address these trends and knowledge gaps to better understand how innovations in financial technology can support the growth and development of SMEs, thus contributing to economic growth and financial inclusion at the regional and national level [51].

### *1.2 Statistical analysis*

In terms of the scope of research conducted by the different types of papers, the following stand out: exploratory research articles (65.4%), correlational research articles (19.2%), literature research articles (7.7%) and mixed research articles (7.7%). which suggests a predominant interest in understanding and exploring new areas of knowledge or understudied phenomena related to FinTech Companies and SMEs. On the other hand, "correlational research articles" suggest an interest in establishing relationships between different variables within the topic. In summary, this reflects the breadth and variety of approaches used by scholars to investigate and understand the field of FinTech firms and their impact on SMEs.

The frequency of each unified keyword was calculated. Table 5 shows the 20 most common keywords with their frequency.

Table 5.
Most common keywords.

| Keywords | Frequency |
|---|---|
| SMEs | 15 |
| Financing | 8 |
| Finance | 8 |
| Digital Finance | 5 |
| Restrictions | 4 |
| Innovation | 4 |
| Technology | 4 |
| Financial inclusion | 3 |
| Fintech | 3 |
| Growth | 3 |
| Information | 3 |
| Digital | 3 |
| Banks | 2 |
| Performance | 2 |
| Digital Marketing | 2 |
| Digital payments | 2 |
| Quality | 2 |
| Covid-19 | 1 |
| Subsidy | 1 |
| Credit reasoning | 1 |

Source: Own elaboration.

Regarding the geographic contexts of observation, the geographical distribution of the studies is mostly concentrated in Asia (65.4%), with predominantly empirical validations coming from China (64.7%) and Thailand (17.6%). In Europe, there is participation from Italy (33.3%). Other research focuses on Colombia, Korea, Indonesia, Lithuania, Poland, United Kingdom, Sri Lanka, South Africa, Switzerland, and Tanzania.

The number of studies published on FinTech and SME financing has shown an increasing trend in recent years. A highest with 12 publications was observed in 2022, indicating a growing interest in this topic. Correspondence analysis using PCA (Principal Component Analysis) provides a visual representation of the relationships between keywords in study titles. This helps to identify groupings and patterns in the literature reviewed. This methodological approach, which combines descriptive statistical analysis and textual data analysis, transforms qualitative findings into quantitative data, strengthening the validity and justification for publication of the work.

The keywords “financial”, “digital”, and “medium-sized” are recurring, which is consistent with the focus on FinTech and the impact on SMEs. The word “credit” suggests a particular interest in the credit aspects of financing. The presence of keywords such as “internet” and “board” may indicate topics related to digital infrastructure and corporate governance. The keyword analysis reinforces the qualitative findings of the paper by identifying the most recurrent terms in the literature on FinTech and SME financing. The highlighted keywords are indicative of trends and areas of interest in the field of study, underlining the relevance and topicality of the topic under investigation.

## 2 Discussion

One of the key discussion points is the positive impact of FinTech on SMEs financial inclusion. Research highlights how the adoption of financial technologies can expand access to financial services for companies that previously had difficulty obtaining financing [66]. However, it is recognized that there are still barriers that limit the participation of some SMEs in this new financial paradigm [47]. This debate raises the need to address specific challenges, such as the lack of financial education and insufficient technological infrastructure in certain regions and sectors [51].

The discussion also focuses on the balance between convenience and security. While FinTech offer greater agility and accessibility in SMEs financing, they also raise concerns in terms of cybersecurity and data privacy [49]. The need to strike a balance between innovation and the protection of SMEs' financial and personal information is a hot topic in the discussion on the widespread adoption of FinTech in the business sector [63].

Another relevant issue is how FinTech can interact with existing regulatory frameworks. Regulators play an essential role in the advancement of the FinTech industry and in realizing their main objective of ensuring the stability of the financial system [9]. Effective collaboration between FinTech firms and regulators is crucial to ensure the stability and integrity of the financial system [59]. For example, the Bank for International Settlements (BIS) plays a key role in regulating and supervising the activities of financial institutions worldwide. In the context of the interaction between FinTech and SMEs, the BIS has established guidelines and recommendations that influence the coordination, cooperation, and support of these activities.

The BIS has been instrumental in maintaining financial stability in the digital age and in the expansion of FinTech. It works closely with regulators in each nation to establish appropriate regulations for SMEs and FinTech companies. Collaboration between regulators, financial institutions and FinTech is essential to ensure the effectiveness and security of digital financial solutions for SMEs [72].

In addition, the impact of FinTech on building trust between SMEs and investors is discussed. Transparency, effective communication and ensuring a secure financial environment are essential elements in building trust in FinTech solutions [62]. The discussion focuses on how FinTech can address these issues and establish lasting trust relationships in an increasingly digital financial environment.

In summary, the discussion around the relationship between FinTech and SMEs finance encompasses several crucial issues, from financial inclusion and cyber security to regulatory collaboration and trust building. These debates reflect the complexity and importance of the interplay between FinTech and SMEs finance support and point to areas for continued research and development in this evolving field.

## 3 Conclusions

There are several key determinants driving the operation of FinTech firms in the SMEs space. First, the growing adoption of mobile devices and Internet penetration have expanded the potential customer base for these companies. In addition, the quest for efficiency and agility in financial transactions has led to an increase in demand for FinTech services [46,53]. However, there are also significant constraints facing FinTech companies. One of the most important challenges is government regulation and supervision. Financial authorities are grappling with creating adequate regulatory frameworks to ensure consumer protection and the stability of the financial system. In addition, competition is intense in the FinTech space, which may make it difficult for some companies to stand out and gain market share [52].

Technology also enables greater transparency in financial transactions, which helps build trust. SMEs can better track and understand their cash flows and assets, which is essential for making informed financial decisions [65].

As FinTech companies continue to expand, they face crucial future challenges. One of the main challenges is the issue of cyber security. With a growth in the use of digital financial services, data protection and fraud prevention become even more critical [49]. Collaboration with regulators and governments is another important challenge. FinTech need to work together with authorities to ensure that their operations comply with financial regulations and to address money laundering and terrorist financing concerns [59]. In addition, access to long-term financing for FinTech firms themselves is an obstacle they must overcome to continue growing. Investment and financing are essential for the expansion of these companies [68,70].

The state of the art in the FinTech industry reveals a constantly evolving landscape. Research and practice have shown that FinTech have contributed significantly to SMEs financing, driving innovation, financial inclusion, and economic development, these companies have had a positive impact on the business economy [46,53].

Nonetheless, the outlook is not without challenges. According to [52], it is essential to address the challenges and risks associated with these technologies to ensure their long-term sustainability. Collaboration with regulators, risk management and trust building have become critical areas of research and development. Innovation in funding models, such as crowdfunding and blockchain, is also emerging as a promising trend [61]. These research opportunities offer a path toward developing more effective and sustainable solutions that will drive the growth and development of SMEs in the future [67,68,70].

### *3.1 Towards the future*

In today's dynamic environment, a transformational process has been unleashed that promises to reshape the way SMEs access finance and manage their financial operations. Through a rigorous analysis of the 26 studies reviewed, we have explored significant trends emerging from the convergence between FinTech and SMEs finance. In addition, we have identified areas for future research that require further attention.

The evidence accumulated in these studies provides us with a clear vision of the potential impact of FinTech. They

emerge as crucial enablers of SMEs financial inclusion, drivers of innovation and catalysts for economic growth. However, as we explore this terrain, questions arise that merit further reflection and exploration. How can we ensure that FinTech solutions are truly inclusive, overcoming existing regional and sectoral barriers? What is the right balance between agility and security in the adoption of financial technologies? How can SMEs take full advantage of technology, including AI and other emerging innovations?

In addition, the relationship between FinTech and regulation emerges as a crucial aspect that requires closer examination. How can regulators promote innovation while protecting the interests of SMEs and consumers? What is the role of collaboration between stakeholders such as governments, FinTech companies and traditional financial institutions? Building and maintaining trust emerge as fundamental elements in this new financial era.

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# Preventive maintenance plan for SKF Latin Trade SAS equipment

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**Abstract**
This research presents the design and implementation of the preventive and predictive maintenance plan developed for the seven polishing machines of the Swedish multinational SKF, of the LSB (Large Size Bearing) line. Based on Reliability Centered Maintenance (RCM), which allows identifying the most relevant equipment for the process through a criticality analysis adopting strategies in order to eliminate the occurrence of failures. The methodology implemented in this research allowed the generation of maintenance tasks that facilitated the management and visualization of the information of each asset. The company provides maintenance services for large bearings used in cement plants, foundries and industrial material transport machines, seeking to optimize production methods and the application of this theoretical and analytical procedure allowed verifying that the conditioning services offered by the company are more efficient, demonstrating with figures the retribution of the plan.

*Key words:* preventive maintenance plan; predictive maintenance; maintenance tasks; failures; equipment; corrective maintenance; SKF Latin Trade SAS.

# Plan de mantenimiento preventivo para los equipos de la empresa SKF Latin Trade SAS

**Resumen**
Esta investigación presenta el diseño e implementación del plan de mantenimiento preventivo y predictivo elaborado para las siete máquinas de pulimento de la multinacional sueca SKF, de la línea LSB (Large Size Bearing). Basado en el Mantenimiento Centrado de Confiabilidad (RCM), que permite identificar los equipos de mayor relevancia para el proceso mediante un análisis de criticidad adoptando estrategias con el fin de eliminar la ocurrencia de fallas. La metodología implementada en esta investigación permitió generar tareas de mantenimiento que facilitaron el manejo y visualización de la información de cada activo. La empresa presta servicios de mantenimiento para rodamientos de gran tamaño usados en cementeras, fundidoras y maquinas industriales de transporte de material, buscando optimizar los métodos productivos y la aplicación de este procedimiento teórico y analítico permitió verificar que los servicios de acondicionamiento ofrecidos por la empresa son más eficientes, demostrando con cifras la retribución del plan.

*Palabras clave*: plan de mantenimiento preventivo; mantenimiento predictivo; tareas de mantenimiento; fallas; equipos; mantenimiento correctivo; SKF Latin Trade SAS.

## 1. Introduction

The maintenance of equipment must be carried out based on its function and taking into account its design, which is why since the beginning of industrialization, maintenance has been conceived as the one in charge of the good performance of the machine. Technological advances have improved the condition and revision of equipment, which has optimized delivery times. SKF Latin Trade is the Latin American branch of a Swedish multinational company in charge of selling and reconditioning bearings, seals, calibration of high precision equipment and multiple engineering works. In Colombia, within its facilities located in Siberia (Cota, Cundinamarca), it remanufactures bearings for freight cars, conveyor belts and manages two reconditioning lines; Train Bearing Units (TBU) and Large

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Size Bearings (LSB). The LSB line uses seven pieces of equipment; horizontal polishing table, compressor, electrical distribution boards and four lathes, which are in daily use and require constant maintenance, therefore, in this research we used tools provided by Reliability Centered Maintenance (RCM) since this work philosophy has been widely accepted by large companies that require reliable monitoring of their machines [1-6]

### *1.1 Description of the research problem*

The maintenance tasks were of low technical scope, there was no clarity for the operator and the maintenance indicators were of low reliability (criticality of 28% of maintainable items). They were not based on accurate measurements such as temperature or vibration. According to the company's maintenance reports, the machines only had monthly preventive maintenance that consisted only of reviewing wear and tear parameters and equipment cleanliness. The useful life of the serviceable parts was not considered to facilitate the calculation of the probability of failure. The most common consumable parts were drive belts, bearings, safety elements, mechanical seals. In addition to this, after the COVID-19 pandemic, the remanufacturing area decided to have an annual stock, since it had the resources and strategic planning to manage each one [7-10]

The purpose of planning the stock for one year was for purchasing purposes, since, from this area, the processes of quotation, acquisition and arrival of spare parts are delayed. These processes can last from two to six months, and it is critical for productivity reasons to have a machine stopped due to an unforeseen failure that works eight hours a day. Considering the 192 hours they work per month; the resource consumes about 20% per month among the total number of inspections. However, constant spare parts changes indicate a failure in the follow-up that needs to be adjusted to obtain better production performance and foresee the improvements to be made, without compromising product delivery times. The cost per inspection changes if a spare part is required; however, maintenance is normally of an autonomous type, so it does not involve external labor, although it compromises the company's productivity. Based on the above and taking into account the parameters established for the development of this project, the following question arises: How to improve the monitoring of each equipment for a timely maintenance of the LSB line in the company SKF Latin Trade SAS? [11-16]

### *1.2 Research justification*

The company had the necessary instruments for the inspection and verification of each equipment, this was a way to evolve the processes managed without the need to resort to other equipment or suppliers in most cases. After the routine use and common wear of the machines, the company needed to standardize a predictive maintenance plan that would indicate how often they should be performed; vibration analysis, ultrasound and thermography. To evaluate the behavior of the machines without compromising their function and service delivery schedule. It is important to highlight the importance of this process, since it contributed to save time and money, allowing the operators to concentrate on their daily remanufacturing operations and making the work schedule where the dates were specified, being necessary the study of each asset for its analysis. The author's contribution from Mechanical Engineering in this project is the implementation of ISO 14224 and ASTM 1934-99 (Thermography analysis), D3580 (Vibration analysis), E114-10 [4] (Ultrasound test), which were to be used, also in the parameters of standardization, monitoring and support of maintenance according to workload and optimization of the current plan. All this to facilitate the tasks of the operators that will speed up delivery times, increasing production capacity in the plant [17-20]

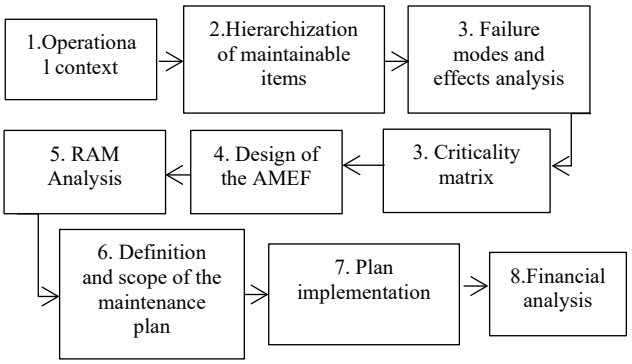


Figure 1. Project methodology.
Source: Author.

## 2. Methodology

This research had a qualitative and systematic approach, to achieve the objective, information was collected from the maintenance history and the supplier manual. It was captured in the format and considered the errors that each equipment presented in the maintenance tasks of the last two years, the spare parts required in the corrective maintenance previously done and the criticality of the equipment based on its productivity, time in operation and relevance within the operation (Fig.1). The project was structured in a series of steps as follows [21-23]:

### *2.1 Operational context*

An analysis of the workload of the line's equipment was carried out, taking into account the corrective maintenance history, the life history of each one, technical data sheets and operating manuals. In addition to the comments of the operators in charge of operating the equipment and the two people in charge of performing the weekly and monthly maintenance tasks. In order to better address the problem [24,25]

### *2.2 Hierarchization of maintainable items*

Each piece of equipment was broken down into system, function and maintainable item, according to ISO 14224. Where we went from the most general to the most particular, from the equipment to the type of maintenance it requires to

function in the best way, within the categories are included: Equipment, system, maintainable item (engines, transmissions, coolants), type of failure that could present and maintenance [26-28]

### *2.3 Failure modes and effects analysis*

In order to identify the failure modes of each piece of equipment, a thorough preventive maintenance was carried out to note down the details of each machine and thus, together with the suggestions indicated in the manuals, adjust the failure mechanism and obtain more rigorous severity criteria. For this we reviewed the maintenance history, taking the maintenance tasks of the last two years, which for security and privacy reasons of the company is not authorized to use these documents in this article, to have a clear outline of what has happened with the machine, raise possible failure scenarios and based on that raise the necessary solutions or repairs [29-32].

### *2.4 Criticality matrix*

A criticality matrix was developed together with the chief engineer, workshop chief engineer and maintenance engineer to assign values and importance to the severity criteria that took into account industrial safety, environmental impact, maintenance costs, lost production time and quality control of the finished product. Based on the company's quality and productivity parameters, the maintenance route was programmed based on the worst-case scenarios proposed by the work table created for this maintenance plan. Where the worst scenarios where it is necessary to do a corrective maintenance were classified with the letter A and the red color in the AMEF format, the scenarios where a preventive maintenance could be implemented with the letter B and the yellow color and finally the scenarios where it is only necessary to do lubrication and cleaning with the letter C and the green color [33-35].

### *2.5 Design of the AMEF*

The FEA first prioritizes the taxonomy of the equipment, the failure modes and effects by which the equipment could fail, the severity criteria proposed with the area engineers in the criticality matrix in Table 1, the valuation obtained from the calculation of the severity criteria, which range from one to three, where one is considered non-critical, two medium critical and three very critical. Each value was recorded in the criticality matrix developed with SKF engineers (Table 1), where it is described why the value is assigned to each criterion and it is related to the failure frequency. Taking into account the value assigned for each one, a value of A, B or C is obtained, where C is not critical, B is medium critical and A is very critical. From this concept, a predictive inspection frequency calculation is made, according to the criticality level of the maintainable item. For the equipment categorized as non-critical; Horizontal Polishing Table, Medium Lathe and Large Lathe, the maintenance benefits are evaluated to define if its maintenance is essential [36,37], or on the contrary, the option that the component works until breakage is considered. The severity criteria defined determine the maintenance tasks that will be implemented for maintainable equipment and items.

After obtaining the criticality of each maintainable item, the frequency of predictive inspections is calculated, where the periodicity between each measurement is obtained to better monitor the condition of the maintainable items that require greater attention due to their use. Based on the above, maintenance tasks are proposed that lead to a better performance and extension of useful life to avoid unexpected cost overruns [38-40].

### *2.6 RAM analysis*

#### 2.1.1 Equations

For the reliability of the plan, five management indicators were established that will contribute to a better evaluation of the quality and reliability of the plan itself:

- **Mean time between failures:** It consists of measuring the total time of good operation of the equipment between each repair and is calculated as follows:

$$MTBF = \frac{Working\ hours\ in\ good\ condition}{Number\ of\ corrective\ interventions\ per\ year} \quad (1)$$

- **Maintainability:** Ease with which equipment returns to operations after a failure:

Table 1.
Criticality matrix.

| Criticality matrix for reliability analysis | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Severity criterio: Impacts | | | | | | Occurrence criterion | | |
| Months (M), Days (D) and Hours (H) | | | | | | | | |
| | | | | | | Probability of failure | | |
| Classify | safety | Environment | Maintenance | Time lost | Quality | 1D < 1M | 1 < 6M | > 6M |
| | | | | | | A | B | C |
| A | Incapacity > 3D - Fatality | High impact - Control > 3 H | CM > 1.500.000 | P > 16H | High | 9 | 6 | 3 |
| B | Incapacity 1-3D | Control < 3 H | $500,000<CM<=$1,500.000 | 4 H < P <= 16 H | Medium | 6 | 4 | 2 |
| C | No incapacity | No impact | CM =< $500,000 | P< 4H | Low | 3 | 2 | 1 |

Source: Author.

$$MTTR = \frac{Hours\ spent\ on\ repair}{Number\ of\ interventions\ per\ year} \quad (2)$$

- **Availability:** This indicator evaluates the condition of the equipment to fulfill its function based on the mean time between failures and maintainability as follows:

$$Availability: \frac{MTBF}{MTBF + MTTR} \quad (3)$$

- **Maintenance cost over replacement value:**

$$CPMV = \frac{Total\ maintenance\ cost}{Price\ of\ new\ equipment} X100 \quad (4)$$

- **Cost of maintenance over billing:**

$$CMF = \frac{Total\ maintenance\ cost}{Gross\ invoicing} \quad (5)$$

To find the criticality value, the failure modes and effects were taken and assigned a value in each box of the severity criteria. A value between one and three was assigned as indicated in the criticality matrix and, within the equipment evaluation, the severity of the failure was calculated from the criteria and the probability of failure. Thus, the equation was obtained:

$$Severity = (IS * 0.25) + (EI * 0.2) + (MC * 0.1) + (TLP * 0.25) + (QC * 0.2) \quad (6)$$

Where:
IS: Industrial Safety
EI: Environmental impact
MC: Maintenance cost
TLP: Time lost in production
QC: Quality control

Now, the probability of failure was also assigned a range between 1 and 3, where 1 meant likely to fail in 6 months or more and 3 meant likely to fail between 1 day and one month, as indicated in the criticality matrix. This value was assigned based on the corrective history of the equipment, multiplied by the severity equation (Equation 1) and the severity rating of the equipment failure was obtained, as indicated below:

$$Classification = Severity * Probabilty\ of\ failure\ occurrence \quad (7)$$

Finally, the FEA format was programmed with conditionals to obtain the criticality as follows:

$$If\ Classification \leq 3\ put\ C$$
$$If\ Classification \leq 6\ put\ B$$
$$If\ Classification \geq 6.1\ put\ A$$

The matrix is required to quantify and explain on what basis each value is assigned according to the failure method. For this, the following values are assigned:
A: Highly critical
B: Average criticism
C: Non-critical

### *2.1 Definition and scope of the maintenance plan*

Based on the modes and effects of the AMEF, the maintenance tasks were proposed, taking into account the assessment obtained and the severity criteria proposed for each failure mode in order to act correctly in the intervention of the assets. Failure modes and actions prior to corrective maintenance were raised at the maintenance plan creation meeting together with the other three engineers in charge. The comments and suggestions of the operators were taken into account in order to have a complete scheme and not to omit any possible failure mode [41,42].

### *2.2 Plan implementation*

The plan is standardized and programmed through the maintenance software used by the company, leaving two monthly tasks for each piece of equipment and a weekly task for the compressor oil level. The tasks have a schedule to be updated based on the comments of the operator who performed the maintenance. Since, it is necessary to take into account whether to avoid corrective maintenance, it is necessary to change a machine element such as gears, belts, bearings, among others, that could generate a massive failure in the production line and generate cost overruns [43,44].

### *2.3 Financial analysis*

Finally, a financial analysis was performed in order to evaluate the cost-benefit of the plan for the company. With the calculation of ROI (Return on Investment). It was found that the maintenance plan gives a clearer idea about the budget that must be had per semester, the machine elements that can be easily purchased and replaced, as well as those that require to be imported and if it is necessary to dismantle the complete equipment to replace it. Besides, the maintenance history is required to specify which parts were replaced, which elements were used and with this the budget, the downtime of the machine in production and the delivery times of the product [45,46]

## 3. Results

When making the calculation for each of the seven pieces of equipment, it was found that four of them; parallel lathe, small lathe, compressor and electrical distribution, are moderately critical, therefore, they require specific maintenance in the failure modes and effects that yielded this result.

The AMEF format indicates that four of the seven pieces of equipment in the line are of medium criticality. Taking into account that they will be treated as if they were of high criticality, a specific follow-up is made to maintainable items such as: motor, mobile elements, electrical connectivity and mobile elements that require greater lubrication, revision due to aging and wear according to their use.

Table 2.
Classification for each team.

| Classification for each equipment | | | | |
|---|---|---|---|---|
| **Equipment** | **System** | **Maintainable item** | **Failure** | **Maintance** |
| Parallel and Small lathes | Transmission | Electric motor | Excess vibration | Lubrication and vibration analysis |
| | | Transmission box | Transmission case misadjusment | Lubrication and vibration analysis |
| Compressor | Dryer | Refrigeration | Hoses are cristallized | Replace hoses and oil leveling |
| Electric distribution | Distribution board | Damage to contactors | Short circuit | Change of terminals |

Source: Author.

For a better analysis, the equipment with medium criticality was taken to classify the maintainable items by the type of probable failure they may present and to obtain a model where the maintenance tasks are adapted to the specific needs of each equipment, as shown in Table 2.

## 1. Analysis of results

Taking a percentage of this equipment out of a total of 25 maintainable items, of which 7 are critical and correspond to the line (motors, control boxes, heat exchanger, dryer), the criticality percentage is twenty-eight percent (28%) (see Fig. 2).

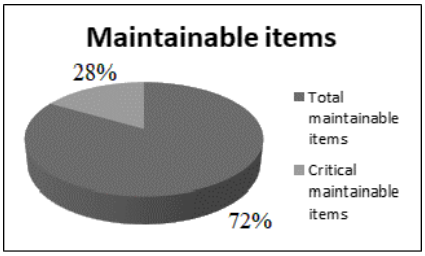


Figure 2. Maintainable items.
Source: Author.

Based on the results of the total number of maintainable elements and the criticality matrix, if one of them fails, maintenance tasks are issued for each piece of equipment according to the criticality of its components:

Table 3.
Maintenance tasks.

| **Maintance tasks** | |
|---|---|
| Smal lathe | Spindle and clamping cup adjustment<br>Gear lubrication<br>Brake check |
| Parllel lathe | Gear cleaning and lubrication<br>Adjustment of the spindle and clamping cup<br>Cleaning of the banacada |
| Compressor | General compressor cleaning<br>Cubicle cleaning<br>Exchanger cleaning<br>Checking for air and oil leaks<br>Dryer cleaning<br>Data collection (Amperages, temperatures and pressures) |
| Electrical distribution | Data collection (Amperages, temperatures and pressures)<br>Cleaning of connections and aging check |

Source: Author.

Preventive maintenance had an improvement with the creation of this plan, since the monthly routes now have a specific date of the month so that the operator can take the time to do the autonomous maintenance in the best way. Predictive maintenance is applied quarterly to the routes of each equipment such as; vibration analysis based on physical accessibility to take the collection of inspections of the same. This inspection interval is calculated through the AMEF format, facilitating the follow-up of the condition of the maintainable items to avoid unplanned shutdowns and expenses in spare parts above what was planned. Similarly, when an equipment shows very high measurements, we consult with the engineers in charge of the plant to evaluate if a replacement of the machine is required in order to cancel the machine and start the management of quotation, purchase and delivery time of the new equipment. This facilitates the acquisition of good equipment at a not very high price, since it can be purchased or imported from one of SKF's global branches (see Table 3) [47,48].

## 5. Conclusions

The contribution of this maintenance plan to the company was the collection and organization of data, valuable information that was archived without being registered for two years. From a research and qualification point of view, the most relevant data was corrective maintenance history, maintenance periodicity, and creation of predictive maintenance for the bearing market leader. The proposal of new preventive and predictive maintenance routes, taxonomy, technical sheets and resumes for each piece of equipment that had not been worked on before and are an essential part of good equipment monitoring. They are an essential input to prioritize and classify the line according to the requirements of the ISO 14224 standard.

The evaluation of the equipment based on the ISO 14224 standard contributed to the easy preparation of a standard maintenance plan and greater clarity for the support engineers to implement it together with the operators in charge. The equipment severity and taxonomy criteria under the ISO 14224 scheme were necessary to classify the severity of each equipment, giving rise to a more detailed analysis of each item based on the calculation of the monitoring cost based on the operator's rate and the maintenance. Preventive and predictive tasks for the design of a preventive and predictive maintenance plan that ensures that each piece of equipment is correctly monitored to reduce the risk of unexpected line stops, which affects delivery times, maintenance budget and quality. of each product.

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UNIVERSIDAD NACIONAL DE COLOMBIA

# Selection of optimal areas for the installation of Wind Farms in the north-eastern part of Cuba

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**Abstract**
The present research aims to select optimal areas for the installation of wind farms in the north-eastern part of Cuba. The research is based on the free software QGIS, Hierarchical Process Analysis, databases of the information of the alternatives and criteria and Geographic Information Systems (GIS), which makes it possible to know the places where these farms will be installed. In addition, experts were consulted to obtain the weights or level of importance of the selected criteria, such as distance to ports, distances to common roads, distances to population centers, to electrical grids and finally the wind speed. As a result, a mathematical conceptual model was obtained for the selection of optimal zones for the installation of wind farms in the eastern north of Cuba, by means of the MCDM and GIS methods, where it was determined that, within the evaluated alternatives of wind farms, Gibara III is the optimal one. These models will allow the development of wind projects in the eastern region of Holguin, and to be able to manage human, financial and material resources.

*Keywords:* Geographic Information System (GIS); Multicriteria Decision Support Methods (MCDM); Decision Support Methods (MCDM); wind farms; multicriteria analysis; Hierarchical Process Analysis (AHP)

# Selección de zonas óptimas para la instalación de Parques Eólicos en el norte Oriental de Cuba

**Resumen**
La presente investigación tiene como objetivo seleccionar áreas óptimas para la instalación de parques eólicos en la zona nororiental de Cuba. La investigación se basa en el software libre QGIS, Análisis Jerárquico de Procesos, bases de datos de la información de las alternativas y criterios y Sistemas de Información Geográfica (SIG), que permite conocer los lugares donde se instalarán estas granjas. Además, se consultó a expertos para obtener los pesos o nivel de importancia de los criterios seleccionados, como distancia a puertos, distancias a vías comunes, distancias a centros poblados, a redes eléctricas y finalmente la velocidad del viento. Como resultado se obtuvo un modelo conceptual matemático para la selección de zonas óptimas para la instalación de parques eólicos en el norte oriental de Cuba, mediante los métodos MCDM y GIS, donde se determinó que, dentro de las alternativas de energía eólica evaluadas fincas, Gibara III es la óptima. Estos modelos permitirán desarrollar proyectos eólicos en la región oriental de Holguín, y poder dirigir recursos humanos, financieros y materiales.

*Palabras clave*: Sistemas de Información Geográfica (SIG); Métodos de Soporte a la Decisión Multicriterio (MCDM); Métodos de Soporte a la Decisión (MCDM); parques eólicos; análisis multicriterio; Análisis Jerárquico de Procesos (AHP)

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## 1. Introduction

The most advantageous conditions for locating wind farms in Cuba are located in 21 zones near the northern coast, 13 zones for short and medium term installation of up to 600 MW of wind farms (including those already installed). There are also 6 zones suitable for installing up to 400 MW in the medium and long term.

For the installation of wind turbines, previous studies of the terrain are carried out, avoiding soft and unstable soils, which could cause damage to the structures due to the vibratory forces of the blades, although the new wind turbine technologies minimize these effects.

All this analysis leads to know the places where these farms will be installed, which will allow directing human, financial and material resources. The objective is to select optimal areas for the installation of wind farms in the north-eastern part of Cuba.

In the research work carried out by [1] in their recommendations, it is proposed to define the physical location of the equipment, the distances to be covered and the energy transmission lines within the territory and other complementary factors, so it will be sought, through the GIS, to find the best options of areas for the installation of Wind Projects, in the north of Holguín.

Applied [2] the IntiGIS model to define the most convenient technology to cover the electrification needs of Zapara Island. On the other hand, MDMC methods are based on explicit criteria, to evaluate several alternatives, it is used when a group of people must make an important decision in which different and complex aspects concur, especially in the stages of selection and evaluation of alternatives. In multi-criteria models, the decision-maker will be able to estimate the possible implications of each course of action, so that a better understanding of the links between his actions and his objectives can be obtained.

The entire GIS requires the methods that will be used to complete tasks and procedures. To create maps, a raster format or a vector format can be used; The source of obtaining the maps can be: scanning images, purchasing the maps, through GPS, using remote sensing or using a web service; but it is important to define the methods to use in each process. Therefore, there are only two formats to represent and systematize GIS in a geographic database: the vector model and the raster model. [3] with GIS-AHP methods studied the wind potential, concluding that these methods are appropriate for the selection of wind power plants. Applied [4] GIS-AHP methods, in the Kozani Regional Unit, to study the wind and solar economic potential, with the social and environmental dimensions, showing that the study area is suitable for solar energy than for wind energy, and finally [5] and [6] propose that renewable energies are closely linked to issues such as energy decentralization and rural electrification, and affirm that this geographical dependence means that GIS They can play a very important role in site location, regional planning, impact assessment, socio-economic analysis, multi-criteria analysis, etc.The multicriteria evaluation technique (MCA) has been applied in different planning processes and at different scales: the location of landfills [7] environmental planning and management, the analysis and study of the territorial impact of wind farms in Cantabria under a GIS environment [8] the techniques of multicriteria evaluation, fuzzy logic and Geographic Information Systems as tools for land use planning [9] urban simulation scenarios using GIS and multicriteria analysis [10], GIS based sensitive analysis with multi-criteria decision [11] sustainable site selection using GIS and multi-criteria method [12] and multi-criteria decision for the location of renewable energy sources [13].To search for optimal solutions to multi-objective land use allocation problems, authors such as [14] used multi-objective optimization techniques. Other authors such as [15], incorporated genetic algorithms that explored and demonstrated the usefulness of different tools and approaches and finally [16] published in OLADE, an approach for rural electrification projects, where he raises the problems of renewable energy and its future solution.

## 2 Materials and methods

The research is based on the free software QGIS, Hierarchical Process Analysis and Databases of alternatives and criteria information. For its development, the work of [17] and [18] was taken as a reference, applied to 60 public agencies and 12 private companies in the wind energy sector in the United Kingdom, considering the following constraints:

- Optimal areas <10 km from the power grid,
- Avoid high hill ridge,
- Slope < 10%,
- Wind speeds greater than 5 m/s,
- 10 km to the road. 10 km to the power grid,
- 400 meters to aquifers,
- 1 km to area of ecological value or area of special scientific interest,
- Grade 1 or 2 soil.

The problem is restricted to the following conditions:

- Incompatibility in land use, protected space, or with high environmental value,
- Areas located less than 300 m from an urban or residential area, to minimize visual and acoustic impact,
- Area located less than 100 m from a forest mass, to avoid turbulences,
- Areas with aeronautical restrictions, taking into account air safety, radio-electric interference, civil and military security.
- A methodological proposal is made, which is based firstly on the application of the Hierarchical Analysis

Hierarchical Analysis (AHP) method, to find the weights of each criterion or constraint with a view to its evaluation within the GIS, where first the hierarchical structure is modeled, based on the model of [18]. Then, the priorities among the criteria are established (relative importance of evaluation). Here a priority vector is constructed for the evaluation of the importance given by each expert to each criterion, this numerical value should be as tight as possible, by direct assignment, through a scale.

The pairwise comparisons will determine the weights of each criterion and will be presented as a square matrix, where each element is compared with each other [19]. One of the drawbacks of this method is that there is not always consistency between the judgments issued by the decision maker, so it is necessary to measure the consistency of judgments, called consistency ratio (CR), because for this, first the consistency index (CI) is calculated, as shown in Eq.1:

$$CI = \frac{\lambda max - n}{n - 1} \quad (1)$$

Table 1.
Random consistency index (RI) as a function of the size of the n matrix

| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| RI | 0 | 0 | 0,52 | 0,88 | 1,11 | 1,25 | 1,8 | 1,4 |
| **n** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** |
| RI | 1,45 | 1,48 | 1,51 | 1,53 | 1,55 | 1,57 | 1,5 | 1,5 |

Source: Saaty Thomas, L.2015

And where, for the improvement of the consistency of the judgments, the random consistency index (RI) is compared with the size of the n matrix, as can be seen in Table 1.

Finally, the consistency ratio (CR) is calculated by the following Eq.2:

$$RC = \frac{CI}{RI} \quad (2)$$

This term must be less than 0,10 for the results to be reliable and to be recognized as acceptable [14]. After the consistency analysis, if the condition is met, we proceed with the method, evaluating in a paired way each criterion, and arriving at a weighting that provides the degree of importance of one criterion over another, actually what the expert choice software does, is after obtaining the score of the experts, it normalizes by the sum of the columns, then dividing each element xij, on the sum, In this way each criterion is left in a single range, to be able to operate each criterion, then, the normalized values of each criterion are added, becoming the weighting of the same, in the same way, the normalized values of each column are added, obtaining the weight of each alternative, finally each alternative is operated by the weights of each criterion, and the alternative that has the highest value, will be the best.

Procedure to implement the GIS method

The remarkable thing about GIS is that they allow working with georeferenced spatial information. That is, they can present a digital map, in which all objects have a common identifier and their own attributes. This allows the information to be separated and stored independently by thematic layers, which with their superposition (always under the same reference system) make up the digital map. This makes it possible to work with the information in a very versatile way, with easy access and facilitating the user to generate new information related to the existing one Fig. 1.

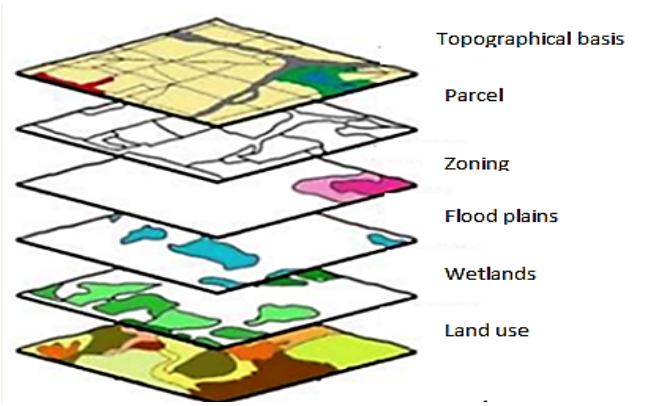


Figure 1. Capable overlay in GIS systems.
Source: García-Cascales, 2013.

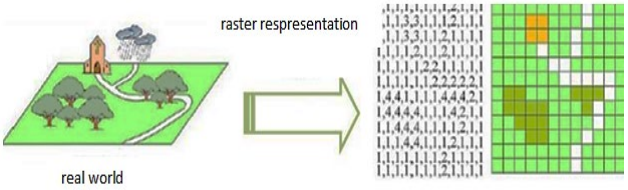


Figure 2. The vector geometric elements used are: points, lines, polygons and multipolygons.
Source: Self-made Imagen.

## 3 Vector data

ESRI Shapefile (SHP) format. In order to maintain the geometric characteristics of the elements of a digital map, its boundaries are defined by vectors. This makes it possible to process geographic information with high spatial accuracy Fig. 2.

### *3.1 Characterization of the alternatives to be evaluated*

***Alternatives to be studied:***

1. **Gibara III Wind Power Plant**: it is located in Gibara municipality, 40 km northeast of Holguin province, it is expected to generate 51 MW and its start-up is planned for the year 2022, according to two UNE statistics.
2. **Cabo de Lucrecia Wind Power Plant**: Located in Punta de Mula, Banes municipality, Holguin province, it comprises a half moon from Cabo Lucrecia almost at the latitude of Cabo Lucrecia, to Punta de Mula to the Northwest, from 200 m from the coast and up to 2 km in depth, with an estimated length of 6 km and an approximate surface extension of 13 km2, it has sustained winds throughout the day, This condition differentiates this territory from the southern coast, because the arrival of the trade winds is not affected by the mountains and also, during the daytime period the wind direction coincides with the sea breeze, which contributes to increase the wind speed, results obtained from the database studied, the average winds at Cape Lucrecia are 17 km / h (4,7 m/s), a favorable condition to obtain electrical energy from the wind using low (less than 100 kW) and moderate power (100-500 kW) machines.
3. **Punta de Mula Wind Power Plant**: Located in Puerto Rico Libre beach, Banes municipality, Holguin province.
4. **Rio Seco I Wind Farm**: Located in Punta Caleta Honda, in Banes municipality, Holguin province, the Rio Seco Wind Farm will have a power of 51 MW and will have 34 GAs of 1.5 to 2 MW, with a configuration in 2 rows almost parallel to the coast and no less than 300 m from it, with its GAs in the most advantageous positions to avoid unfavorable geotechnical conditions.

## 4 Results and discussion

Results of the application of the Hierarchical Process Analysis method.

To check the consistency of the experts' evaluation, the Expert software was used, in its small configuration, in case it does not exist, the process is performed again, Table 2.

Table 2.
Expert choice evaluation.

| Hierarchieze criteria for the evaluation of areas to install wind farms<br>Pairwise comparations Matrix | | | | | |
|---|---|---|---|---|---|
| | **Distance ports** | **Distance of roads(Railway)** | **Distance to communication** | **Distance to electrical network** | **Wind speeds** |
| **Distance ports** | 1 | 5 | 1/5 | 1/3 | 1/7 |
| **Distance of roads(Railway)** | 1/5 | 1 | 1/3 | 1/3 | 1/5 |
| **Distance to communication** | 5 | 3 | 1 | 4 | 1/3 |
| **Distance to electrical network** | 3 | 3 | 1/4 | 1 | 1/5 |
| **Wind speeds** | **7** | **5** | **3** | **5** | **1** |

Source: Own elaboration.

Table 3.
Consistency analysis.

| **AHP** | | **Consistency check** | **AHP-1** | **CA** | **Lambda** | **Ci** | **CI/RI** |
|---|---|---|---|---|---|---|---|
| 0.101 | 10.1 % | | 0.101 | 1.6363 | 5.9706445 | 0.2427361 | 0.2167286 |
| 0.056 | 5.6 % | **Check your results** | 0.056 | 0.9476 | | **Randomness index, RI** | |
| 0.249 | 24.9 % | **22 %** | 0.249 | 1.19281 | 3 | 0.58 | 1.12 |
| 0.123 | 12.3 % | | 0.123 | 1.31044 | 4 | 0.9 | |
| 0.471 | 47.1 % | | 0.471 | 0.88374 | 5 | 1.12 | |

Source: Own elaboration.

Table 4.
Relative weights found for the evaluation of areas to install wind farms.

| **Objective: To prioritize criteria for the evaluation of areas to install wind farms.** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **#** | **Criteria** | **C1** | **C2** | **C3** | **C4** | **C5** | |
| **C1** | Distance Ports | 1 | 5 | ⅕ | ⅓ | 1/7 | |
| **C2** | Distance of roads (Railway, Highway) | ⅕ | 1 | ⅓ | ⅓ | ⅕ | |
| **C3** | Distance to population center | 5 | 3 | 1 | 4 | ⅓ | |
| **C4** | Distance to electrical networks | 3 | 3 | 0.25 | 1 | ⅕ | |
| **C5** | Wind speeds | 7 | 5 | 3 | 5 | 1 | |
| | **Addition.** | 16.00 | 17.00 | 4.25 | 10.00 | 1.00 | |
| | | | | | | | |
| **#** | **Criteria** | **C1** | **C2** | **C3** | **C4** | **C5** | |
| **C1** | Distance Ports | 1 | 5 | 0.2 | 0.333 | 0.142 | |
| **C2** | Distance of roads (Railway, Highway) | 0.2 | 1 | 0.333 | 0.333 | 0.2 | |
| **C3** | Distance to population center | 5 | 3 | 1 | 4 | 0.333 | |
| **C4** | Distance to electrical networks | 3 | 3 | 0.25 | 1 | 0.2 | |
| **C5** | Wind speeds | 7 | 5 | 3 | 5 | 1 | |
| | **Addition.** | 16.20 | 17.00 | 4.78 | 10.67 | 1.88 | |
| | **Normalized** | | | | | | **Average** |
| **C1** | Distance Ports | 0.062 | 0.294 | 0.042 | 0.031 | 0.076 | 0.101 |
| **C2** | Distance of roads (Railway, Highway) | 0.012 | 0.059 | 0.070 | 0.031 | 0.107 | 0.056 |
| **C3** | Distance to population center | 0.309 | 0.176 | 0.209 | 0.375 | 0.178 | 0.249 |
| **C4** | Distance to electrical networks | 0.185 | 0.176 | 0.052 | 0.094 | 0.107 | 0.123 |
| **C5** | Wind speeds | 0.432 | 0.294 | 0.627 | 0.469 | 0.533 | 0.471 |

Source: Own elaboration.

Likewise, the result of the consistency analysis, equal to 0.21, slightly higher than 0.10, which is ideal, but can be considered for this study, Table 3.

Summarizing the application of the AHP method, Fig. 4 shows the weights of each criterion to be taken into account in the process. each criterion to be taken into account in the process are shown in Table 4.

As can be seen in Table 4, the wind speed criterion was the most weighted by the experts; if there were no acceptable speeds, it would be impossible to operate the turbine, followed by the distance to populated communities, which would benefit from the energy produced, and finally the electrical grids and communication routes for installation logistics.

The criteria or restrictions that were taken into account in the GIS modeling are shown below. Are shown below:

### *4.1 Variable criteria*

1.That they are located in the strata Gibara III, Rio Seco I, Punta de Lucrecia and Punta de Mula,

2.That the ports are close to the areas of location to guarantee the transfer of the resources imported by the country, distance of 40 km, considering that this will be the optimum with a value equal to 5, between 40 and 50 km value equal to 3, and more than 60 km, value equal to 1, to be taken into account for the buffers,

3.That the future facilities are close to communication

lines such as roads and railways, also to ensure that inputs reach the installation site, between 0 and 3 km, value of 5, between 3 and 5 km value of 3, and more than 5 km value of 1.

4.That future installations are close to population centers (potential consumers) and not only in isolated communities, because the energy generated must be consumed or transferred to the grid, for a distance of 2 km, value of 5, from 2 km to 3 km value of 3, more than 3 km value of 1,

5.That future facilities are close to the grid to reduce the levelized energy costs, value of 5, for distance of 5 km, between 5 and 8 km, value of 3 and more than 8 km, value of 1,

6.That the future installations wind speeds are optimal, based on a wind study, based on the wind map of Cuba, for speeds between 5 and 6 m/s, value of 1, for speeds between 6.5 and 7 m/s, values of 3 and greater than 7 m/s, values of 5,

7. That future installations do not intercept migratory air corridors of birds,

That future facilities do not intercept areas of flora and fauna reserves.

Data source for conceptual modeling through GIS Table 5.

### *4.2 Making Buffers*

With the data obtained, the buffers of each variable are made in the QGIS software. Fig. 3, shows the buffers made to the wind speed polygonal, wind speed polygonal area with a criterion of 5, 1 km buffer with a criterion of 3 and 2 km buffer evaluated with a criterion of 1.

Fig. 4 shows the buffers made to the polygon shapefiles of the population centers. The 2 km buffer was given a criterion of 5, the 3 km buffer a criterion of 3 and the 5 km buffer a criterion of 1.

Table 5.
Data origin for GIS modeling.

| Supplies | Type of data |
|---|---|
| Stratum 1,2,3 y 4 | Poligon shapefile |
| Position | Poligon shapefile |
| Road mesh | line shapefile |
| Population core | Poligon shapefile |
| Electrical line meshes | line shapefile |
| Wind speed | Wind map of Cuba |
| Migratory flyways | Google earth |

Source: Own elaboration.

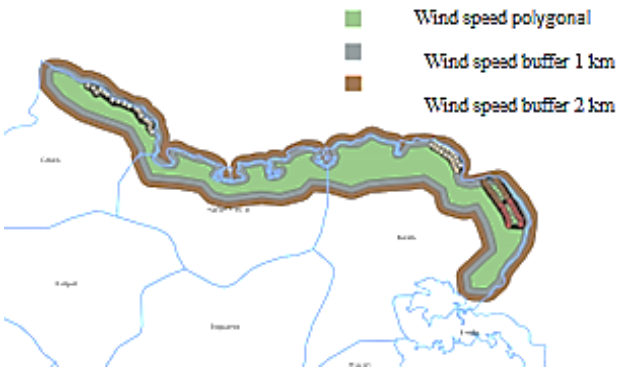


Figure 3.
Buffer to wind speed, source: Own elaboration.
Source: Self-made Imagen

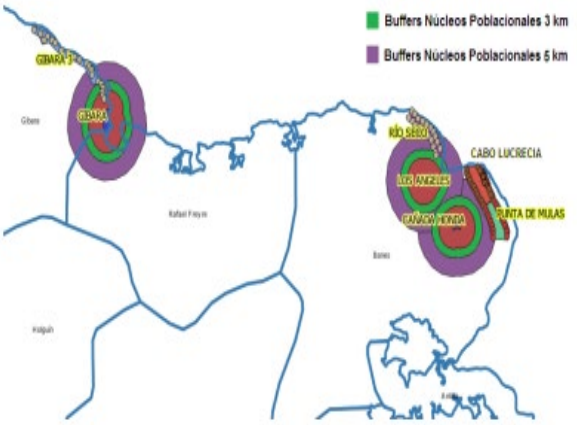


Figure 4. Buffers of population centers.
Source: Self-made Imagen

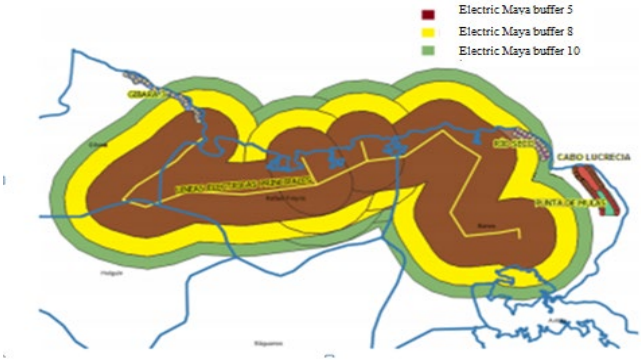


Figure 5. Electrical line buffers
Source: Self-made Imagen

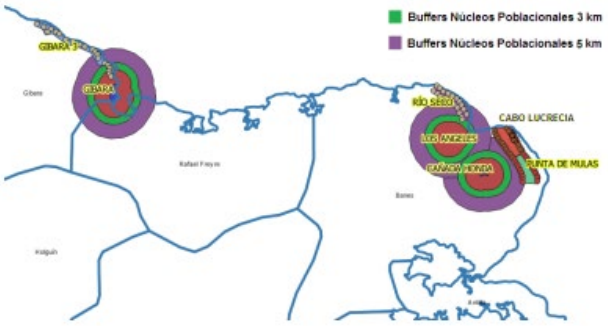


Figure 6.
Buffers of population centers.
Source: Authors

Fig. 5 shows the buffers made to the shapefiles of the electric grid lines, giving a criterion of 5 to the buffer of 5 km, a criterion of 3 to the buffer of 8 km and a criterion of 1 to the buffer of 10 km.

Fig. 6 shows the buffers made to the polygon shapefiles of the population centers. The 2 km buffer was given a criterion of 5, the 3 km buffer a criterion of 3 and the 5 km buffer a criterion of 1.

Fig. 7 shows the buffers made to the shapefiles of the

electric grid lines, giving a criterion of 5 to the buffer of 5 km, a criterion of 3 to the buffer of 8 km and a criterion of 1 to the buffer of 10 km.

Fig. 9 shows the buffers made to the shapefiles of the road map lines, the 3 km buffer was given a criterion of 5, the 5 km buffer was given a criterion of 3 and the 8 km buffer was given a criterion of 1.

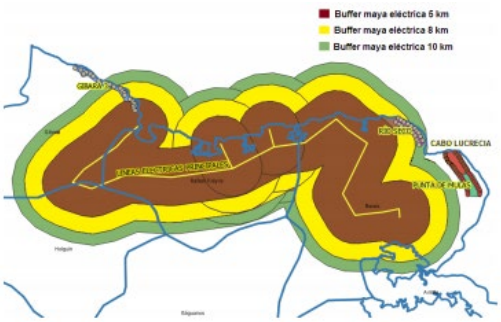


Figure 7.
Power line buffers. Sources: own elaboration.
Source: Authors

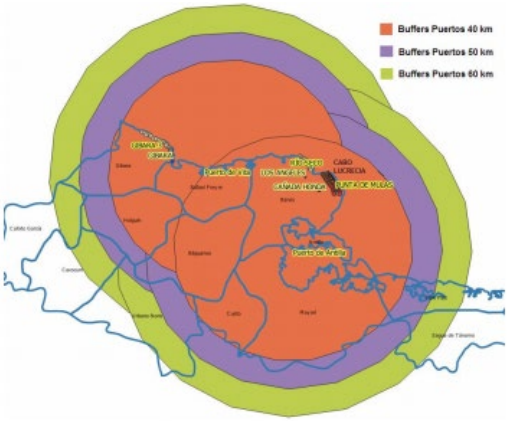


Figure 8.
Buffers of the ports
Source: Self-made Imagen.

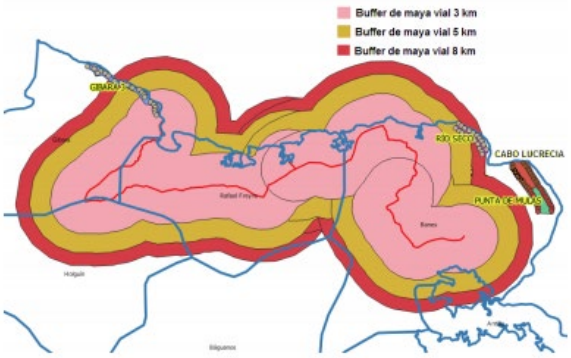


Figura 9.
Topes de la calzada
Source: Authors

Figure 10. 2 km raster of the population centers.
Source: Self-made Imagen.

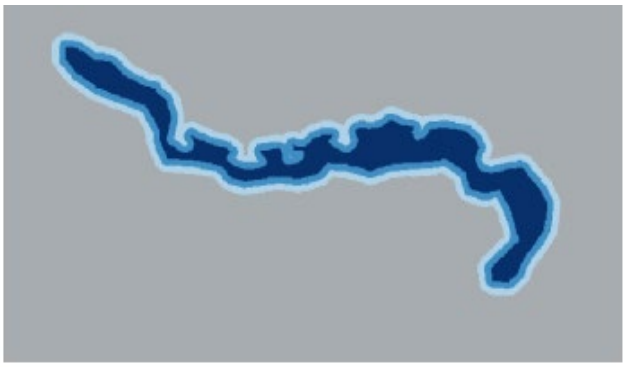

Figure 11. Raster sum of wind speed
Source: Self-made Imagen.

### *4.3 Rasterization of buffers*

Each buffer is converted to a raster image with the value reached according to its criteria, this operation is performed with the conversion tool of this software, which is called rasterize. Fig. 10 shows an example of the rasterization of the 2 km buffer of the population centers.

### *4.4 Sum of the raster images of each variable*

The raster images of each variable are added in the QGIS software tool, called raster calculator. Fig. 11 shows the raster calculator in the procedure of adding the raster images made to the buffers of the population cores. Fig. 12 shows the result of the sum of the raster images of the wind speed variable.

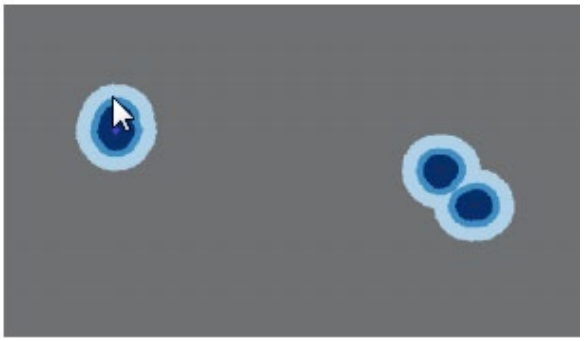

Figure. 12. Shows the result.
Source: Self-made Imagen

Likewise, Fig. 12 shows the result of the sum of the raster images of the population core variables.

Figs. 13 and 14 shows the result of the raster sum of the population centers variable.

### *4.5 Sum of all raster*

With the raster sums of each variable, we proceed to add them all, each one multiplied by the weight of its variable obtained by the AHP method, to obtain a raster image of all the variables.

Fig. 15, shows the raster image of the sum of all the rosters of each variable, where the areas with the highest concentration of variables with their best criteria can be seen in dark blue.

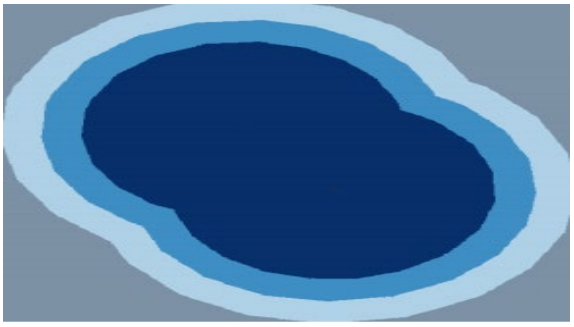

Figure 13. Raster sum of population centers.
Source: Self-made Imagen

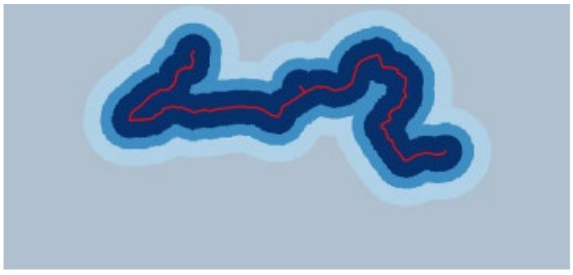

Figure 14. Shows the result of the raster sum of the Power lines variable.
Source: Self-made Imagen.

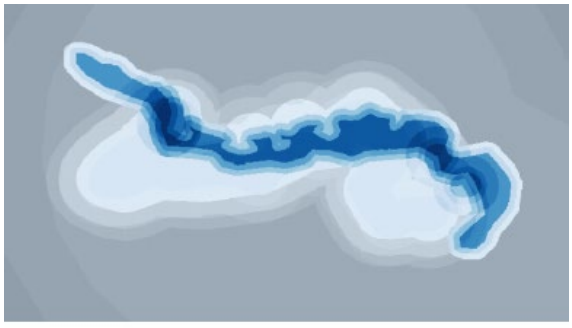

Figure 15. Shows the raster image of the sum of all the rosters.
Source: Self-made Imagen.

### *4.6 Vectorization*

The raster image was vectorized to find the polygons with the highest variable content and their criteria, where the polygons were labeled with their values, from 1 with the lowest variable content to 9 with the highest variable content, Fig. 16.

Fig. 17 shows an enlarged image of the vectorization, where the polygon of the Gibara III wind farm project can be seen, which encloses in its area a polygon with a value of 9, that is, it meets all the variables in its highest criterion.

Fig. 18 shows an enlarged image of the vectorization, where the polygons of the wind farm projects in the municipality of Banes can be seen. It can be observed that the Río Seco wind farm project has a polygon with a value of 7 and in the areas of Cabo Lucrecia and Punta de Mulas, the polygon with the best value is 6.

From the analysis it was obtained that the Gibara III Wind Farm project was the project with the optimal zones in the eastern region of Holguin, since it encloses in its stratum, zones with all the variables and its best criteria with a value of 9. The Rio Seco project enclosed in its stratum zones with a maximum value of 7, this means that it does not comply with all the variables in its best criteria, as well as Cabo Lucrecia and Punta de Mulas, with zones with a maximum value of 6.

Table 6 shows the Wind Farm projects, in what could be an order of priority in their construction for their optimal zones, according to the variables and criteria evaluated in the research.

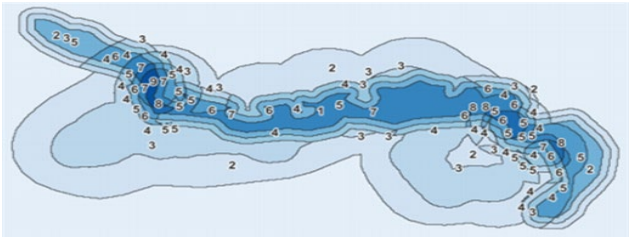

Figure 16. Vectorization of the total raster.
Source: Self-made Imagen

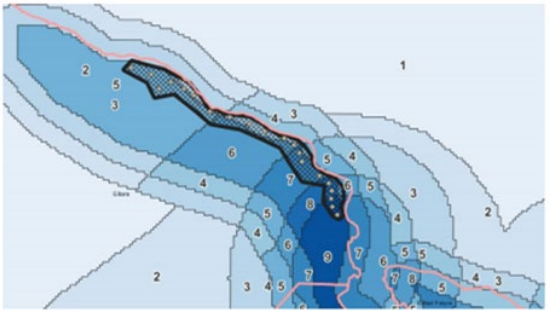

Figure 17. Gibara III in vectorization
Source: Self-made Imagen.

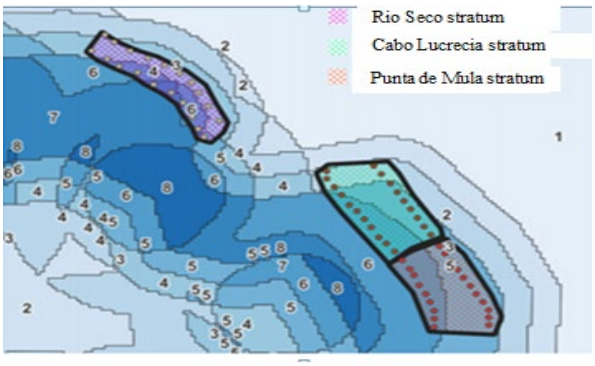


Figure 18. Dry river, Cape Lucrecia and Punta de Mulas in the vectorization
Source: Self-made Imagen

Table 6.
Results of the research

| Wind Farm Projects | Priority |
|---|---|
| Gibara III | 1 |
| Rio Seco | 2 |
| Cabo Lucrecia | 3 |
| Punta de Mulas | 4 |

Source: Own elaboration

## 5 Conclusions

1. With the research carried out, it was possible to elaborate, for the first time, a mathematical conceptual model for the selection of optimal zones for the installation of wind farms in the eastern north of Cuba, by means of the multicriteria and GIS methods, where it was determined that, within the evaluated alternatives of wind farms, Gibara III is the optimal one.
2. As a result of the combination of Multicriteria Decision Support Methods (MCDM) and Geographic Information Systems (GIS), a procedure was obtained that can be generalized for the optimal selection of areas in different fields of science.
3. These models will allow the development of wind projects in the eastern region of Holguin, and to be able to manage human, financial and material resources.

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UNIVERSIDAD NACIONAL DE COLOMBIA

# Distributed generation powered by smart grids

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**Abstract**
Smart grids are conceived as a system to optimally manage the set of means that are part of the electricity grid to achieve adequate performance in the distributed generation system in the supply of quality electricity. The objective of this study was to analyze the importance of smart grids in distributed generation and how the elements that make it up allow the implementation of this technological innovation. The methodology was based on the mixed approach, of experimental design with descriptive scope and documentary support,the experimental method was applied for programming with the use of Homer Pro software. The results were obtained by simulation, carried out for a distributed generation system with a consumption of 197.78 kWh/day, obtaining important data such as the amount of kWof electricity generation supplied in a year, with a value of 98,114 kWh/year.

*Keywords*: distributed generation; homer pro; monitoring; smart networks; scada, smart grids.

# Generación distribuida potenciada con las redes inteligente

**Resumen**
Las redes inteligentes, están concebidas como un sistema para gestionar de manera óptima el conjunto de medios que forman parte de la red eléctrica para lograr un adecuado desempeño en el sistema de generación distribuida en el suministro con calidad de la electricidad. El presente estudio tuvo como objetivo analizar la importancia que tienen las redes inteligentes en la generación distribuida y cómo los elementos que la conforman permiten la implementación de esta innovación tecnológica. La metodología se fundamentó en el enfoque mixto, de diseño experimental con alcance descriptivo y apoyo documental, se aplicó el método experimental para la programación con el uso del software Homer Pro. Los resultados se obtuvieron por simulación, realizada para un sistema de generación distribuida con un consumo de 197,78 kWh/día, obteniéndose datos de importancia como la cantidad de kW de generación eléctrica suministrada en un año, con un valor de 98.114 kWh/año.

*Palabras clave:* generación distribuida; homer pro; monitoreo; redes inteligentes; scada; redes inteligentes.

## 1 Introduction

Since its discovery, electrical energy has been presented as a necessary resource for the development of humanity [1].Over time, societies have evolved and along with them, the demands of users have increased rapidly. From this, the processes of generation, distribution, and commercialization of electrical energy have undergone changes to adapt and guarantee at an adequate level the requirements for reliable, efficient, and quality supply that consumers of this indispensable service currently demand.

Distributed generation of electricity has been gaining ground in various countries around the world, as an alternative to centralized generation; the latter, as a traditional production model that currently provides a large part of electrical fluid on a global scale, through thermal, nuclear, and hydraulic power plants, whose processes entail alarge polluting load of greenhouse gases (GHG) for the environment. atmosphere. This has caused strong global pressure on the supply of electricity with technologies basedon fossil fuels, which do not allow sustainable development,and to develop new technologies for the generation of electricity based on

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cleaner energies. According to the Transform Energy group and the government relations and international affairs technical team of the World Wildlife

Fund (WWF) [2], globally, the energy sector contributes three-quarters of emissions greenhouse gases (GHG).

To this end, according to the report published by the International Energy Agency [3], the electricity sector must cease to be the largest emitting sector in 2020 and begin to be the first sector to reach net zero worldwide by 2040. Sothat, in this way, it contributes to planetary sustainability. In this framework, the energy transition that the sector has been experiencing in several countries around the world for some decades now imposes the responsibility of following the route of what has been called [3] the 5D's (decarbonization, decentralization, digitalization, democratization, and deregulation) that implies challenges in the planning and operation of electrical systems. The adoption of this route brings with it various benefits, among which [4] have been identified: greater proximity between generation and consumption, less need for additional infrastructure, and sales options by prosumers with other prosumers.

Under this approach of centralized energy generation process, it has become evident in various studies developed on this topic that problematic situations involving the generation, transportation, and distribution of electrical energy have been created through its use [6]. The issues thatseem to have the most impact on the above are, firstly, the high cost of generation and maintenance of this type of plant; secondly, the supply of energy through the centralized generation scheme requires transportation over long distances, which is why technical difficulties arise in this transmission stage that implies energy losses in the electrical networks. For this reason, it is essential to strengthen the capacity of the distribution and transmission system, where the appearance of disturbances and instability within the National Interconnected System (SNI) affects the quality of supply.

Hence, the dynamics of the development of alternatives to solve the problems and achieve an improvement andefficiency in the electricity supply has focused on different options, of which, in this work, distributed generation (DG) is particularly relevant.

Regarding the Energy Foundation of the Community of Madrid [7], The so-called distributed generation, as an alternative model to the traditional scheme, is understoodas the generation of energy that is closer to the consumer, both physically and virtually. It does not imply using a specific particular technology. DG applications range from base generation, peak generation, and cogeneration, to improving quality supply, backup, andsupport to the transportation and distribution network.

It is interesting to note that scientific and technological evolution has allowed the development of smart grids, a typeof intelligent electrical networks that favor the distributed generation of electricity and constitutes a tool with great potential to support energy transition. The implementation of smart networks that effectively manage the flow of energy in these networks requires the modernization of the current electrical energy transport networks, for their transformation into smart grids or smart electrical grids [6]. The concept of smart grids is synonymous with technological change in the electricity sector [8].

The purpose of converting current electrical networks into smart grids is to satisfy electrical demand with higher quality of supply, using energy from environmentally friendly energy sources and creating a smart electrical network, from generation to consumers. There are several advantages that smart networks offer, among which are: a) it improve the reliability of the system; b) improve system efficiency; c) allow the integration of distributed energy resources; d) the possibility of two-way communication with clients; e) optimization of the use and more efficient operation of assets; f) promote energy demand management and; g) mitigation and adaptation to climate change [9].

It is recognized that Ecuador has also been receptive to the need to make substantial changes in the electrical system; However, much more still needs to be done for the country to catch up with advanced countries, in terms of the advances achieved in modern self-sustainable generation systems and the new technologies used in automated control for the distribution and commercialization of electrical energy on a small and large scale.

Currently, in Ecuador, centralized hydroelectric generation plants provide 92% of the electricity consumed inthe country, thermal plants participate with 7% of electricitygeneration and the participation of electricity generation fromnon-conventional energy sources is barely 1%. Althoughwater is a so-called non-polluting resource [5], the construction of large electrical infrastructures for generating and transporting energy to the final consumergreatly impacts the environment in the different areas where these plants have been built. hydroelectric plants,as well as losses and problems related to the efficiency of the electrical energy supply.

Taking into account all of the above, the objective of this work is to analyze the importance of smart grids in distributed generation and how the elements that comprise it allow the implementation of this technological innovation, with an important group of applications aimed at achieving asupply of electrical energy in a reliable, efficient and qualitymanner to end users, as well as ease of control of the elementsinvolved in generation, transmission, and distribution.

## 2 Materials and methods

The present research was carried out with a descriptive exploratory study on smart grids, for which an abundant bibliography was compiled, through academic search engines, such as Scopus, IEEE Explore, AMC, Scielo, and Google Academic, to substantiate the theoretical andreferential part of the investigation.

In addition, an experimental type of analysis was carried out, with the use of Homer Pro software, for the simulation of a generation system that allows knowing which operating energy systems use renewable energy sources in their operation, under the principle of decentralized electrical energy generation, in addition to the creation of a model that allows demonstrating and explaining how to use the smart grids with distributed generation.

Therefore, a mixed approach was applied, using quantitative and qualitative methods, since it proceeded with the description of the characteristics and data required for the implementation of distributed generation and the smart grids,as

well as the analysis of the values obtained with the Homer Pro software, to obtain the costs per execution of a simulated project with the environmental and economic benefit obtained by implementing these decentralized generation systems.

## 3 Results and discussion

It is important to highlight that there is still no definitive, clear, and specific definition of distributed generation (DG); therefore, various specialized institutions have given valuable contributions to the afore-mentioned term that should be considered. The Institute of Electrical and Electronics Engineers (IEEE) or Institute of Electrical and Electronics Engineers, defines DG as "electrical generation facilities connected to the electrical system through a common connection point: a subset of distributed sources." For its part, the International Council of Large Electrical Systems (CIGRÉ) mentions that distributed generation (DG) "It's not usually planned; It is not dispatched centrally either; and its capacity is less than 50 or 100 MW." At least, it is relevant to point out its main characteristics such as electrical generation, transmission to load centers, and energy distribution, with the advantage of buying or selling electrical energy in the National System. Interconnected (SNI) or in isolation [10].

The GD has the purpose of covering the demand that the main electrical substations cannot supply by direct connection to the grid of small generation systems. It is also presented as an efficient alternative to supply isolated communities with renewable energy sources.

### *3.1 Smart Grid*

The smart grid is defined as a smart grid with all the elements that are part of the electricity grid. These networks can census, monitor, and analyze information from all the elements that compose it and do so in real-time, for optimal performance of the electrical networks, control energy flows, including DG, and can detect failures to improve their performance. This makes it possible to link regulatory areas such as protection, control, instrumentation, measurement, quality, and energy management into a single management system, with the main objective of achieving efficient and rational use of energy [12].

Table 1.
Shows some benefits of DG.

| | Main benefits |
|---|---|
| Economical | Reduction of costs in the construction and/or expansion of transmission networks.<br>Increase in energy security.<br>Lower production and transportation costs. |
| Technical | Reduction of technical losses.<br>Expansion of distributor networks.<br>Positive impacts on the distributor system. |
| Socio-environmental | Reduction of polluting emitters. Decarbonization and transition to renewableprojects.<br>Promotion for the incorporation of newrenewable technologies.<br>Increase in the electrical frontier.<br>Reliability |

Source: Grisales, L., Restrepo, B., & Jaramillo, F., 2017.

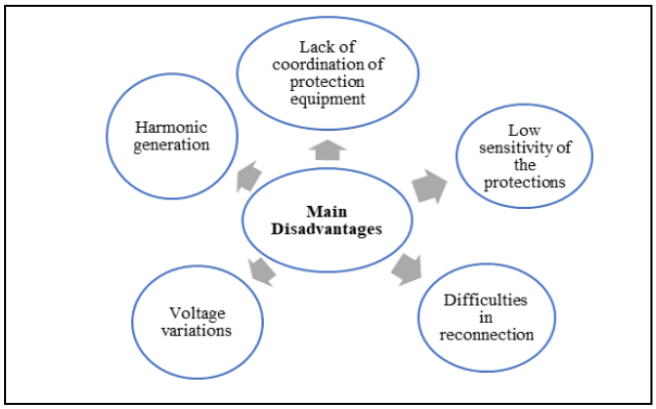



Figure 1. Main disadvantages of distributed generation.
Source: Own elaboration

Likewise, there are some disadvantages linked to DG systems that, although they may be of minor importance, are always relevant (see Fig. 1).

**Geographic Information System (GIS)**

The quality of the data in the GIS must be reliable, since erroneous data in the procedure that automatically controls the electrical distribution system is not acceptable, because errors can cause prolonged downtime and accidents. Data requirements in smart grid operations imply the need tomeasure how quickly changes are reflected in the GIS; sincethe longer the time, the greater the risk of something failing.The GIS needs to update its database to accurately associate the equipment of the client with the electrical system [15].

**Advanced Metering Infrastructure (AMI)**

Smart grid designs envision the use of advanced digital meters with two-way communication that can connect and disconnect services remotely, record waveforms, and monitor voltage and current. These should replace previous counters in the same location to avoid changing the design with large dimensions [16].

**Outage Management System (OMS)**

This phase of the smart grid aims to identify and correct power failures quickly and efficiently. The OMS serves not only as a useful tool for operations departments but also as a customer service tool that allows planning, asset management, and providing engineering and regulatory departments the information collected in the database [15].

**Data Acquisition, Supervision and Control System (SCADA)**

In this system, an HMI (human-machine interface) resides under software designed and installed on a server dedicated to production control, which cancommunicate with field devices (automatons) and automatically control processes from monitoring screens. The system makes available to the different users all the information generated in the production process. It can also provide them with detailed information about the system such as monitoring, data storage, quality control and production [17].

**Distribution Management System (DMS)**

The Distribution Management System or Distribution Management System (DMS) constitutes a basic part in the control of the smart grids, whose fundamental objective is the

management of these intelligent networks under the premiseof reducing risks and costs by optimizing operations [18]. The implementation of a DMS for the operation of the electrical network will allow a distribution company to improve its level of efficiency in the planning, design and operation of the electrical distribution network, optimizing itsresources (human, financial, assets, others) [19]. The DMS functions as a means for the transition to the smarts grids andprovides the starting basis for modeling operational anddirect field activities safely and efficiently [20].

DMS is a combination of many technologies focused onthe electrical distribution sector. They are packages implemented on multiple platforms that include diverse hardware and software components, which, in addition to the constant evolution of technology, generate a wide spectrumof variables that must be integrated into a single system [19]. DMSs are programmed with an emphasis on reliability, efficiency, security, and interoperability [20].

DMS has numerous advantages, including a) actionable information and real-time control; b) more efficient ability to meet regulatory requirements; c) more efficient customer service through fault management and better voltage; d) open systems platform; e) security; f) scalability and g) simplified workstations. Due to its usefulness, it is the strategic systemthat facilitates the management of an intelligent network and its advantages [21].

**Distribution Automation (DA)**

This system is responsible for monitoring, controlling, and establishing communication functions located in the feeder; within it are the areas of communication and protection. The elements of this system have the purpose of interrupting the flow of current when it detects faults in the line; For which, it monitors the current and voltage that circulates in the network to automatically restore electrical service to customers. This system is required to be capable, flexible, and fast to reconfigure the feeder network; Thus, the distribution components will have the capacity to accept transfers, in addition, it is also required that the protection system can isolate the fault in the reconnected topology [15].

Smart grids currently entail a series of advantages and disadvantages, as described in Table 2 [22]. To manage additional services to users, the stage known as Advanced Metering Infrastructure (AMI), which is based on the association of communication networks, can provide clients with a group of benefits such as monitoring energy use, to economize based on the price of the energy used, giving riseto distribution companies also having access to the load, to manage demand remotely [15].

**Hybrid systems**

Many authors have shown that the network connectivity with the hybrid system has been more efficient and reliable than the standalone system. Today, solar and wind energy constitute a better option to generate electricity by synchronizing each other, both systems independently can provide results, but with difficulties according to the demand to be covered, because the resources are clean but intermittent due to their duty cycle. To achieve optimization and productivity of this hybrid system, the selected location must be in accordance with the minimum requirements necessary to use generation elements [23].

Table 2.
Advantages and Disadvantages of the Smart Grids.

| Advantages | Disadvantages |
|---|---|
| Existence of interconnected electrical net Works throughout the planet. | High costs in its implementation at thestate level |
| Reduction of power outages | Obsolete electrical networks |
| Grid frequency stabilization | Little standardization of the products that make up this technology. |
| Automation of some processes in the electrical system | Complex urban infrastructures. |
| | Lack of incentives on the part of governments to promote the use of this type of technology. |
| | Lack of international standards. |

Source: Duque, M., & Romero, G. 2016.

One of the tools or software that allows simulations or feasibility studies to be carried out is the Homer Pro “Hybrid Optimization Model for Renewable Electrical Energies”. Midwest Research Institute holds the copyright to this software. It was developed by the National Renewable Energy Laboratory (NREL) of the United States [24]. This program is mainly used to design power plants incorporating non-conventional energy sources such as solar or wind or a combination of both since it includes configurations that allow studies to be carried out to implement the type of energy to be used and thus optimally establish the operating cost concerning current prices [25].

**Related Studies**

In this section, some international and national studies were considered whose central subject dealt with elements, tools, and new technologies that make up DG and smart grids.

In the first instance, at the international level, a study is presented aimed at determining the incidence of the implementation of a smart grid in the distribution system in a province of Peru. The methodology was adaptive, correlational using software smart grids which collect real-time data on the normal state and failures of the electrical system. The results show that the response time was improved, since it was reduced from 148.50 minutes to 86.92minutes, with a total of 61 minutes and 58 seconds, reachinga considerable time difference. Likewise, reliability increased from 98.62% without the use of smart grids to 99.92% when implementing smart grids in the distribution system. It concluded that response time and reliability were improved through the implementation of a smart grid in the distribution system [26].

The research is closely linked to thepresent study, on the topic of integration of smart grids in thedistribution system to achieve the optimization of theelectrical system and improve the response time, reliability and quality of its supply. Likewise, software is used to obtain real-time data on the operation of the generation of theelectric fluid.

In another contribution, a study from the University of Zaragoza, Spain, whose objectivewas to analyze and evaluate the impact on the electrical system already established in the Cape Verde archipelago using new smart grid technologies. Protection against energy theft and control of effective payment of electricity consumption were analyzed; determining that an update of the electrical system is required to quickly respond to

energydemand. In addition, the financing problems that may appearwere analyzed if it is not sized correctly; proposing the inclusion of an AMI to solve the electrical losses that occur in the archipelago due to conventional measurements [27].

This research is articulated with the present work because it is focused on reducing costs that are sometimes not economically convenient for the consumer, studying how to achieve an effective and reliable supply, through smart networks.

In the same order, [28] in his investigation proposed the objective of reducing the polluting effects to influence the massive use of renewable energy sources and in turn, sustain energy in the country. In this research, with the qualitative method, the attributes, problems, and benefits involved in the installation of small power plants are explored. Obtaining that distributed generation, using medium voltage photovoltaic systems, allows improvement in the quality of electrical energy; conclude that distributed generation helps maintain voltage at stable levels in theelectrical system and users use decentralized generation systems which help their economy and the environment.

This study is also connected with this research, since it is focused on the reduction of polluting effects resulting from centralized and conventional generation, because the area where the study was carried out: the Atacames municipality in theprovince of Esmeraldas is a tourist place, wherein they sought to managethe use of resources in an environment-friendly manner, to attract the attention of tourists and in turn generating savings in the use of electrical energy.

It also conducted a study that consisted of estimating the costs of electricity distribution, considering the status and performance of the current infrastructure system in the generation, transmission, and distribution of energy, to guide technological development through the application of distributed generation, using a comparison between distribution companies versus network systems, designed with optimization criteria [29].

The results obtained in this research demonstrated that the costs are not high to implement DG in the short term, in the Colombian network. It was determined that the implementation of DG would not establish large implementation costs, nor could it affect the quality of the service; considering that the costs will depend on the demand that needs to be covered, the infrastructure that will be installed, and the quality of service that will be provided on a low, medium andlarge scale.

The research was based on analyzing the energygenerated by a photovoltaic system in the city of Manizales-Colombia, implementing a system for monitoring and characterizing the energy performance of the proposed system [30].

The methodology assumed was experimental and quantitative, the information collected was related to climatic factors at a given time. The results are obtained from the analysis of external factors that affect the efficiency of solar panels, and climatic variations such as radiation, rainfall, and ambient temperature. Likewise, some points were taken into account that affect and benefit the installation of photovoltaic systems in the city of Manizales, because being a territory with a lot of cloud cover affects solar gain; despite this, it has the advantage of being located in the Andean Mountain range where the winds clear the clouds. Another aspect analyzed focused on the use of centralized inverters and microinverters, finding that the capacity to generate more power lies in the use of microinverters in this case

In this sense, the research is linked to this work in aspects such as the technical part and location of the photovoltaic systems, in the most suitable place for better capture of solar radiation

Conditions in Ecuador for the development of distributed generation and smart grids

Ecuador has established a normative-legal body for the use of DG, which is endorsed, in the first instance in the Constitution of the Republic, and then by a set of laws that emerge from it, such as the Organic Law of Public Service Electrical Networks [13]. In this law, it is established that, to move towards modernization of electricity networks, regulatory aspects must be considered for energy transportation and distribution networks, communications networks, distributed generation, energy storage, smart meters, distributed control, active demand management, new products, and services; also take into account the opportunity to do so [13].

It also has a series of regulations identified as ARCERNNR: 001/2021 and 002/2021, which establish provisions for the process of qualification, connection, installation, and operation of distributed generation systems based on renewable energy sources for the self-supply of regulated consumers, and determines the technical and commercial conditions that must be met concerning the development and operation of distributed generation plants, owned by companies that are duly authorized by the respective government ministry, to carry out generation activities [14].

In the national context, research [11] was developed whose objective was to understand and report on the effectiveness and importance of distributed generation and the different types of renewable sources. As a result, the use of renewable sources aimed at distributed generation in Ecuador was successfully verified, which can be used for future research, making known, in conclusion, the types of sources available in our Ecuadorian territory.

The scientific article is linked to the present work, in the interest of knowing the renewable resources that can be usedin the country, to implement generation technologies with renewable sources in various places in the Ecuadorian territory, in harmony with the environment.

On the other hand, the study presented by the authors [31] focuses on exposing the possible scenarios that arise when implementing wind as an energy resource in Ecuador.

The methodology used is described as exploratory, which allowed collecting information from different sources; determining that Ecuador meets all the requirements to plan activities for the massive use of renewable resources; however, the high costs and lack of vision have limited the country to an environmentally friendly energy change, concluding that Ecuador, geographically, cangenerate green energy through the use of wind, and take fulladvantage of the potential that this natural resource has.

The previous investigation presents similarities with this study, in that it presents an approach related to the use of wind energy, as an alternative source for the generation of electricity aimed at improving energy distribution, reducing fossil fuel consumption, and achieving the implementation of the use of hybrid generation technologiesin the national energy system.

Finally, in the investigative work developed by the authors [32], the objective was to install a photovoltaic system to

reduce costs on the electricity bill, giving importance to the use of renewable energy sources. The sizing and justification of the elements of a photovoltaic solar installation dedicated to supplying a free house is carried out,providing daily help to a total of 6 people. To obtain these resources, the PVSyst program has been used, which offers great help to make an appropriate simulation of the installation, making useful and precise data easier to achievethe future installation. The reason why the analysis has beenchosen with this type of installation is the area in which the home will be located, a coastal location where most of the days of the year are sunny days, where temperatures are considered high. In conclusion, the estimated sizing is capable of achieving optimal functioning of the devices used in the analysis and producing electrical performance withoutpower outages.

The study is associated with the present research work, since both are oriented towards the implementation of an alternative electrical generation system with the objective of reducing the costs of electrical energy delivered by the network, thanks to the introduction of systems called clean generation, giving the opportunity to renewable resources asa better alternative for generation and savings.

Experimental analysis through the simulation of a DG network with the Homer Pro software

The Homer pro software allows you to handle real data in this study because it groups factors that allow you to estimate the appropriate costs and resources to use simulations that allow you to implement a project of this type.

The simulation is carried out for the Salima parish of the Atacames municipality in the province of Esmeraldas. Based on the results, it is possible to propose the implementation of a system to improve the electricity supply through the application of DG, which will allow the use of generated electricity in a sustainable manner and at a lower cost, and even inject the surplus energy generated and not consumed by the end-user into the national electricity system.

To carry out the simulation, it was necessary to manage the installation and temporary license, for academic purposes of the mentioned software. In this first stage of the program, the software interface is presented. Fig. 2 shows how this interface is presented, in which the project was developed, executing the steps mentioned in the following paragraphs, in this way, the feasibility of the study is configured, sized, analyzed, and determined.

As a first step, the coordinates were inserted, to geographically locate the place where the study was conducted, in this case, it was located at 0° 55' 54.04" N - 79°46' 19.02" W, this place is located in Atacames-Esmeraldas specifically in the Chávele campus, once the information was incorporated, the program allows the visualization on the map of the location of the chosen place, then the descriptionof the activities carried out was established to detail the corresponding loads.

The second phase begins once the steps described above have been carried out, thus, the data of the calculated load was incorporated, which corresponded to the value of 197.78kWh/d, distributed among the consumption elements such asappliances and systems lighting, at this same point the software allows for determining the level of the project, in this case, a residential system was selected.


Figure 2. Homer Pro Program Interface
Source: Source: Own elaboration whith Home Pro

After defining the load, the components or generation system that covered the indicated demand were selected. This software allowed simulations to be carried out with elementsof distributed generation with renewable energy sources suchas wind turbines, photovoltaic systems, and hydraulic turbines; Likewise, support systems with energy generation from non-renewable sources also allow the use of elements such as voltage inverters and storage batteries, which are components that enhance generation using alternative energy sources.

Programming requires the use of data such as DNI or irradiation index in the year of the selected place; This data is consulted on the NASA website, (https://power.larc.nasa.gov/) as well as the wind speed available at the location to be implemented. These allowfordetermining the feasibility of using the type of equipment according to the energy values provided by the resources to be used.

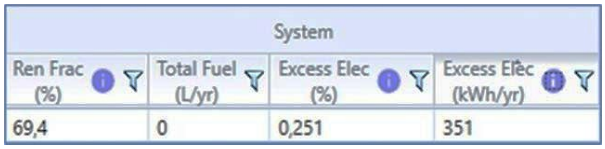
It is important to note that the study, to be conceptualizedas a DG system, was located in the public supply network, which was connected to the system, in this case, CNEL EP Atacames, because this generation system is projected from the types of smart grids. The program allows knowing the sales values of kW/h in the electrical system of Ecuador, as well asknowing the consumption that is generated in the case of consumers (prosumers). Once these parameters were determined, the structure of the system could be observed with the different components referred to above.

After carrying out the analysis with the program, the values can be processed in Excel for better visualization andin this way to determine the estimated investment costs for the projection of the system, as well as the investment recovery times, the energy sales and purchase values.

The results provided by the simulation in the Homer Pro determine the best options for arrangements to include in the

| Architecture | | | | | | Cost | | | |
|---|---|---|---|---|---|---|---|---|---|
| ⚠ | | | | | Dispatch | COE ($) | NPC ($) | Operating cost ($/yr) | Initial capital ($) |
| | | | | | LF | $0,108 | $169.537 | $12.671 | $24.236 |
| | | | | | LF | $0,112 | $176.685 | $12.618 | $31.999 |
| | | | | | LF | $0,243 | $385.072 | $27.095 | $74.367 |
| | | | | | LF | $0,248 | $392.222 | $27.059 | $81.934 |
| | | | | | | LF | $0,890 | $736.746 | $64.249 | $0,00 |
| | | | | | LF | $0,899 | $744.434 | $64.212 | $8.113 |

Figure 3. Architecture options in relation to investment costs. Where: COE→ Cost of Energy NPC→ Net Present Cost
Source: Own



| System | | | |
|---|---|---|---|
| Ren Frac (%) | Total Fuel (L/yr) | Excess Elec (%) | Excess Elec (kWh/yr) |
| 69,4 | 0 | 0,251 | 351 |

Figure 4. System Resulting Values. Where: Ren Frac→ Renewable Fraction (Renewable Fraction)
Source: Own

| Cost | | | |
|---|---|---|---|
| COE ($) | NPC ($) | Operating cost ($/yr) | Initial capital ($) |
| $0,108 | $169.537 | $12.671 | $24.236 |

Figure 5. Operation cost table.
Source: Own

distributed energy generation project, considering the elements and costs required for it, as shown in Figure 3, where it can be observed the parameters and equipmentconsidered in the study or design of the network. The simulated distributed generation system consists of a 59-kW photovoltaic array, the 30-kW converter and a 10 kW wind turbine connected to the CNEL EP network.

The software displays the results, shown in Fig. 4, in which you can observe data such as the fraction of energy delivered to the load that originated from renewable energy sources, thetotal fuel which for this simulation is 0% as well as the % ofsurplus energy generated and the value of this respectively

Another value that the software provides is the amount ofenergy purchased and sold to the grid, these values are 41,968 kWh and 54,046 kWh respectively

Fig. 5 shows the table of the operating cost values and the value obtained according to the simulation of the program, such as the life cycle cost of the system in relation to spare parts and maintenance, as well as the operating cost with theannualized value of all costs and income other than the initialcapital costs and the cost of the initial investment programmed for a period of 30 years of the useful life of the system.

The expansion of distributed generation in the energy systemcan bring enormous benefits, but it also requires deep andthorough research of its technologies, because to be able todo it with full functionality, all signals from these sources must be managed through a robust communication system that guarantees their availability at the time of implementation in the network, thus becoming a smart grid. According to the analysis of the results, the smart gridsconstitute an optimal process for its implementation in the development of modern, efficient, effective, and qualityelectrical systems in the energy supply. Although it is true that currently, the investment costs to implement this systemare high, a factor that could influence the decision toimplement this system. [29], The benefits reportedthroughout this study may constitute an incentive for the fulladoption of this system in the coming time

## 4 Conclusions

The analysis of the importance of smart grids in distributed generation and how the elements that compose them allow the implementation of this technological innovation, with an important group of applications aimed at achieving a reliable, efficient, and quality supply of electricity to end users, as well as the ease of controlling the elements involvedin generation, transmission, and distribution.

on the previous literary review, it was possible to verify that smart grids or smart networks present a set ofadvantages that make it possible to contribute to the control and monitoring of electrical systems for the collection, transportation, and distribution of electrical energy. However, it is necessary to modernize the current electrical networks, introducing a set of elements that allow it to be converted intoan intelligent network (smart grid).

The results obtained in the experimental analysis with a simulation of a DG network using the Homer pro software, based on the proposed objective, of analyzing the importanceof smart grids in distributed generation and how the elementsthat make it up, allow the implementation of this technological innovation. It was found that:

- Simulation tools such as Homer Pro are presented as an important element, as demonstrated in this study, to be able to carry out feasibility studies for the design of a mixed system, which allows the application of smartnetworks in the distributed generation system, because it allows knowing and analyzing how they interact with the supply network thanks to the elements of generation, transformation, energy storage, andmeasurement control.
- The elements of smart grids are essential for their use as bidirectional meters or electricity meters that allow measuring the energy flowing from the network to the user and vice versa and can be installed in homes in industry and/or commerce, in such a way that the user can control the energy used, which leads to take care of their economy and consequently the environment.
- The systems and elements that intervene in a distributed generation system with the support of smart electrical networks allow greater efficiency and effectiveness in terms of generation, transmission, distribution,monitoring, and control. Therefore, they are estimated as necessary for the provision of efficient, safe, and quality electrical energy service in the country.

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# Optimization of the refined used lubricating oil/diesel mixture to incorporate it into drilling fluids

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**Abstract**
The use of refined used lubricating oils (RULO) is an opportunity for use for the industrial sector, improving the environment. The objective of the research was to evaluate different RULO/diesel mixtures from the AT80 and AT40C1 treatments. The experiment consisted of applying different proportions of RULO, forming five different mixtures between ALUR/diesel. The mixes were 85/15, 70/30, 55/45, 40/60 and 30/70. The results showed that the best mixtures were M4 and M5 of the AT80 treatment, with average density of 0.80 g/cm3, viscosity of 5.83 cP, electrical stability of 1694.33 V, flash point of 95°C and 96.67% oil. With these results, a new alternative and use is created, reducing diesel and economic costs for the oil industry that prepares oil-based drilling fluids.

*Keywords*: drilling fluids; refining; rheology; reuse; used oil.

# Optimización de la mezcla aceite lubricante usado refinado/diésel para incorporarlo en fluidos de perforación

**Resumen**
El aprovechamiento de los aceites lubricantes usados refinados (ALUR), son una oportunidad de uso para el sector industrial, mejorando el medio ambiente. El objetivo de la investigación fue evaluar diferentes mezclas de ALUR/diesel a partir de los tratamientos AT80 y AT40C1. El experimento consistió en aplicar diferentes proporciones de ALUR, formando cinco mezclas diferentes entre el ALUR/diésel. Las mezclas fueron 85/15, 70/30, 55/45, 40/60 y 30/70. Los resultados mostraron que las mejores mezclas fueron M4 y M5 del tratamiento AT80, con promedios de densidad de 0.80 g/cm$^3$, viscosidad de 5.83 cP, estabilidad eléctrica de 1694.33 V, punto de inflamación de 95°C y 96.67% de aceite. Con estos resultados se crea una nueva alternativa y aprovechamiento, disminuyendo el diésel y los costos económicos a la industria petrolera que prepara fluidos de perforación base aceite.

*Palabras clave*: refinación; aceite usado; reología; fluidos de perforación; reutilización.

## 1 Introduction

The refining techniques for used lubricating oils (ULO) developed in the world are a good strategy for using them and reducing the environmental impact they represent. As the essential oil market has grown considerably, the waste stream has also increased significantly [1]. According to [2], the management of used lubricating oil is important for the sustainability of resources, including crude oil, and better economic, social and environmental benefits. Used lubricating oils contain Chromium (Cr), Cadmium (Cd), Arsenic (As) and Lead (Pb) and other harmful chemical compounds, such as polynuclear aromatic hydrocarbons, benzene and chlorine [3]. According to [4], globally, since 2015, lubricating oil consumption averaged 35 million tons per year.

For economic reasons, recycling used lubricating oil is more convenient, which is why there are several reuse methods (filtration, distillation, Extraction, Cracking, co-cooking, pyrolysis, etc.) for the treatment of used lubricating oils; that according [5], can be presented as pyrolytic distillation, extraction and distillation with liquid propane,

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solvent extraction and filtration with different types of clays [6].

According to [7], many researchers have successfully worked on generating energy from several alternative sources, such as converting some renewable agricultural substances into fuel. According to [8], the need to find a renewable lubricant that is safe, environmentally friendly, economical and that meets the lubrication standards of the drilling industry becomes imperative. The use of the appropriate drilling fluid is a crucial part of any successful drilling operation [9]. These drilling fluids are water-based muds, oil-based muds and/or synthetic-based muds [10].

In recent years, the development of oil-based drilling fluids has increasingly attracted attention, particularly for situations where water-based drilling fluids are ineffective [11]. Oil-based muds are used for many reasons, some of which are the ability to withstand higher heat without decomposing and environmental cost considerations [10]. The objectives of the drilling are to achieve safely, in the shortest time and at the lowest cost, with the restrictions of additional evaluation and sampling required dictated by the particular application [12].

Currently, the attention of researchers has been directed towards oils generated from vegetable crops, taking great importance. However, according to [13], the available biolubricants, the vegetable oil polyols prove to be the most suitable lubricants for many drilling conditions, although their application is still very limited. The temperature, pressure, depth and formation evaluation procedure to be used, the environmental and ecological impact, costs, are some of the main factors to consider in the preparation of drilling fluids [14]. For this, different oils have been used, such as those extracted from rubber plants [15], from the seeds of the white star apple (*Chrysophyllum albidum*) [8]. The disadvantage of these types of oils is directed towards the volume needed by the oil sector industries, which is not possible to obtain; On the other hand, there is a very high volume in the generation of used lubricating oils [16], which, when refined, could extend their life cycle in the environment, or use them for the preparation of oil-based drilling fluids [17].

The present study was carried out from refining through two treatments, AT80 and AT40C1 to optimize the mixture RULO/diesel. As well as the opportunity to use them as an alternative in the formulation of oil-based drilling fluids. The above, with the aim of improving its rheological characteristics, and comparing them with the diesel reference values, in order to evaluate its efficiency in the parameters: density, viscosity, electrical stability and flashpoint, and use them in the formulation of drilling fluids base oil.

## 2 Materials and methods

The refined used lubricating oils (RULO) used in this study were collected in different automotive service workshops, until a batch of 200 L was collected in each of them. After collection, the oil was deposited in a metal container (drum) with a capacity of the collected volume (200 L).

The experiment was established in a completely randomized design with a factorial arrangement, the factors studied were: the RULO (AT80 and AT40C1) and the proportion of diesel at five levels, and three repetitions. The witness did not receive any of the treatments tested. Once the assumptions of normality of the resulting data, parametric tests were performed for the data that met this and non-parametric tests for those that did not (ANOVA or Kruskal-Wallis tests respectively). As post-hoc tests, multiple rank contrasts were applied by Fisher's method (LSD) for normal data and Bonferroni's multiple rank contrast test for those that did not comply with normality.

Table 1.
Mixture proportions between refined oil and diesel in each treatment.

| Treatments | Proportion Rulo (%) | Proportion Diesel (%) |
|---|---|---|
| Untreated oil | | |
| Refined oil | 100 | 0 |
| M1_AT80 | 85 | 15 |
| M2_AT80 | 70 | 30 |
| M3_AT80 | 55 | 45 |
| M4_AT80 | 40 | 60 |
| M5_AT80 | 30 | 70 |
| | | |
| Refined oil | 100 | 0 |
| M1_AT40C1 | 85 | 15 |
| M2_AT40C1 | 70 | 30 |
| M3_AT40C1 | 55 | 45 |
| M4_AT40C1 | 40 | 60 |
| M5_AT40C1 | 30 | 70 |

Source: Prepared by the author

Table 2.
Parameters analyzed in the simples of each proposed refining treatment.

| Parameter | Units | References |
|---|---|---|
| % Oil retort | mass % | API RP 13B2 |
| % Water retort | mass % | API RP 13B2 |
| % Retort solids | mass % | API RP 13B2 |
| Density | gm c-g$^3$ | ASTM-D743 |
| Viscosity | cP | |
| Electrical stability | Volts | |
| Flashpoint | $^{O}$C | ASTM D93-2000 |

Source: Prepared by the author

The parameters to be evaluated were established based on the oil quality requirements for use in the formulation of oil-based drilling cuttings, which are: oil, water and solids content per retort, density, viscosity, electrical stability, point of inflammation. The proportions of refined used lubricating oil (RULO) were: 85, 70, 55, 40 and 30%. The proportions of diesel are: 15, 30, 45, 60, 70%. The evaluated mixtures are shown in Table 1.

### *2.1 Sample analysis*

Table 2 shows the analyzes and methods that were carried out for each of the RULO refining treatments evaluated in the present study.

### *2.2 Analysis of moisture, solids and oil content by the API RP 13B2 method*

To carry out the analysis, an Ofi Testing Equipment Inc. (OFITE®) complete kit brand evaporation chamber (retort)

was used, filled with number 0 steel wool to trap the solids extracted by boiling 10 mL of the sample.

The drainage tube was introduced into the hole at the lower end of the condenser and the 10 mL test tube was placed under it and an approximate time of 15 minutes was left until the distillation finished at 560 °C.

### *2.3 Density analysis*

The ASTM-D854 method was suitable for measuring the density of oil samples. The analysis consisted of weighing an empty 10 mL test tube, later it was filled with the oil sample up to 10 mL and its mass was quantified. By difference in weight, the mass of the oil was obtained and with the known volume the density of the sample was calculated. The analysis was carried out at a temperature of 28 °C.

### *2.4 Viscosity analysis at 300 RPM*

A Model 800 viscometer (Ofi Testing Equipment, Inc) was used. The team determines the flow characteristics of oils in terms of speed and tension.

All oil samples were analyzed at 300 revolutions per minute (RPM) at a temperature of 28°C. The oil samples were deposited in the stainless-steel cup in which the rotor was introduced. The flow and stress reading exerted by the ULO samples was taken using the magnified dial.

### *2.5 Electrical stability analysis*

The analysis was carried out with an Ofi Testing Equipment, Inc. brand equipment, model ESM-30B with serial No. 2801. The electrical stability meter automatically applies increasing voltage (0 to 2000 volts) through a separation of the probe electrodes. This equipment shows the voltage of the current flowing in the oil sample. The equipment reading represents the stability of the oil, the higher it is, the greater the stability of the sample and it is represented in volts.

### *2.6 Flash Point Analysis*

The determination of this parameter was carried out with a Koehler brand open cup equipment. The analysis consisted of filling the cup with the homogenized sample, the cover was placed on the cup, and then the test flame was lit, the cover was placed along with the cup in the equipment, then the equipment was turned on and it was conducted the measurement of the flash point, and finally the temperature.

## 3 Results

Fig. 1 presents the density results of the AT80 and AT40C1 treatments in the 5 mixtures of RULO/Diesel and the control sample (untreated oil).

The density of the AT80 treatments (refined oil, applying only temperature) was 0.84 g/cm$^3$ and AT40C1 (oil refined with sulfuric acid and nonylphenol) was 0.87 g/cm$^3$, being below the control which was 0.89 g/cm$^3$. Although the two treatments showed a better density compared to the control, AT80 is still the best treatment.

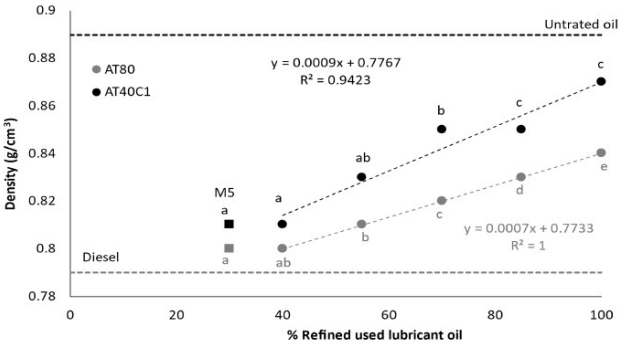


Figure 1. Comparison of density results of refined ULO/Diesel mixtures. Different letters indicate statistically significant differences (Kruskal-Wallis + Bonferroni p< 0.05).
Source: Prepared by the author

From mixture M1 to M4 in the AT80 treatment, the density values decreased, starting from 0.84 g/cm$^3$, up to 0.80 g/cm$^3$, being slightly above the density of diesel which is 0.78 g/cm$^3$.

The density values in the AT40C1 treatment were from highest to lowest in the mixtures, starting with 0.85 g/cm$^3$ in the M1 mixture until reaching a density of 0.81 g/cm$^3$ in the M4 mixture. It is observed that the M5 mixtures of the AT80 and AT40C1 treatments showed similar behavior. However, they were not considered in the central tendency lines, because by adding more diesel to the RULO, the values will be the same as what it presents.

The mixtures M4 and M5 of the AT80 and AT40C1 treatments presented a lower average density with 0.80 g/cm$^3$, but this did not have statistically significant differences (P>0.95) with the density of the diesel.

### *3.1 Viscosity of the RULO/Diesel mixture*

The viscosity results of the RULO/Diesel mixtures in the 2 treatments are shown in Fig. 2.

The refined oil from the AT80 treatment presented a viscosity value of 116 cP, which is slightly below the untreated oil that showed a viscosity of 117.67 cP and exceeded the viscosity of diesel which was 2.83 cP.

The viscosity of the refined oil from the AT40C1 treatment was 104.3 cP, a value somewhat higher than that obtained in the untreated oil which was 102.67 cP but higher than the value of the diesel which was 2.83 cP.

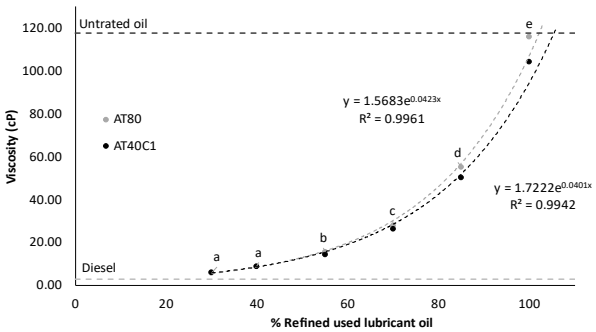


Figure 2. Comparison of viscosity results for refined ULO/Diesel mixtures. Different letters indicate statistically significant differences (Kruskal-Wallis + Bonferroni p<0.05).
Source: Prepared by the author

The viscosities of the mixtures of the AT80 and AT40C1 treatments were in the order of 50.33 cP and decreased to 5.83 cP. The two treatments presented similar viscosities in the mixtures made, being below the RULO. A direct effect is observed on the viscosity, as the proportion of diesel over the RULO increases, it decreases to 5.83 cP in the M5 mixture of the AT80 treatment, being slightly above the value of diesel, which is 2.83 cP. This same behavior was shown in the M5 mixture of the AT40C1 treatment, having a viscosity of 6.17 cP.

The M5 mixture of the AT80 and AT40C1 treatments presented slightly higher average viscosity with 5.83 cP, but this did not have statistically significant differences (P>0.95) with the viscosity of diesel.

### *3.2 Electrical stability of the RULO/Diesel mixture*

In Fig. 3, it can be observed that the electrical stability in the untreated oil was 1147 V, being low compared to the data presented in the RULO of the AT80 treatment, which was 1697.67 V and that of the diesel which was of 1822.33 V.

The electrical stability of the refined oil in the AT40C1 treatment was 291.33 V, well below the untreated oil which was 1076.67 V and the diesel which was 1822.33 V.

This same behavior was observed in the AT40C1 treatment mixtures, starting with a value of 153.33 °C in the M1 mixture and ending at 88.33 °C which is equal to the result of diesel which was 88.33 °C.

The mixtures of the AT80 and AT40C1 treatments presented similar average flashpoints, starting in a range of 153.33 to 88.33 °C with statistically significant differences (P>0.95) with the flashpoint of diesel.

The M1 mixture of the AT80 treatment has an electrical stability of 1536 V, being slightly above the value of the M2 mixture, which was 1521.67 V. The M3 mixture increased considerably, reaching 1874 V, being above the value obtained from the diesel, which was 1822.33 V. The M4 and M5 mixtures had a decreasing trend with a value of 1748.33 and 1694.33 V, being below the value of diesel.

In the AT40C1 treatment, from mixture M1 to M5 there was a trend of decrease in electrical stability, in a range from 233 V to 150.67. These values were below the diesel value, which was 1822.33 V.

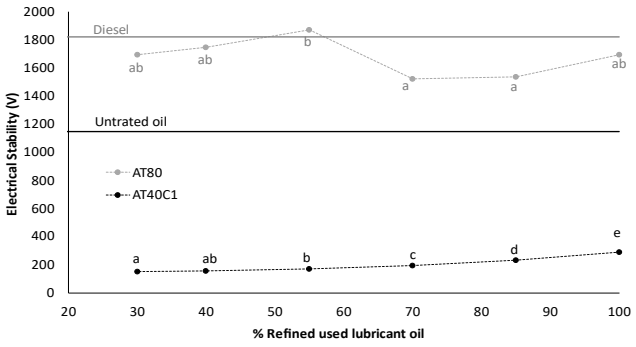


Figure 3. Comparison of the electrical stability results of the RULO/Diesel mixtures. Different letters indicate statistically significant differences (Kruskal-Wallis + Bonferroni p<0.05).
Source: Prepared by the author

In terms of mixes, the best value is presented by M3; and with respect to the best treatment, the best results were obtained by AT80. The M3 mixture of the AT80 treatment presented a higher average electrical stability with 1874 V, having a statistically significant difference (P>0.95) with the value of diesel.

The mixtures of the AT40C1 treatment presented similar averages of electrical stability in the order of 233 to 150.67 V, with statistically significant differences (P>0.95) with the electrical stability of diesel.

### *3.3 Flash point of the RULO/Diesel mixture*

Fig. 4 shows the flashpoint results of the RULO and diesel mixtures made in the treatments and of the untreated oil.

The flashpoint (point at which the material ignites) in the untreated oil of the AT80 treatment has an average of 231.37 °C. This result is above the value presented by the untreated oil of the AT40C1 treatment, which was 226.67 °C.

The refined oil from the AT80 treatment obtained a flashpoint of 236.67 °C, higher than that presented by the RULO from the AT40C1 treatment, which was 178.33 °C. The flashpoint results went from high to low, as the proportion of diesel increased in the mixtures of the AT80 and AT40C1 treatments.

In the AT80 treatment mixtures, it started at 163.33 °C in the M1 mixture, and ended at 95 °C in the M5 mixture, being slightly above the diesel value which was 88.33 °C.

### *3.4 Percentage of solids, oil and humidity of the RULO/Diesel mixture*

Fig. 5 shows the results found of the percentages (%) of solids, humidity and oil of the RULO and diesel mixtures of the AT80 and AT40C1 treatments, in addition, the value of untreated oil and refined oil is included as a reference.

The RULO from the AT80 treatment had a solids content of 6.50%, with 2.33% humidity, and 91.17% oil. The RULO from the AT40C1 treatment had a solids content of 5.67%, with 5.33% humidity, and 89 % of oil. Based on the results obtained, the best treatment was AT80. But the results found were far below those obtained in the untreated oil from the AT80 and AT40C1 treatments, which were 12% humidity, 75% oil and 13% solids.

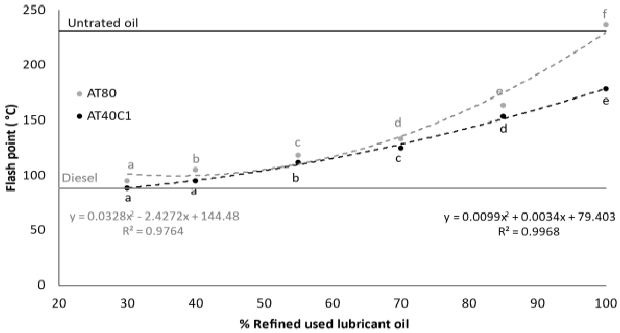


Figure 4. Comparison of flashpoint results for refined ULO/Diesel mixtures. Different letters indicate statistically significant differences (Kruskal-Wallis + Bonferroni p<0.05).
Source: Prepared by the author

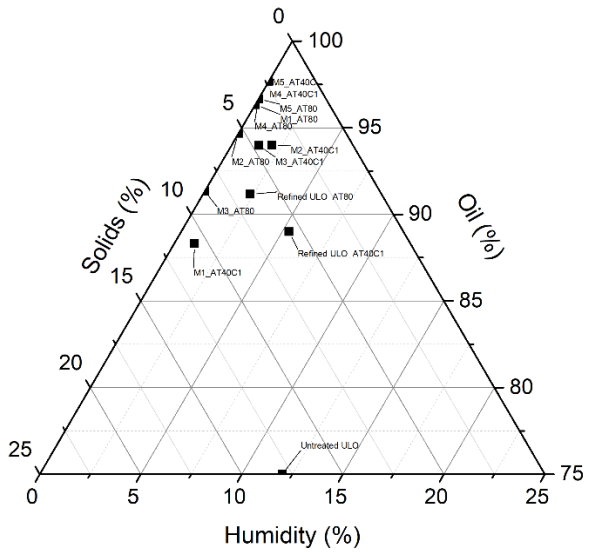


Figure 5. Behavior of the percentage (%) of solids, oil and in the different treatments evaluated.
Source: Prepared by the author

The mixtures of the AT80 treatment presented zero humidity, increasing the percentage of oils in the range of 91.33% to 96.67%. The solids were in the order of 3.33% to 8.67%, with mixture M3 being the one with the highest percentage of solids.

In the AT40C1 treatment, the mixtures presented humidity percentages ranging from 0 to 2%. The oil results were from 88.33% to 97.67%, while the solids results were from 2.33 to 10.67%, with mixture M1 being the one that presented the highest oil percentage value.

The percentages of moisture, oil and solids found in the mixtures of the AT80 and AT40C1 treatments were higher than those found in the diesel.

## 4 Discussion

The density results of mixtures M4 and M5 of the AT80 and AT40C1 treatment are the lowest. However, the mixtures M4 and M5 of the AT80 treatment were the best, having density averages below those obtained in the mixtures M4 and M5 of the AT40C1 treatment and slightly above the density presented by the diesel, which was 0.78 g/ $cm^3$, a value lower than that obtained by [18] which was 0.83 g/$cm^3$ in a diesel.

In their study [8], they reported densities in vegetable biodiesel that range between 0.85 g/$cm^3$ to 0.91 g/$cm^3$, values that were higher than those obtained in the mixture M4 and M5 of the AT80 treatment, which were 0.84 g/$cm^3$, up to 0.80 g/$cm^3$. In another investigation [1] reported density of diesel mixtures with vegetable oils in the order of 0.85 to 0.86 g/$cm^3$ values that were higher than those found in the mixtures of the AT80 and AT40C1 treatments, results that were also below the found by [19] in a mixture of lubricating oil with an additive composed of zinc that was 0.88 g/$cm^3$.

With respect to viscosity, the mixtures of each of the AT80 and AT40C1 treatments showed a decrease as the proportion of diesel in the mixtures with RULO increased, starting with values of 50.33 cP to 5.83 cP, slightly above the viscosity of the diesel which was 2.83 cP. These results were below those reported by [12] with 65 cP in oil-based drilling fluids. In their research [7], they found viscosity values in mixtures of diesel and sesame oil from 3.28 cP to 4.34 cP, and while [20], they obtained values of 1.93 cP in mixtures of diesel with biodiesel and ethanol, values lower than those found in the mixtures of the AT80 and AT40C1 treatments of the present investigation. The flash point in the AT80 and AT40C1 treatment mixtures showed a decrease in the M1 mixture from 163.33 °C to 88.33 °C in the M5 mixture, as the proportion of diesel increased. These results were above those obtained by [21] who obtained a flash point at 57 °C in a mixture made with lubricating oil and diesel; while [19] found it at 210 °C in a mixture of lubricating oil and a zinc additive, above those found in this study. In the research carried out by [12], the aforementioned authors mention that the flash point of a base oil for drilling fluids is 66 °C, and of a biodiesel at 160 °C [22], being below those found in this research.

In the electrical stability results, a considerable increase is observed from the M3 mixture with a maximum value of 1874 V, being above the diesel, which was 1822.33 V, decreasing slightly from the M4 and M5 mixtures with a value of 1748.33 V and 1694.33 V. These values represent greater electrical stability than those found by [10] with values of 480 V, the same as [23], which was 610 V in drilling muds, lower values than those obtained in this studio. In their research [11], they mention that by increasing the additives in the drilling fluids, electrical stability was obtained in a range of 731 V to 1054 V, while [12] mention that in a basic oil for drilling fluids, the electrical stability must be above 400 V, results that are still below those found in this work.

The percentage of solids, humidity and oil were lower in the RULO of the AT80 and AT40C1 treatments. The M4, M5 mixtures of the AT80 and AT40C1 treatments showed considerable benefits, obtaining the best results in the order of 96.63% to 97.33% of recovered oil.

## 5 Conclusions

The AT80 and AT40C1 treatments applied to used lubricating oils improved their quality, the best values were obtained for the AT80 treatment. Although these results could be supported with future studies on these same tests.

The proportion of diesel in the different RULO mixtures had a direct effect on its properties, influencing the results.

The M4 mixture of the AT80 treatment in a proportion of 40% RULO and 60% diesel, turned out to be the best in this study, obtaining values similar to those presented by diesel. Results that are very encouraging to be able to venture into the preparation of oil-based drilling fluids.

From a technical, economic and environmental point of view, this creates a new alternative, reducing the environmental impact that these wastes represent. This new use would lengthen the life cycle of this waste, using less diesel and reducing the economic cost to oil companies that are dedicated to the preparation of oil-based drilling fluids.

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# CEMPRI, a primary cementing software for vertical onshore wells as a tool for petroleum engineering education

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**Abstract**
The use of simulation software applicable to the various stages of petroleum engineering facilitates decision-making and, at the same time, minimizes possible failures, problems, and incidents during each well intervention. In addition, a computer tool provides the user with instant and accurate results that can be used during personnel training and higher education. The objective of the present work was to develop an open-source computational tool with a graphical, numerical, and schematic interface to facilitate the teaching and learning of operations related to primary cementing. The tool considers four sections: (a) wellbore diagram, (b) identification of the relation between volumetry and the geometric design of the well, (c) integration of the mechanical state with the number of intervals, slurry design, and operating characteristics of the pumps, and (d) the wellbore diagram integrated by drilling, displacement and slurry fluids, according to each of the cementing stages. Among the results, it was combined programming with specialized technical and scientific material, considering academic and field experience characteristics. The program is a versatile tool that integrates the general mechanical state and each of the five stages with a maximum depth of 5,000 m.

Keywords: onshore oil well; primary cementing; software; wellbore diagram; casing.

# CEMPRI, un software de cementación primaria para pozos verticales terrestres como herramienta para la educación en ingeniería petrolera

**Resumen**

El uso de software de simulación aplicable a las distintas etapas de la ingeniería petrolera facilita la toma de decisiones y, al mismo tiempo, minimiza posibles fallas, problemas e incidentes durante cada intervención en el pozo. Además, una herramienta informática proporciona al usuario resultados instantáneos y precisos que pueden utilizarse durante la formación del personal y la educación superior. El objetivo del presente trabajo fue desarrollar una herramienta computacional de código abierto con una interfaz gráfica, numérica y esquemática para facilitar la enseñanza y el aprendizaje de operaciones relacionadas con la cementación primaria. La herramienta considera cuatro secciones: (a) diagrama de pozo, (b) identificación de la relación entre volumetría y diseño geométrico del pozo, (c) integración del estado mecánico con el número de intervalos, diseño de lechada y características operativas del pozo. las bombas, y (d) el diagrama de pozo integrado por los fluidos de perforación, desplazamiento y lodo, según cada una de las etapas de cementación. Entre los resultados, se combinó programación con material técnico y científico especializado, considerando características académicas y de experiencia de campo. El programa es una herramienta versátil que integra el estado mecánico general y cada una de las cinco etapas con una profundidad máxima de 5.000 m.

*Palabras clave*: pozos petroleros terrestres; cementación primaria; estado mecánico; tubería de revestimiento.

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## 1 Introduction

The use of simulation software applicable to the various stages of petroleum engineering allows for maximizing decision-making and, in parallel, minimizing possible failures, problems, and incidents during each intervention. Furthermore, a computer tool provides the user with instant and accurate results that can be used during personnel training and education. Several researchers have studied the effective displacement of drilling fluid by cement slurry and the mixing of the two fluids during primary cementing operations [1-3]. The first 2D annular displacement simulator was introduced in 1990; however, the industry has kept its attention on the issue of mud displacement for the last 60 years [4].

Various studies have described the importance of cementing, software development, automation, and several operations in the petroleum industry. Among these, primary cementing is the most important task performed during well completion. This involves depositing a specific amount of cement slurry in the space between the drilled formations and the casing pipes installed inside the well [5]. The primary purpose of this operation is to provide zonal isolation, improve wellbore stability, seal off oil and gas in the formation, and prevent uncontrolled flows that could occur at the wellhead [6-8]. To ensure the integrity of oil wells, it is essential to avoid problems during primary cementing and before any additional thermal, mechanical, and/or chemical loads are applied [9]. Significant losses of mud or slurry into the formation can have a negative impact on the petroleum industry, the economy, the integrity, and the life cycle of the well [10]. It is essential to carry out primary cementing activities with profound knowledge of the actual behavior of the fluids in the wellbore. Otherwise, a possible change in the turbulent flow profile might occur, reducing the isolation between the edge of the formation and the pipes [11]. The efficiency of the displacement process is influenced by several factors, including the condition of the well, the formulation and properties of the drilling fluid and cement (including the spacer and flushing fluid), and the flow regime during displacement, among others [12, 13]. If the pipes were corroded or damaged, it could lead to contamination of the hydrocarbon flowing to the surface or it could be conducted to an area of lower pressure. Cementing aims to protect the outer walls of the pipes against blows during the drilling process and to create a seal between the areas of lost circulation. Hence, primary cementing is vital during wellbore completion.

The importance of a primary cementing system for personal computers as support for the soundness of cementing jobs has been identified by [14]. They also justified the development of this system by pointing out that it saves operation time and simplifies decision-making. However, Villegas-Javier later identified that the development and execution of integral cementing in wells with severe conditions, such as reduced annular spaces and depressed zones, are current technical challenges in the Mexican petroleum industry [15], while [16] consider that investigating displacement efficiency is crucial for improving the quality of cementing. Visual Basic is one of the most used programming languages in engineering, as it is frequently used for simulator development in the petroleum industry. According to [17], engineers can develop various applications using Visual Basic, which is an easy-to-learn and flexible programming tool that can be tailored to their needs. For instance, an interactive pipe selection and laying software with commonly used engineering physical units was developed using Visual Basic [18]. Additionally, [19] mentions that the Shell "SPOT" software has its origins in Microsoft Excel's Visual Basic, while Utsalo et al. [20] created a Microsoft Excel Visual Basic application for casing selection.

Primary cementing involves complex calculations and considerations, which can be overwhelming even with the availability of sufficient information, tools, physical and chemical characteristics of additives, and laboratory equipment for slurry design. The purpose of this work is to develop an open-source computational tool with a graphical, numerical, and schematic interface to simplify the teaching and learning of primary cementing-related operations.

## 2 Methodology of the CEMPRI software development

The software was developed by following the steps outlined below: i) Firstly, a wellbore diagram is created, which includes the wellbore, casing, and liner as per the oil well design. ii) The relationship between the volumetric equations for annular, internal, and total volume is established based on the geometric design of the well. iii) The following factors are then integrated to develop the software: wellbore volumetry, slurry design, percentage of each slurry additive, operating characteristics of the mud pumps (liner diameter, rod diameter, and length, volumetric efficiency), volume of displacement fluids, rheology, and others. iv) Finally, a wellbore diagram is created that includes drilling, displacement, and slurry fluids, as per each cementing stage. The CEMPRI software is developed using the methodology described in the specialized literature for the training of engineering and operational technical personnel in the field of drilling and well maintenance [21]. This is shown in the flow diagram in Fig. 1.

The CEMPRI software was written in Visual Basic for Applications in Microsoft Excel. One of the advantages of this application is its simple and intuitive design with a comfortable and user-friendly interface. Additionally, The CEMPRI software provides clear and concise graphical data visualization.

## 3 Cover

Fig. 2 shows the main cover of the CEMPRI software named: “Datos del Pozo/Well Data”, requesting the following information: name, number, location, placement, and classification of the well. Additionally, the name of the engineer or technician responsible for designing the well is also required.

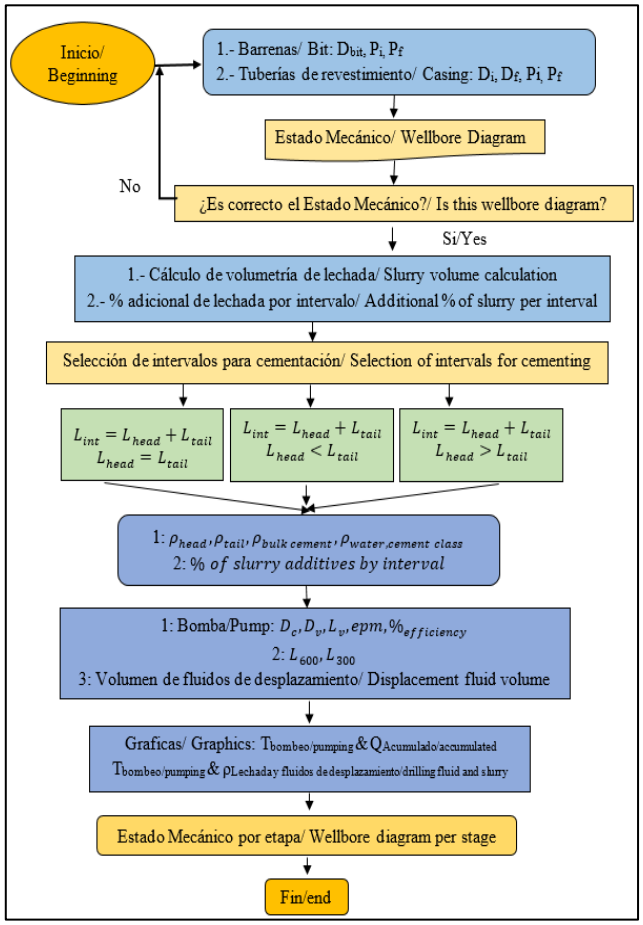


Figure 1. Functional structure of the software.
Source: Own elaboration.

### *3.1 Wellbore diagram*

Fig. 3 shows the wellbore diagrams composed of the wellbore, casing, and liner (a short pipe that does not extend back to the wellhead and generally is suspended or anchored), respectively. The first case corresponds to the wellbore with five casing pipes and the second a wellbore with four pipes and a liner. The black lines represent the walls of the formations, and the yellow lines are the pipes or liner (the last pair of yellow lines, as appropriate to the design); the distance between each pair of parallel and yellow lines corresponds to the diameter of the wellbore and the outer and inner diameter of each pipe.

Fig. 4 begins with the upper label "Wellbore Diagram-Cementing". The yellow boxes on the left correspond to the input data, and the ones on the upper part are for the diameters, and the initial and final depths of each stage. The lower boxes are for the outer and inner diameters of each of the casing pipes, with their respective depths. This will finally outline the wellbore diagram as follows: the yellow, green, blue, purple, and orange columns represent the annular spaces between the wellbore and the casing pipes, which will be the slurry volumes to be determined. In CEMPRI, all the labels specify variables and parameters with their respective units of measurement. These physical units correspond to those used in primary cementing operations in national drilling equipment, for example: for internal and external diameters and lengths for casing or liner pipe, inches (in) are used; for bulk cement densities, density of slurry and water in g/cm$^3$, bags of cement in kg, drilling depth in m, annular volumes in L, among others. Furthermore, it was pertinent to use the same units that are applied in field operations.

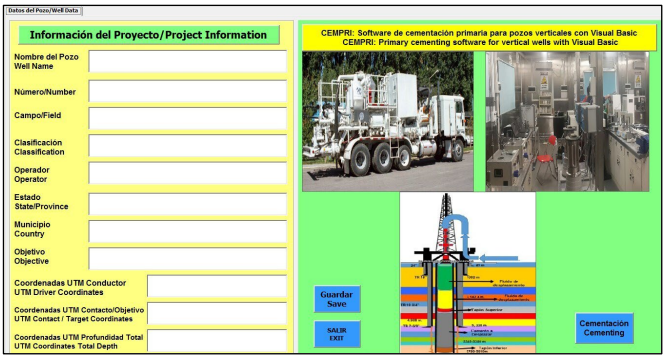


Figure 2. Software cover screen.
Source: CEMPRI software.

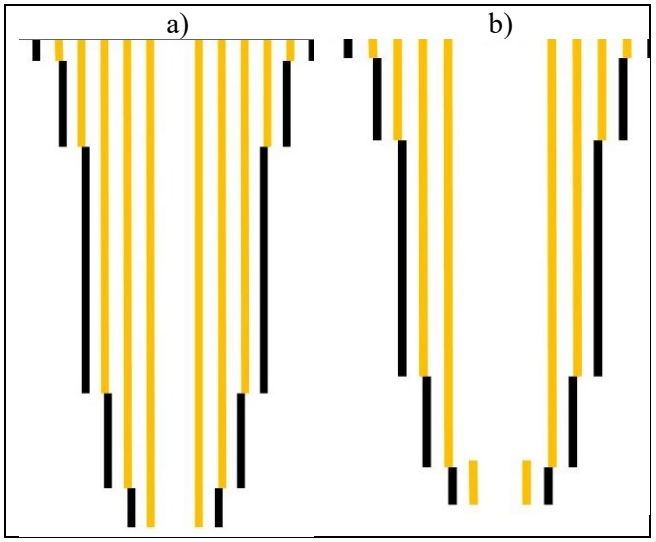


Figure 3. Wellbore diagram with a liner and a) Five casing pipes, b) four casing pipes.
Source: Own elaboration.


Figure 4. Data entry and wellbore diagram
Source: CEMPRI software.

This program can represent wells with depths of up to 5,000 m. The black lines, shown below the yellow ones, indicate that drilling continues with a smaller bit diameter after the casing has been placed. This causes the pipe to have a telescopic shape and forms an annular space between the walls of the formations and their respective pipes and depths.

### *3.2 Cementing design*

In Fig. 5, the section titled "Cementing Operation" is comprised of five sub-sections: a) Hole-conductor and Graph 1, b) Conductor-surface and Graph 2, c) Surface-intermediate and Graph 3, d) Intermediate-production and Graph 4, e) Production-liner and Graph 5. In each of them, the volume of slurry for the annular space is determined, according to the values of the drill and pipes, allowing the user to assign an additional percentage of slurry since the annular space to be cemented is generally irregular at each stage [22]. The internal volume for each pipe is then determined. Using the data on slurry density, cement type, and bulk cement density, the values for the number of cement sacks, performance, and the volume of water for cementing are obtained for each stage, considering the annular volume and the additional percentage.

The "Laboratory data" section corresponds to the percentage values of each of the additives that will make up the slurry, which will allow calculating the mass of each of them to finally know the total mass of all the solid additives of the slurry mixture, as reported by [23] and [24]. Additionally, the slurry design is tested in specific areas where cement is placed, such as fractured areas or areas with low pore pressures [25]. During the testing, the following parameters are observed: pore pressure, fracture gradient, downhole temperature and pressure, physical properties of the formation, geometric deviation of the well, and others.

The program provides five names of additives and allows the addition of up to three more additives, subject to prior laboratory approval. To determine the total volume of the slurry, the user can use two methods: The first method involves calculating the initial and final depth of the perforated stage in two intervals: lead volume and tail volume. The second method has three options: 1. The total depth of the stage is divided equally for each section, "lead and tail"; 2. The length or depth of the lead section is greater than the tail section; and 3. The length or depth of the lead section is less than the tail section.

It is important to note that the program will notify the user of any errors that may occur when assigning depth and length values to the sections of the stage. This is because both values need to match the total depth of the stage. These warnings are crucial in following the observation made by [26], where the design of the fluids, the operating conditions of the displacement flow, and a tool that helps to understand the flow dynamics play a crucial role in achieving an efficient placement of cement.

Fig. 6 displays the "Hole-Conductor" tab, which depicts the integration of the operation data of pumps and volumes of washing, viscous, and separating fluids. This integration helps to determine the flow rate and pumping time of duplex and triplex pumps while considering the sleeve diameter, rod

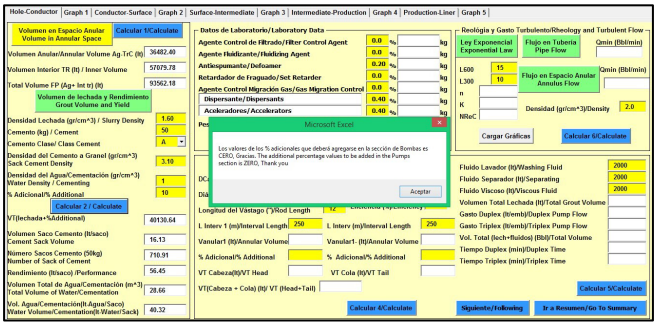


Figure 5. Calculation section on volumetry, additives, lead and tail volume, and others.
Source: CEMPRI software.

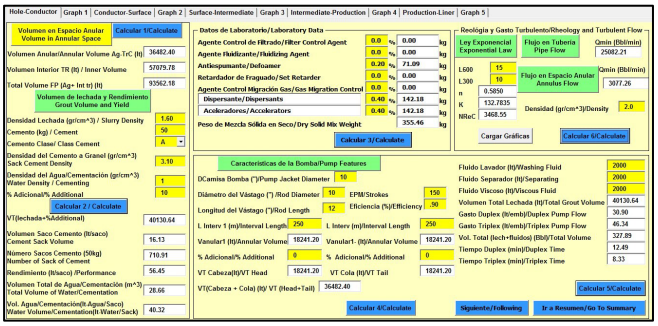


Figure 6. Calculation section on volumetry, additives, lead and tail volume, and others.
Source: CEMPRI software.

diameter, and length diameter, as required by the operation [21]. The Fann viscometer readings at 600 rpm and 300 rpm are used to determine the flow behavior index "n", consistency index "K", and the critical Reynolds number. These readings are also used to find the minimum flow rate in the annular and interior space of the pipe, in case of a turbulent flow occurs.

### *3.3 Cementing distribution*

Effective fluid displacement during drilling operations is essential for ensuring high-quality cementing jobs. This, in turn, guarantees zonal isolation and strong bonding of the cement to the casing and formation. Incomplete mud removal can result in poor cement placement, which can cause several critical operational problems and significant environmental hazards [7]. Similarly, [27] suggested using spacer fluids to prevent drilling fluid contamination in the annular space between mud and cement. Since mud and cement are incompatible, using spacer fluids as buffers can help avoid contact between the two substances. The spacer fluids can also aid in removing mud from the annular space. The cement contains calcium that can cause the clay in the drilling fluid to flocculate, resulting in contamination if the two substances come into contact.

In Fig. 7, the numerical values for volumes, lengths, and hydrostatic pressure generated by each fluid are presented. The central image in Fig. 7 represents the distribution of different types of fluids that will move inside the casing and

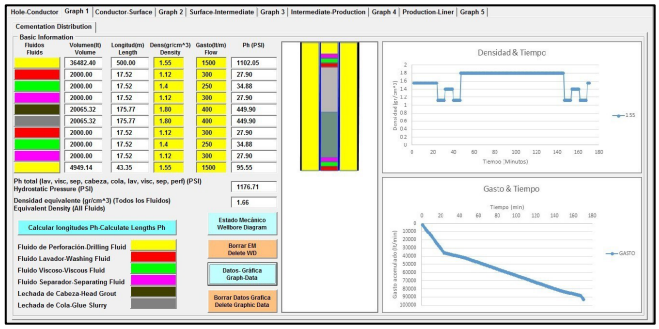


Figure 7. Distribution of fluids in the wellbore, pumping profile of density, and flow rate.
Source: CEMPRI Software.

Table 1.
Information that is entered into the program for the wellbore diagram.

| Stage number | Auger diameter (in) | Initial depth (m) | Final depth (m) |
|---|---|---|---|
| 1 | 20.000 | 0 | 500 |
| 2 | 14.750 | 500 | 1 000 |
| 3 | 10.625 | 1 000 | 3 470 |
| 4 | 8.500 | 3 470 | 3 875 |
| 5 | 6.125 | 3 875 | 4 800 |

| Casing | Outer diameter (in) | Inner diameter (in) | Initial depth (m) | Final depth (m) |
|---|---|---|---|---|
| Conductor | 16.000 | 15.010 | 0 | 500 |
| Superficial | 11.750 | 10.586 | 0 | 1 000 |
| Intermediate | 9.625 | 8.031 | 0 | 3 470 |
| Production | 7.625 | 6.000 | 0 | 3 875 |
| Liner | 5.000 | 4.000 | 3 720 | 4 800 |

Source: Own elaboration.

Table 2.
Information that is entered into the program for the wellbore diagram.

| Stage | Interval (m) | | $\%_{add}$ Extra volume (%) | $\rho_{lsurry}$ Slurry density (g/cm³) | | $\rho_{cement}$ Cement density (g/cm³) | | Cement type | | $\rho_{water/cem}$ Water density (g/cm³) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 500 | | 10 | 1.60 | | 3.10 | | A | | 1 |
| 2 | 500 | 500 | 5 | 1.60 | 1.75 | 3.15 | 3.25 | A | C | 1 |
| 3 | 1 000 | 2 470 | 15 | 1.80 | 1.90 | 3.10 | 3.13 | D | E | 1 |
| 4 | 3 470 | 4 050 | 10 | 1.85 | 1.91 | 3.11 | 3.15 | E | E | 1 |
| 5 | 3 720 | 4 800 | 10 | 1.92 | | 3.15 | | F | | 1 |

**Volume percentage of additives for slurry per stage and interval (%)**

| Stage | Foam* | Accelerant* | Disperser* | Cwater* | Cfiltered* | Extender | Interval |
|---|---|---|---|---|---|---|---|
| 1 | 0.20 | 0.40 | 0.40 | | | | 1 |
| | 0.20 | 0.20 | 0.40 | 0.15 | 0.00 | 0.00 | 1 |
| 2 | 0.10 | 0.50 | 0.00 | 0.00 | 0.00 | 0.80 | 2 |
| | 0.20 | 0.00 | 0.70 | 0.00 | 1.20 | 0.00 | 1 |
| 3 | 0.20 | 0.40 | 0.45 | 0.00 | 0.00 | 0.00 | 2 |
| | 0.20 | 0.20 | 0.30 | 0.15 | 0.00 | 0.15 | 1 |
| 4 | 0.10 | 0.40 | 0.35 | 0.00 | 0.00 | 0.60 | 2 |
| 5 | 0.10 | 0.40 | 0.50 | 0.00 | 0.00 | 0.00 | 1 |

**Pump operating characteristics**

| Dc (in) | Dv (in) | Lv (in) | EPM(Stroke/min) | Efficiency (%) |
|---|---|---|---|---|
| 10 | 10 | 12 | 150 | 90 |

**Displacement Fluid Volumes**

| | Washing (L) | Separator (L) | Viscous (L) | Viscometer readings |
|---|---|---|---|---|
| Fluid volume | 2 000 | 2 000 | 2 000 | L600 = 15 L300 = 10 |

* Quantities determined in Laboratory data as described in Figure 6.
Dc: Pump jacket diameter, Dv: Rod diameter, Lv: Rod length, EPM: stroke/min.
Source: Own elaboration.

will be distributed in the corresponding annular space. The yellow columns in the figure represent the drilling fluid already present in the annulus, which will be displaced by the displacement fluids. In addition, the upper right graph shows "Density & Time" while the lower one shows "Accumulated Flow Rate & Time" during cement pumping. The program allows for adjusting the volume, density, and flow rate of the scrubber, viscous, and separator fluids to manage the free fall phenomenon mentioned in [11] and [28] during slurry placement. This is done by determining the required amounts of fluid and pumping times and setting the operating parameters for each stage. It is crucial to understand this phenomenon to avoid any misinterpretation as a loss of circulation during cementing. When planning for effective mud removal and cement placement, two main flow regimes are considered: effective turbulent flow and laminar flow [29]. The quality of cementing in the wellbore depends on the quality of mud displacement by the fluids injected into the annular space during the cementing work [30]. Optimal displacement requires knowledge of flow patterns, frictional pressure losses, and the interactions of the mud, spacers, and cement in the annular spaces [31]. According to [32], rheology plays only a minor role in these turbulent flows, although the density differences are still significant. On the other hand, cement slurry rheology and the fluid behind the casing are commonly considered as Bingham-type [33].

## 4 Results and discussion

An illustrative example was chosen to demonstrate the capabilities of the CEMPRI software, consisting of three parts. Table 1 provides the input data for wellbore diagram schematization. Table 2 contains the information to carry out the design and calculations of each stage to generate the diagram. The cementing space can be designed for one or two intervals, the slurry density, cement type, and the type and percentage of additives can differ between these intervals.

The exercise example results obtained for each stage in the primary cementing are presented in Table 3. Fig. 8 comprises six images, which outline the wellbore diagram of each stage according to its design considerations and characteristics. For each of the five stages, the specific design characteristics are considered while generating the two graphs shown in Fig. 8: "Density & Time" and "Accumulated Flow Rate & Time." The wellbore diagram for the sample well is depicted in Figure 8a. The diagram shows the annular spaces (slurry volume) for each stage in five colored rectangles: yellow, green, blue, purple, and orange. The wellbore diagram is composed of four casing pipes and a liner. For Figures 8(b-f), the yellow color represents the drilling fluid volume, while the red, green, and purple colors correspond to the displacement fluids before and after the slurry volume. The dark green and gray colors represent lead and tail slurry volumes, respectively.

Fig. 8b corresponds to the first stage, where the volume of slurry (represented by dark green and grey lines) and the displacement fluids (shown in red, green, and purple) constitute 91.3% of the internal capacity of the pip. The remaining 8.7% is

occupied by the drilling fluid (in yellow) and is present in the annular space. The second stage is represented by Figure 8c, where the total slurry volume was divided into two equal portions referred to as “lead” and “tail”. Here, the total volume of displacement fluids (in red, green, and purple) and slurry (dark green and gray) occupy 99.2% of the internal capacity of the pipe while the remaining 0.8% is occupied by the drilling fluid (yellow). It is important to note that in this case, “Lead” Vslurry is equal to “Tail” Vslurry.

The third stage is represented by Figure 8d. At this stage, the slurry volume and displacement fluids together occupy 46.3% of the internal capacity of the pipe, while the drilling fluid occupies the remaining 53.7%. In this case, we consider “Lead” Vslurry < “Tail” Vslurry.

Figure 8e represents the fourth stage, in which 38.9% of the internal pipe capacity is occupied by the total volume of mud and displacement fluids, while the remaining 61.1% is occupied by drilling fluid. In this case "Lead" Vslurry > "Tail" Vslurry.

The fifth stage corresponds to Figure 8f, where a cemented casing (liner) is observed. This pipe is anchored at a shallower depth than the last pipe, depending on the overlap length between the last pipe and the liner.

It is important to note that the physical unit of the additives that make up the slurry is the percentage symbol (%) [34]. Chaudhry [35] presents a diagram of the pipe and wellbore for each stage of the process but does not include a wellbore diagram or graphs showing the pumping and distribution of different types and volumes of fluids used for primary cementing.

Table 3.
Results of the primary cementing of each of the stages.

| Volumetry results | Stages | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | | 3 | | 4 | | 5 |
| Annular volume (L) | 36 482.4 | 20 141.3 | 22 101.7 | 25 343.9 | 9 841.5 | 2 895.4 | 11 176.0 | 6 729.96 |
| Annular volume with increment (L) | 40 130.6 | 21 148.4 | 23 206.7 | 29 145.5 | 11 317.8 | 3 185.0 | 12 293.6 | 7 402.96 |
| Internal volume of casing pipe (L) | 57 079.8 | | 56 782.5 | | 113 401.7 | | 70 684.7 | |
| Total slurry volume (L) | 40 130.6 | | 44 355.1 | | 4 0463.2 | | 15 478.6 | 7 402.96 |
| Bag/cement Volume (L/Sk) | 16.1 | 15.9 | 15.4 | 16.1 | 16.0 | 16.1 | 15.9 | 15.87 |
| N of cement bags (50 kg) | 710.9 | 371.8 | 502.9 | 688.4 | 299.3 | 79.8 | 327.8 | 199.59 |
| Performance (L/Sk) | 56.5 | 56.9 | 46.2 | 42.3 | 37.8 | 39.9 | 37.5 | 37.09 |
| water/cementing total volume ($m^3$) | 28.7 | 15.3 | 15.5 | 18.0 | 6.5 | 1.9 | 7.1 | 4.24 |
| Water/cementing V (L/Sk) | 40.3 | 41.0 | 30.8 | 26.2 | 21.8 | 23.8 | 21.6 | 21.22 |
| **Additive Weight** | | | | | | | | |
| Defoamer (kg) | 71.1 | 37.2 | 25.1 | 68.8 | 29.9 | 8.0 | 16.4 | 9.98 |
| Dispersant (kg) | 142.2 | 74.4 | | 240.9 | 67.4 | 12.0 | 57.4 | 49.90 |
| Accelerants (kg) | 142.2 | | 125.7 | | 59.9 | 8.0 | 65.6 | 39.92 |
| Filter control agent (kg) | | 27.9 | | 413.0 | | 6.0 | | |
| Setting retarder (kg) | | 74.4 | 100.6 | | 59.9 | | 65.6 | |
| Extender (kg) | | | 201.1 | | | 6.0 | 98.4 | |
| Total weight (kg) | 355.5 | 251.0 | 452.6 | 722.8 | 217.0 | 39.9 | 303.2 | 99.80 |
| **Pumping Data** | | | | | | | | |
| Duplex pump flow (L/stroke) | 30.9 | 30.9 | | 30.9 | | 30.9 | | 30.9 |
| Triplex pump flow (L/stroke) | 46.3 | 46.3 | | 46.3 | | 46.3 | | 46.3 |
| Total volume of displacement fluid (Bbl.) | 327.9 | 316.7 | | 4 0463.2 | | 135.1 | | 84.3 |
| Duplex time (min) | 12.5 | 12.1 | | 11.1 | | 5.2 | | 3.2 |
| Triplex time (min) | 8.3 | 8.0 | | 7.4 | | 3.4 | | 2.1 |
| **Turbulent Spending** | | | | | | | | |
| Flow behavior index “n” | 0.585 0 | | | | | | | |
| Consistency index “K” | 132.783 5 | | | | | | | |
| Critical Reynolds “NRc” | 3 468.5 | | | | | | | |
| Minimum expense in drilling pipe (Bbl./min) | 082.2 | 4 413.3 | | 9 299.0 | | 5 855.2 | | 077.3 |
| Minimum expense in annular space (Bbl./min) | 077.3 | 1 949.6 | | 341.2 | | 276.0 | | 411.3 |

Source: Own elaboration.

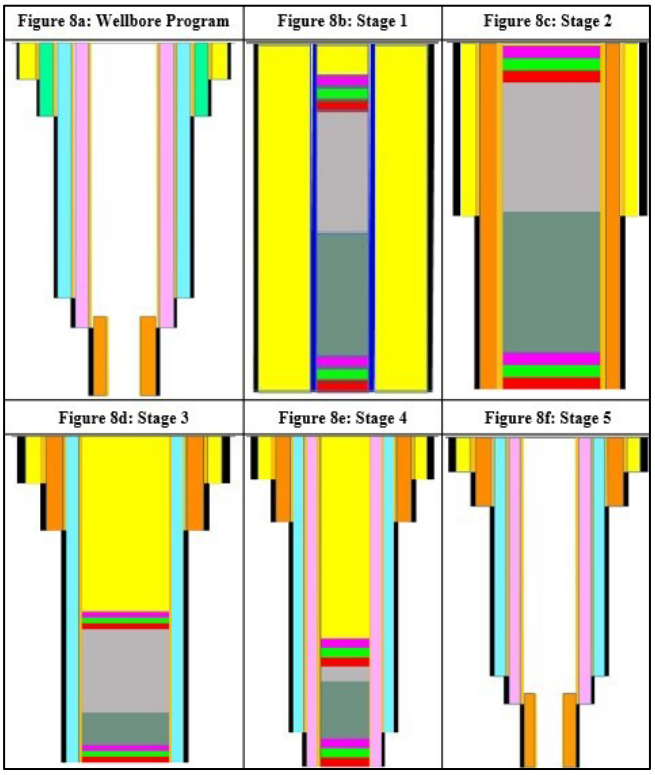


Figure 8. General wellbore diagram of each stage.
Source: CEMPRI Software.

## 5 Conclusions

The CEMPRI program was created using Visual Basic for Applications in Microsoft Excel, with a macro environment. It is an efficient and useful software for instantaneously calculating primary cementing. The interface design is simple, intuitive, and easy to use, with fast communication and adaptation between the user and the program. It is a versatile tool that integrates a wellbore diagram for up to five stages, allowing for both numerical and graphical calculations individually, with a maximum depth of 5,000 m.

The CEMPRI software was developed to integrate theoretical knowledge with practical activities in oil well

design and field departments. The program includes wellbore schematization, diagrams, and graphics that follow the real values of the bits, casing pipes, cementing intervals, chemical materials in the slurry design, pump operating characteristics, volumes, depths, hydrostatic pressures, total hydrostatic pressure, circulation equivalent density, and much more. It is important to have prior knowledge of all these parameters and variables when conducting calculations, analyses, and interpretations. CEMPRI is an open-access academic tool that aims to become a leading program in the field.

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# Predicting Internet addiction in college students using a 1D-CNN model: analysis of influencing factors

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**Abstract**
This study constructs a deep learning-based model to predict internet addiction among college students and analyzes significant influencing factors. A random survey of 4,895 students from a university in Shandong Province was conducted using questionnaires on general information, internet addiction (CIAS-R), personality (CBF-PI-B), psychological traits (SDS, SAS), parenting styles (EMBU), behavioral issues (SAS-C), and social support (ASSRS) to establish a database. A predictive model was developed using a 1D Convolutional Neural Network (1D-CNN), extracting key influencing factors of internet addiction. The model showed 92.77% accuracy, with high precision and recall rates for predicting normal users and addicts. The gradient calculation indicates that in second-year students, negative and withdrawal behaviors, depression, over-interfering families, and anxiety significantly contribute to Internet addiction, with factors exceeding 0.5. The 1D-CNN model offers robust performance and accuracy in predicting internet addiction, identifying significant factors for early prevention and potential integration with apps for real-time monitoring.

*Keywords*: internet addiction; 1D-CNN; predicting; college students; model.

# Predicción de la adicción a Internet en estudiantes universitarios mediante un modelo 1D-CNN: análisis de los factores influyentes

**Resumen**
Este estudio construye un modelo basado en el aprendizaje profundo para predecir la adicción a Internet entre los estudiantes universitarios y analiza los factores influyentes significativos. Se realizó una encuesta aleatoria a 4.895 estudiantes de una universidad de la provincia de Shandong mediante cuestionarios sobre información general, adicción a internet (CIAS-R), personalidad (CBF-PI-B), rasgos psicológicos (SDS, SAS), estilos parentales (EMBU), problemas de conducta (SAS-C) y apoyo social (ASSRS) para establecer una base de datos. Se desarrolló un modelo predictivo utilizando una red neuronal convolucional 1D (1D-CNN), extrayendo los factores clave que influyen en la adicción a Internet. El modelo mostró una exactitud del 92,77%, con altos índices de precisión y recuerdo para predecir usuarios normales y adictos. El cálculo del gradiente indica que, en los estudiantes de segundo curso, los comportamientos negativos y de retraimiento, la depresión, el exceso de interferencia familiar y la ansiedad contribuyen significativamente a la adicción a Internet, con factores superiores a 0,5. El modelo 1D-CNN ofrece un rendimiento y una precisión robustos en la predicción de la adicción a Internet, identificando factores significativos para la prevención temprana y la integración potencial con apps para la monitorización en tiempo real.

*Palabras clave*: adicción a Internet; red neuronal profunda; predicción; estudiantes universitarios; modelo.

## 1 Introduction

With the revolution of science and technology, Internet technology has become an indispensable tool in people's daily lives. However, this also brings about a brand new problem, the abuse of the Internet and the unrestrained use of modern electronic devices, causing a large number of teenagers to have Internet Addiction Disorder (IAD) [1, 2].

Goldberg et al. [3] first proposed the concept of Internet addiction, and Young. [4] further studied the influencing

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factors of Internet addiction based on the Diagnostic and Statistical Manual of Mental Disorders (DSM) [5, 6]. The study found that excessive Internet use harms physical health, causes interpersonal difficulties, decreases academic performance and interferes with normal work. Therefore, in order to prevent college students' Internet addiction in advance, it is urgent to build an Internet addiction prediction model and extract significant influencing factors of Internet addiction, so as to provide a research basis for deploying Internet addiction detection software to grasp the Internet addiction status of college students in real time.

Early research on Internet addiction mainly used methods based on statistical analysis. Yang. [7] conducted a questionnaire survey on 1,216 junior high school students in a nine-year compulsory education school in Jinan City, Shandong Province. After T-test analysis, the results show that the incidence rate of Internet overuse among junior high school students is 9.5%, and they have obvious characteristics such as anxiety, depression, psychoticism, and neuroticism. Chemnad et al. [8] conducted a survey among 479 teenagers in Qatar. After K-Prototype clustering, the results showed that family environment and school environment were negative and significant predictors of adolescent Internet addiction, with a prevalence rate of 29.64%. Lai et al. [9] conducted a psychological test on 844 Chinese adolescents in Hong Kong using demographics, the Internet Addiction Test Scale (IAT), and the Internet Addiction Scale-Revised (CIAS-R).

After validation analysis in statistical methods, the results show that “the IAT is a valid and reliable scale for screening Internet addiction among Chinese adolescents”. The above research methods usually require complex data processing and calculations before obtaining results through analysis, and their reliability and accuracy need to be further improved. Considering the limitations of the number of psychologists and self-answer questionnaires, it is difficult to effectively screen out Internet addicted subjects on a large scale.

With the rise of Internet technology and the development of science and technology, using machine learning and deep learning algorithms to process massive data and identify data patterns has become a trend and even a necessary method. This technology is widely used in manufacturing, finance, life sciences and healthcare industry [10,11]. Di et al. [12] used multiple personality questionnaire data and support vector machine algorithms to detect Internet addiction symptoms among middle school students. They classified the samples and optimized parameters through support vector machines and grid search algorithms, and their Internet addiction detection performance reached 96.32%. Chaudhury et al. [13] used naive Bayes, support vector machine and radial basis function neural network to analyze the impact of smartphones on the academic performance of 222 college students. The results showed that there is a correlation between smartphone addiction and academic performance sex. Shae et al. [14] constructed an unsupervised artificial intelligence (AI) model (XGBOOST) for internet addiction prediction using an auto encoder AI model (GAN) to generate training data. This model preliminarily discusses the prediction mechanism of Internet addiction based on deep learning technology, and provides a direction for research on using deep learning technology to detect Internet addiction. The limitations of the above-mentioned studies are: ① There will be bias in predictions for subjects in different geographical and cultural backgrounds ② The generalization of machine learning models needs to be improved ③ The research on Internet addiction and its main influencing factors is not systematic and comprehensive enough.

In view of this, this study randomly surveyed 4895 college students in a university in Shandong Province. First, one basic questionnaire and seven assessment scales were used to investigate Internet addiction, and then statistics and analysis of factors related to Internet addiction were conducted. On this basis, an Internet addiction database was established, an Internet addiction prediction model was constructed based on a one-dimensional convolutional neural network, and influencing factors with an impact factor greater than 0.5 were extracted in order to prevent Internet addiction among college students in Shandong Province, China. Thereby providing a research foundation.

## 2 Materials and methods

### *2.1 Data collection and processing*

#### *2.1.1 Data collection*

This study employs seven different questionnaires to thoroughly investigate the factors affecting Internet addiction, capturing a wide spectrum of personal attributes. The general information questionnaire collects basic demographic, grades, majors, and family data. Internet addiction questionnaire are measured by the Revised Chinese Internet Addiction Scale (CIAS-R), with a scoring system from normal to addiction levels and a high reliability (Cronbach's $\alpha = 0.930$) [15]. In the present study, Cronbach’s $\alpha = 0.90$. Personality traits are assessed through the Chinese Big Five Personality Inventory Brief (CBF-PI-B), covering five key dimensions with an overall Cronbach's $\alpha$ range of 0.76 to 0.81 [16]. In the present study, Cronbach’s $\alpha = 0.92$. Mental health is evaluated using the Self-Rating Depression Scale (SDS) and the Self-Rating Anxiety Scale (SAS), each with their own scoring criteria and demonstrated reliability (Cronbach's $\alpha$ of 0.751 for SDS and 0.82 for SAS) [17,18]. In the present study, Cronbach’s $\alpha = 0.91$ and 0.90 respectively. The Evaluation of Parenting Styles Scale (EMBU) analyzes parenting attitudes and behaviors, with a reliability range of 0.58-0.922 [19]. In the present study, Cronbach’s $\alpha = 0.98$. Smartphone addiction is assessed using the SAS-C, which features a 5-point scale and a Cronbach’s $\alpha$ of 0.88 [20]. In the present study, Cronbach’s $\alpha = 089$. Finally, the Adolescent Social Support Rating Scale (ASSRS) examines various dimensions of social support, with a reliability range of 0.60-0.76 [21]. In the present study, Cronbach’s $\alpha = 0.93$. Each questionnaire is meticulously validated for accuracy and reliability, making them effective tools for measuring various aspects pertinent to internet addiction in this deep learning-based study.

#### *2.1.2 Participants*

The research was initiated by a university in Shandong Province, aiming to gain a comprehensive understanding of the different characteristics of the student body at the university. The research covered four grades (from freshman

Table 1.
The characteristics of college students in Shandong.

| Survey type | Relevant factor | Classification description | Internet addiction，number/% | | Sum *N*=4895 | *P* value |
|---|---|---|---|---|---|---|
| | | | Normal *n*=3882 (79.29) | Addiction *n*=1013 (20.71) | | |
| General information | 1. Age (Mean, SD) | | 20.45±3.65 | 19.87±5.63 | 21.75±2.31 | 0.587 |
| | Gender | 2. Male | 1947 (79.47) | 503 (20.53) | 2450 (50.05) | 0.939 |
| | | 3. Female | 1935 (79.14) | 510 (20.86) | 2445 (49.95) | |
| | Class | 4. First grade | 1368 (76.99) | 409 (23.01) | 1777 (36.30) | 0.009 |
| | | 5. Second grade | 1206 (79.24) | 316 (20.76) | 1522 (31.09) | |
| | | 6. Third grade | 784 (79.35) | 204 (20.65) | 988 (20.18) | |
| | | 7. Fourth grade | 616 (88.00) | 84 (12.00) | 608 (12.42) | |
| | Only children | 8. Yes | 2522 (80.55) | 609 (19.45) | 3131 (63.96) | 0.446 |
| | | 9. No | 1360 (77.10) | 404 (22.90) | 1940 (36.04) | |
| | Experience of left-behind children | 10. Yes | 2004 (75.20) | 661 (24.80) | 2665 (54.44) | <0.001 |
| | | 11. No | 1878 (84.22) | 352 (15.78) | 2230 (45.56) | |
| | Single parent | 12. Yes | 1075 (61.08) | 685 (38.92) | 1760 (35.96) | 0.002 |
| | | 13. No | 2807 (89.54) | 328 (10.46) | 3135 (64.04) | |
| | Family economic conditions | 14. Poor | 1171 (84.43) | 216 (15.57) | 1387 (28.34) | 0.002 |
| | | 15. Normal | 1139 (64.39) | 630 (35.61) | 1769 (36.14) | |
| | | 16. Rich | 1572 (90.40) | 167 (9.60) | 1739 (35.53) | |
| Psychological characteristics | Depression | 17. No | 944 (85.12) | 165 (14.88) | 1109 (22.66) | 0.018 |
| | | 18. Mild | 1005 (85.17) | 175 (14.83) | 1180 (24.11) | |
| | | 19. Moderate | 923 (79.36) | 240 (20.64) | 1163 (23.76) | |
| | | 20. Severe | 1010 (69.99) | 433 (30.01) | 1443 (29.48) | |
| | Anxiety | 21. No | 904 (85.28) | 156 (14.72) | 1060 (21.65) | 0.017 |
| | | 22. Mild | 1004 (83.74) | 195 (16.26) | 1199 (24.49) | |
| | | 23. Moderate | 932 (82.04) | 204 (17.96) | 1136 (23.21) | |
| | | 24. Severe | 1042 (69.47) | 458 (30.53) | 1500 (30.64) | |
| Big five personality | 25. Extraversion | | 770 (79.14) | 203 (20.86) | 973 (19.88) | <0.001 |
| | 26. Agreeableness | | 788 (79.36) | 205 (20.64) | 993 (20.29) | |
| | 27. Conscientiousness | | 767 (79.32) | 200 (20.68) | 967 (19.75) | |
| | 28. Neuroticism | | 870 (73.11) | 320 (26.89) | 1190 (24.31) | |
| | 29. Openness | | 687 (88.99) | 85 (11.01) | 772 (15.77) | |
| Parenting | Paternal | 31. caring and understanding | 611 (82.97) | 127 (17.21) | 738 (15.08) | <0.001 |
| | | 31. Harsh punishment | 657 (78.97) | 175 (21.03) | 832 (17.00) | |
| | | 32. overly intrusive | 669 (79.36) | 174 (20.64) | 843 (17.22) | |
| | | 33. Favoring the subject | 611 (77.64) | 176 (22.36) | 787 (16.08) | |
| | | 34. Denial | 656 (79.52) | 169 (20.48) | 825 (16.85) | |
| | | 35. Overprotection | 678 (77.93) | 192 (22.07) | 870 (17.77) | |
| | Maternal | 36. caring and understanding | 781 (84.71) | 141 (15.29) | 922 (18.84) | <0.001 |
| | | 37. overly intrusive | 775 (79.16) | 204 (20.84) | 979 (20.00) | |
| | | 38. Denial | 806 (77.50) | 234 (22.50) | 1040 (21.25) | |
| | | 39. Harsh punishment | 768 (78.13) | 215 (21.87) | 983 (20.08) | |
| | | 40. Favoring the subject | 752 (77.45) | 219 (22.55) | 971 (19.84) | |
| Behavioral problems | Smartphone addiction | 41. Social reassurance | 641 (83.68) | 125 (16.32) | 766 (15.65) | 0.001 |
| | | 42. Negative behavior | 660 (76.04) | 208 (23.96) | 868 (17.73) | |
| | | 43. Withdrawal behavior | 605 (76.20) | 189 (23.80) | 794 (16.22) | |
| | | 44. Highlight behavior | 655 (77.33) | 192 (22.67) | 847 (17.30) | |
| | | 45. APP use | 667 (79.40) | 173 (20.60) | 840 (17.16) | |
| | | 46. APP update | 654 (83.85) | 126 (16.15) | 780 (15.93) | |
| Social support | 47. Strong | | 979 (82.97) | 201 (17.03) | 1180 (24.11) | <0.001 |
| | 48. Good | | 938 (80.72) | 224 (19.28) | 1162 (23.74) | |
| | 49. Fair | | 990 (81.15) | 230 (18.85) | 1220 (24.92) | |
| | 50. Poor | | 975 (73.14) | 358 (26.86) | 1333 (27.23) | |

Source: The authors.

to senior) and 175 classes at the university, involving nine colleges. To collect the data, the research team used the Tencent questionnaire tool, which converted the base questionnaire and seven assessment scales into an online format. The questionnaires were distributed by the counsellors of each class through a link.

Regarding the gathering and validity of questionnaires, a sum of 5,247 were amassed, with 4,895 qualifying as valid. The gender distribution among student participants was nearly equal, comprising 2,450 males and 2,445 females, accounting for 50.05% and 49.95% of the participants respectively. Participants' ages varied from 17 to 24 years, averaging at 21.75 years with a standard deviation of 2.31.

In terms of college distribution, the College of Mechanical Engineering had the highest number of participants with 887, followed by the College of Vehicle Engineering (695) and the College of Agricultural Engineering (700). The College of Electrical Engineering had 589 participants, the College of Computer Science had 548, the College of Mathematics and Statistics had 446, the College of Law had 346, the College of Management had 401, and the College of Foreign Languages had 283. The percentage of each college is 18.14%, 14.21%, 14.32%, 12.04%, 11.21%, 9.01%, 7.07%, 8.20%, and 5.80% respectively.

Statistical analysis revealed that the rate of internet addiction was 20.71% and the rate of no internet addiction was 79.28%. Among them, there was no statistical difference ($x^2 = 0.43$, $P > 0.05$) in internet addiction among age, gender, and whether they were only child, whereas there was a statistical difference ($x^2 = 15.43$, $P < 0.05$) in internet addiction among grade level, whether they were single parent, family economic condition, depression condition, anxiety condition, and mobile phone addiction condition. Big 5 personality situation, parenting style, and social support were statistically significantly different, $P < 0.001$.

The detailed findings are listed in Table 1. This research provides a comprehensive and detailed understanding of the student body of a university in Shandong Province.

This study will ensure that participants clearly understand the purpose of the study and participate on a voluntary basis during the data collection phase. The project has been approved by the University's student work department and is strongly supported by the relevant faculty members to ensure compliance and ethicality of the study.

#### *2.1.1 Data processing*

The study's dataset, encompassing both normal Internet users and those with Internet addiction, was strategically divided into three subsets for developing and evaluating a predictive model. This division was done randomly in an 8:1:1 ratio, resulting in a training set of 3916 subjects, a validation set, and a test set, each containing 489 subjects.

The training set's primary role was to facilitate the initial training of the predictive model. The validation set was crucial for testing the model's predictive accuracy and for fine-tuning key parameters such as the learning rate and regularization coefficient. This process was vital to enhance the model's performance and to mitigate overfitting. The test set's function was to conduct the final assessment of the model's prediction capabilities. For effective model training and evaluation, participants were distinctly labeled as "0: normal" for regular Internet users and "1: addiction" for those exhibiting addictive behaviors. This labeling was integral to the model's accuracy in distinguishing between the two groups.

### *2.2 1D-CNN prediction model*

A CNN is a network model that can simulate human vision and recognize images, and was inspired by research on biological visual systems [22, 23]. The CNN can be used to process data such as characters, text, audio, images, and videos, and the 1D-CNN can also be used to deal with traditional data classification problems to achieve the fast learning of the pattern relationships between data [24].

Internet addiction influences are one-dimensional vectors, a multivariate sequential data, involving 20 aspects of influences, containing a total of 50 potential independent variables, and 2 dependent variables. Drawing inspiration from the classical Convolutional Neural Network (CNN) model, AlexNet, a series of experiments were conducted to refine the structure and hyper-parameters of the CNN, culminating in the development of a predictive model for Internet addiction.

This proposed model is architecturally composed of several layers: an input layer for initial data reception, a convolutional layer for feature extraction, a normalization layer to stabilize learning, an activation function layer to introduce non-linearity, a pooling layer for dimensionality reduction, a fully connected layer to synthesize learned features, and an output layer for final prediction. The structural layout of this model is illustrated in Fig. 1.

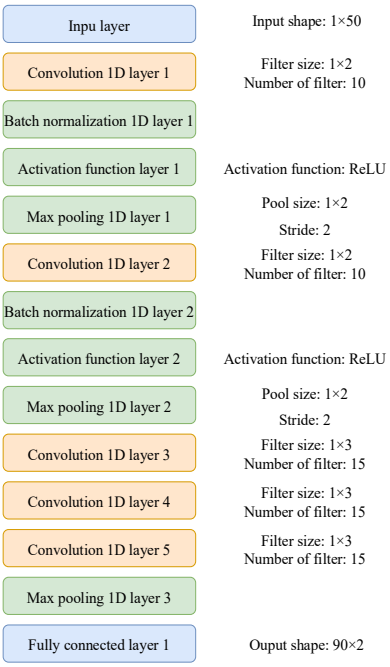


Figure 1. Extraction results of significant influencing factors of Internet addiction.
Source: The authors.

In Fig. 1, he input dimension of the input layer is 1×50, representing the 50 influencing factors of Internet addiction. After data normalization, the characteristics of Internet addiction in the input group with a size of $t$ are $x_t = \{x_{1t}, \ldots x_{2t}, \ldots x_{50t}\}$. Each group of data corresponds to an addiction sample, and the sample labels are $\{y_t\}_{t=0}^{N}, \quad y_t = \{0,1\}$, where $y_0$ corresponds to the normal Internet use sample, $y_1$ corresponds to the Internet addiction sample, and $N$ denotes the total number of samples.

In a convolutional neural network model, the inter-layer relationships primarily facilitate data extraction. The concept of a weight matrix is central to this process. It embodies a subset of locally connected neurons from one layer to the next within the network, thereby generating a feature map. The convolutional layer's multiple feature maps, characterized by their respective weight matrices, are commonly referred to as convolution kernels. The mathematical representation of this convolution process is as follows [25]:

$$y^j = f\left(\sum_i k^{ij} * x^i + b^j\right) \tag{1}$$

In this formula, the symbol $*$ denotes the convolution operation. The term $y^j$ signifies the $j$-th output neuron, $x^i$ represents the $i$-th input feature, $K^{ij}$ denotes the convolution kernel involved in the convolution operation of this specific layer, and $b^j$ indicates the bias associated with the $j$-th feature.

The pooling layer, analogous to the complex cells in the primary visual cortex, exhibits robustness and insensitivity to positional shifts in input data. This layer's function compresses the data dimensions, enhancing the computational efficiency of the network model. There are two primary forms of pooling operations:

1. Average Pooling: This method calculates the mean value within the sampling window, thus determining the feature's eigenvalue.
2. Max Pooling: This approach identifies the most salient feature by selecting the maximum value within the sampling window.

In this research, the max pooling technique was employed, expressed as:

$$f\left(X_k\right) = \max_{a \in X_k}\{a_1, \ldots, a_s\} \tag{2}$$

Here, eq. (2) utilizes max pooling for signal dimensionality reduction. It maps the feature $Y$, derived from the convolutional layer, into multiple non-overlapping regions $X$, with $k$ representing indices 1 through $K$. Each region size is defined as $1 \times s$.

Within Convolutional Neural Networks (CNNs), after undergoing a series of convolutional and pooling layer operations, feature maps are transformed into a one-dimensional vector. This vector subsequently passes through a fully connected layer, where it is assigned weights corresponding to different categories. The output from this layer is then matched against the true labels to assess the effectiveness of the model. The level of deviation between the predicted output and actual labels is calculated using the cross-entropy loss function, which is mathematically expressed in the following way [26]:

$$E = \frac{1}{N}\sum_i L_i = -\frac{1}{N}\sum_i^N \sum_{i=1}^M y_{ic} \log\left(p_{ic}\right) \tag{3}$$

In this formulation, $y_{ic}$ is a binary indicator used to denote whether the true class of the $i$-th sample corresponds to class $c$, taking the value of 1 if it does and 0 otherwise. The term $p_{ic}$ signifies the model's predicted probability that the $i$-th sample observed falls into class $c$. Here, $M$ represents the total count of categories within the dataset, while $N$ denotes the total number of samples under consideration. $E$ is used to represent the error value, with a lower $E$ value indicative of a more successful learning outcome achieved by the model.

The model's weights and biases are updated using gradient descent after calculating the output category's error. The Adaptive Moment Estimation (Adam) algorithm optimizes this process, influencing the training speed and results [27].

The Internet addiction prediction model, which leverages deep learning techniques, underwent a comprehensive process of feature extraction and optimization of its weights before it was fully trained. This model is structured with an input layer, followed by five convolutional layers, three pooling layers, two layers for normalization, and culminates in a fully connected layer. The convolution kernels are designed with dimensions of 1×2 in the initial two layers, changing to 1×3 in the subsequent three layers. To address the potential problems of vanishing and exploding gradients, the Rectified Linear Unit (ReLU) function was chosen as the activation function. Additionally, batch normalization was introduced post the first and second convolutional layers to enhance the rate at which the model converges. Important parameters of the model include a learning rate set at 0.001, a batch size of 64, the employment of the Adam optimizer, and a training regimen spanning 500 epochs.

### *2.3 Experiment platform and evaluation indexes*

The network model was trained and evaluated on a local laptop equipped with a 12th generation Intel® Core™ i5-12500H processor, 16 GB of RAM, and a 1 TB SSD. It featured an NVIDIA GeForce RTX 3060 Laptop GPU with 4 GB of dedicated memory. The operating system used was Ubuntu 18.04, and the model was developed using Python 3.10 in conjunction with the PyTorch 1.10.0 deep learning framework.

The model's performance was assessed using four key metrics: accuracy, precision, recall, and the F1 score. Accuracy represents the ratio of correctly predicted instances to the overall number of instances. Precision is the measure of the proportion of true positive predictions in all positive predictions made. Recall reflects the proportion of actual positives that have been correctly identified. The F1 score, which is the harmonic mean of precision and recall, is scaled between 0 and 1, where higher values denote better performance of the model.

## 3 Results

### *3.1 Internet addiction prediction results*

The efficacy of the proposed model for predicting Internet addiction is demonstrated in Fig. 2. During the training phase,

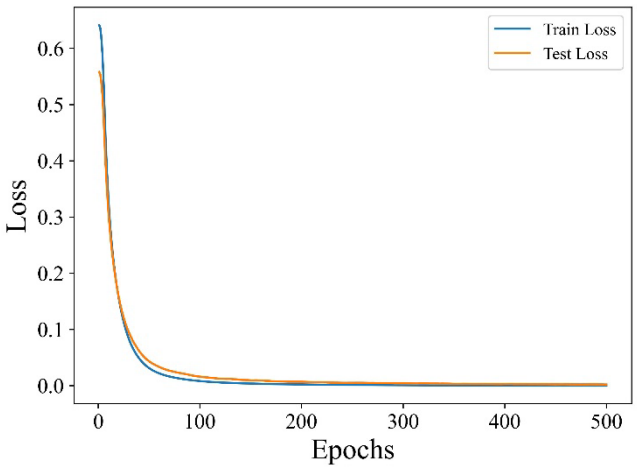


Figure 2. Training results of Internet addiction prediction model.
Source: The authors.

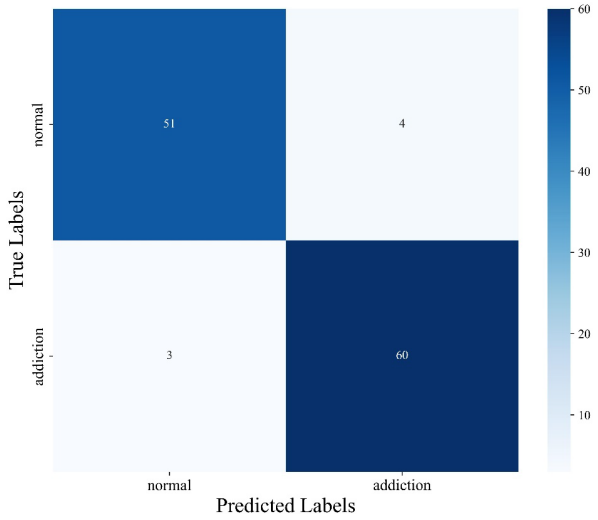


Figure 3. Prediction results of Internet addiction model.
Source: The authors.

the model's loss function initially decreased rapidly, signaling swift learning of the primary data features and robust data-fitting capability. As training progressed, the model reached a state of convergence. In the testing phase, the loss value steadily aligned with the training outcomes, eventually approaching zero, which underscores the model's enhanced predictive proficiency.

For practical evaluation, 118 samples were randomly selected as test data, with results detailed in the confusion matrix in Fig. 3. Of the normal Internet users, 51 were accurately identified, with 3 misclassifications. For users exhibiting Internet addiction, 60 were correctly predicted, with 4 misclassified. This resulted in a prediction accuracy of 94.07%, reflecting the model's substantial generalization capacity.

### 3.2 *Prediction results of different models*

The effectiveness of the 1D-CNN model was compared with that of Support Vector Machine (SVM) and Multilayer Perceptron (MLP) algorithms in a detailed assessment. This comparison was based on identical training data and model parameters, focusing on predicting normal and Internet-addicted users. As per the data in Table 2, the 1D-CNN model achieved a 92.77% accuracy, outperforming the SVM and MLP models by 5.30% and 3.21%, respectively.

In terms of precision, recall, and F1 scores for normal Internet users, the 1D-CNN model scored 93.59%, 93.75%, and 0.937, respectively. For Internet-addicted users, the scores were 99.74%, 98.73%, and 0.992, respectively. The F1 scores for normal users predicted by the 1D-CNN were 0.05 and 0.036 higher than those of the SVM and MLP models, while for addicted users, the improvements were 0.07 and 0.06, respectively. These results establish the 1D-CNN model's superior predictive capabilities compared to SVM and MLP models, making it a viable tool for early detection and prevention of Internet addiction among college students.

### 3.3 *Internet addiction significantly affects the results of factors*

In Table 1, influences with statistically significant differences were selected as input characteristics for the prediction model, namely, first grade (C1), second grade (C2), single-parent family (C3), non-single-parent family (C4), poor family (C5), rich family (C6), negative behavior (C7), withdrawal behavior (C8), neuroticism (C9), extraversion (C10), no depression (C11), depressed (C12), overly intrusive (C13), understanding and caring (C14), anxiety (C15), no anxiety (C16), poor social support (C17), and very good social support (C18).

Table 2.
Prediction results of different models.

| Model | A | Forecast result | | | Internet addiction | | |
|---|---|---|---|---|---|---|---|
| | | *P* | *R* | *F*1 | *P* | *R* | *F*1 |
| SVM | 87.47 | 83.78 | 93.67 | 0.884 | 91.67 | 93.45 | 0.925 |
| MLP | 89.56 | 87.46 | 93.85 | 0.901 | 95.85 | 92.72 | 0.932 |
| 1D-CNN | 92.77 | 93.59 | 93.75 | 0.937 | 99.74 | 98.73 | 0.992 |

Note: A indicates Accuracy, *P* indicates Precision rate, *R* indicates Recall rate, *F*1 indicates F1 score.
Source: The authors.

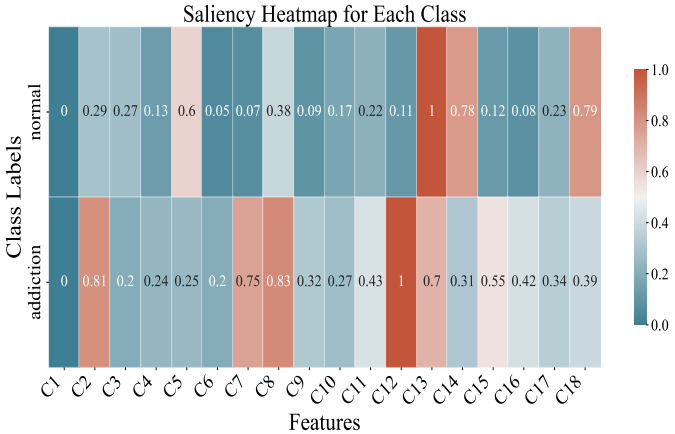


Figure 4. Significant factors affecting Internet addiction.
Source: The authors.

As can be seen in Fig. 4, first grade (C1): there is no difference between Internet addiction and normal Internet users with an impact factor of 0; second grade (C2): the impact factor of 0.81 for Internet addiction is significantly higher than that of 0.27 for normal internet users; single-parent family (C3) and non-single-parent family (C4): the impact factor was less than 0.5, with no significant effect on Internet addiction; poor family (C5): the impact factor for normal Internet users is 0.6; rich family (C6): no difference between Internet addiction and normal Internet users; negative behavior (C7) and withdrawal behavior (C8): significant influence on Internet addiction with an impact factor of 0.75 and 0.83 respectively among Internet addiction, and a smaller weighting among normal Internet users; neuroticism (C9) and extraversion (C10): there is less influence between Internet addiction and normal Internet users; no depression (C11) and depressed (C12): those depressed are more likely to be Internet addicted with an impact factor of 1.0; overly intrusive (C13) and understanding and caring (C14): overly intrusive families have an effect on both Internet addiction and normal Internet users, and understanding and caring families have a positive effect on normal Internet users; anxiety (C15) and no anxiety (C16): those with anxiety have a greater impact on Internet addiction, with an impact factor of 0.55; poor social support (C17) and very good social support (C18): individuals with very good social support have a greater weight among normal Internet users.

Based on the above analyses, the priority of the influence factors of Internet addiction is: C12 (1.0) > C8 (0.83) > C2 (0.81) > C7 (0.75) > C13 (0.7) > C15 (0.55) > C11 (0.43) > C16 (0.42) > C18 (0.39) > C17 (0.34) > C9 (0.32) > C14 (0.31) > C10 (0.27) > C5 (0.25) > C4 (0.24) > C3 (0.2) > C6 (0.2) > C1 (0), and the priority of the influence factors of normal Internet users is: C13 (1.0) > C18 (0.79) > C14 (0.78) > C5 (0.6) > C8 (0.38) > C2 (0.29) > C3 (0.27) > C17 (0.23) > C11 (0.22) > C10 (0.17) > C4 (0.13) > C15 (0.12) > C12 (0.11) > C9 (0.09) > C16 (0.08) > C7 (0.07) > C6 (0.05) > C1 (0). This ranking can help to understand the different effects of the factors on Internet addiction and normal Internet users, and provide direction for future interventions and research.

## 4 Conclusions

The statistical analysis results of the questionnaire show that the Internet addiction rate among college students is 20.71%. There are no statistical differences in Internet addiction among age, gender, and being an only child, $P > 0.05$. There are statistically significant differences in Internet addiction among grade, whether a single parent is a single parent, family economic conditions, depression, anxiety, and mobile phone addiction, $P < 0.05$. There are significant statistical differences in Big Five personality status, parenting styles, and social support, $P < 0.001$.

Using statistical results as original data, we built an Internet addiction prediction model based on one-dimensional convolutional neural network addiction. The results show that the accuracy of the model is 92.77%; the accuracy of predicting normal Internet users is 93.59%, and the recall rate is 93.59%. is 93.75, and the F1 score is 0.937; the precision rate of predicting Internet addiction is 99.74%, the recall rate is 98.73%, and the F1 score is 0.992. Compared with the Internet addiction prediction model constructed by SVM and MLP algorithms, its accuracy is 5.30 and 3.21 percentage points higher respectively. The F1 scores of normal Internet users are 0.05 and 0.036 higher respectively, and the F1 scores of Internet addiction are 0.07 and 0.06 higher respectively.

On this basis, the influencing factors with statistically significant differences were selected as the input features of the prediction model, and the gradient of the input features was calculated using the method of gradient back propagation to get the degree of influence of the input features on the category, and the results showed that second-grade students, negative behaviors and withdrawal behaviors, having depression, over-interfering, and having anxiety had a greater influence on Internet addiction, and the influence factors were all greater than 0.5. Family poverty, excessive interference, understanding and caring family and good social support have a greater impact on normal Internet use and can help students avoid Internet addiction.

After the above analysis, more attention should be paid to second-year students, students with negative and withdrawal behaviors, students with depression, students with over-interfering families and students with anxiety when preventing internet addiction in college to provide a research basis for preventing internet addiction in college students.

## 5 Discussion

The Internet's integral role in daily life has led to concerns regarding Internet addiction, negatively impacting academic, physical, and mental health. Di et al. [12] developed a predictive model using a support vector machine, identifying neuroticism and poor planning as key contributors to this addiction. Huang et al. [28] found a positive correlation between narrative disorders and cell phone addiction. Chemnad et al. [8] examined environmental influences on Internet addiction, using demographic data, diagnostic questionnaires, and scales related to family relationships and health behaviors. They discovered that family and school environments significantly predict Internet addiction, with a 29.64% prevalence rate. Xie et al. [29] demonstrated a positive correlation between anxiety, depression, and Internet addiction. Kuss et al. [30] focused on adolescents, noting that traits like low emotional stability and introversion increase susceptibility to Internet addiction. Chemnad et al. [8] also studied the link between social media usage and problematic Internet behaviors, suggesting the need for monitoring individual application usage for effective intervention strategies. Ioannidis et al. [31] used Logistic Regression, Random Forest, and Bayesian Machine Learning to create predictive models for problematic Internet use, validating the use of impulsivity and compulsivity as key factors in these models.

In this study, a prediction model for Internet addiction was constructed based on a one-dimensional convolutional neural network. One-dimensional convolutional neural networks (1D-CNN) demonstrate superior efficiency in feature acquisition and robustness in model construction with traditional data. Current Internet addiction questionnaires often rely on self-reporting, which may not accurately reflect

addiction behaviors due to students avoiding direct questions. This approach fails to identify and intervene in early stages of addiction considering psychological, social, and familial factors. Our method evaluates Internet addiction based on abnormalities in these factors, employing machine learning and deep learning techniques for precise predictions. Specifically, 1D-CNN effectively identifies the risk of Internet addiction among college students in a university in Shandong Province, aiming to provide targeted early intervention and reduce addiction rates. Future research could implement predictive software in real-time applications to monitor Internet addiction symptoms among college students, thus contributing to early prevention strategies in university settings.

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# Development of biodegradable plastic films from cassava starch

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**Abstract**
Plastic has become part of daily life because it is used in all industrial applications. Although it is beneficial and practical, it is the material that generates the most pollution in ecosystems. Therefore, the main objective of this research is to produce plastic films capable of degrading the environment in a shorter time (bioplastics). For this purpose, different samples were made with cassava starch (pulp or commercial), using amounts in the solution of 4% w/v and 30% w/w of cassava starch and glycerol, respectively, considering variations between the percentages of chitosan. The results showed that it is possible to obtain bioplastic by the casting method with the mixture of cassava starch (pulp or commercial), glycerol, and chitosan. Likewise, thanks to the laboratory tests carried out, was possible to determine that the use of commercial starch to produce biodegradable plastic films significantly favors moisture adsorption, solubility, and biodegradability, compared to starch extracted from cassava by hand, with good statistics validity of the analyzed data.

*Keywords*: bioplastic; biodegradability; plastic; chitosan.

# Desarrollo de películas plásticas biodegradables a partir de almidón de yuca

**Resumen**
El plástico se ha convertido parte del diario vivir debido a que se utilizada en todas las aplicaciones industriales, aunque es muy útil y práctico, es el material que genera más contaminación en los ecosistemas. Por lo tanto, el objetivo principal de esta investigación es la producción de películas plásticas capaces de degradarse con el medio ambiente en un menor tiempo (bioplásticos). Para este propósito, se realizaron diferentes muestras con almidón de yuca (pulpa o comercial), utilizando cantidades en la solución de 4% p/v y 30% p/p de almidón de yuca y glicerol, respectivamente, considerando variaciones entre los porcentajes de quitosano. Los resultados demostraron que con la mezcla de almidón de yuca (pulpa o comercial), glicerol y quitosano, fue posible la elaboración de bioplástico por el método casting. Asimismo, gracias a las pruebas de laboratorio realizadas se determinó que la utilización de almidón comercial para la elaboración de películas plásticas biodegradables favorece a una mayor adsorción de humedad, solubilidad y biodegradabilidad, comparado con el almidón extraído de la yuca artesanalmente, con buena validez estadística de los datos analizados.

*Palabras clave*: bioplástico; biodegradabilidad; plástico; quitosano.

## 1 Introduction

Plastic is one of the primary ecosystem pollutants due to its more than 3,000 chemical substances that make it up [1]. In the long term, plastic devastates maritime life, birds, and humans because they are not exempt from this massive pollution [2]. Most plastics are produced from petrochemical compounds (high molecular weight molecules), which can remain in the environment, producing pollution that is not biodegradable because, as is known, the decomposition process delays hundreds or thousands of years [3]. Plastics derived from petroleum are mostly used in sectors of the world economy, such as livestock, services, industrial, and agricultural because they have properties that benefit their applications and marketing. Considering the above, the demand for these materials has progressively increased, and

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consequently, their participation in solid waste production is also due to their low degradation rate [4]. For this reason, the use of synthetic polymers in agriculture is a technology that has been growing because it has managed to convert unproductive lands into agricultural production, generating a controlled environment and improving the quality of fruits and vegetables. This practice is called plasticulture, which uses plastic in agriculture to make productive land [5].

### *1.1 Literature review*

According to the literary review of scientific articles and works related to the development of biodegradable films that use polymers derived from renewable natural resources, it was possible to highlight:

Briones Muñoz and Riera, 2020, evaluated waste such as cassava peel and beeswax as potential materials to produce bioplastics; the starch from the cassava peel was extracted by wet and dry grinding, while beeswax was obtained by applying heat to the mixture of water with pieces of honeycomb. To determine the proximal composition of the extracted starch, humidity, crude protein, crude fat, ash, and the amount of amylase and amylopectin were determined, while the physicochemical characterization of the beeswax was evaluated: density, saponification index, acidity index, ash, and pH. The results demonstrate that the materials evaluated suitably function as a matrix in bioplastic preparation film-forming solutions. Likewise, using these materials as raw materials to produce thermoplastic starches is suggested [6].

Minh and Rangrong, 2016, evaluated the morphological characteristics and water vapor and oxygen barrier properties of blown starch-chitosan thermoplastic edible film, hydrophilicity of TPS and TPS/CTS films, scanning electron microscopy (SEM), focal laser scanning microscopy (CLSM) and X-ray photoelectron spectroscopy (XPS). Confirming that the existence of chitosan on the surface generates an improved barrier to water vapor and oxygen, reducing the surface hydrophilicity of the film. It is also concluded that biodegradable TPS/CTS films could be edible for food and pharmaceutical products [7]. Minh and Rangrong, 2015, developed thermoplastic starch-blown films incorporating plasticized chitosan, evaluating the effects of chitosan on extrusion processability and TPS melt flow capacity, as well as appearance, optical properties, thermal properties were investigated, viscoelastic properties and tensile properties of the films. Furthermore, FTIR and X-ray diffraction (XRD) techniques evaluated possible interactions between chitosan and starch molecules. The results demonstrated that chitosan and starch molecules interact through hydrogen bonds. Although the incorporation of this caused a decrease in the extensibility and flow capacity of the melt, as well as an increased opacity, the films had better extrusion processability, higher tensile strength, stiffness, temperature stability, and UV absorption, achieving a reduction in water absorption and surface adhesion [8].

Valarezo Ulloa, 2012, developed biopolymers from cassava bark starch (Manihot esculenta), using water and glycerin as plasticizers and acetic acid to modify the hydrophilic character. The starch was obtained by wet grinding and sedimentation, considering that the concentrations of the different components were modified to obtain a biopolymer with the best characteristics. The results showed that the biopolymer presented an average yield of 64% of starch obtained from the bark. In comparison, the biopolymer with the best characteristics was the mixture of 19.36% starch, 6.31% glycerin, 74.08% water, and 0.25% acetic acid; the samples made of this material have a humidity between 9.97% and 11.58%; observing that lower than this humidity the biopolymer becomes fragile and brittle, likewise the density of 6.44 gr/cm$^3$, 25.3% increase in weight due to absorption of water [9].

Bourtoom, 2008, evaluated the plasticizing effect on the biodegradable mixture film of rice starch and chitosan, where three plasticizers were studied: sorbitol, glycerol, and polyethylene glycol in a concentration range of 20 to 60%. Increasing the concentration of these plasticizers resulted in a decrease in tensile strength and increased water vapor permeability, film solubility, and elongation at break. The results of the films plasticized with sorbitol were more brittle, higher tensile strength, and low water vapor permeability compared to the other two plasticizers with a flexible structure, low tensile strength, and high water vapor permeability [10].

Pelissari et al. (2009) studied the effect of adding chitosan to starch-based polymeric systems. Research reports the improvement of the properties of TPS films due to the decrease in the hydrophilic character of these systems since adding chitosan results in a decrease in the interaction of starch with humidity. An essential disadvantage of chitosan is its high cost; however, improvements in mechanical properties have been demonstrated using small concentrations [11]. Lili Rena, et al. 2017 investigated the influence of chitosan concentration on the mechanical and barrier properties of films prepared with the starch solution mixture. In the research, the effects of chitosan were characterized and analyzed, evaluating the physicochemical properties of the material (density, volume, solubility in water mixture (WS) and color), water vapor permeability (WVP), crystallinity, characterization of microstructures. The results showed that incorporating chitosan increased film solubility, color differences, tensile strength, elongation at break, and decreased WVP. The elongation at the break of the films increased as a function of the chitosan concentration and reached a maximum of 41%, making these films suitable for use as active packaging films in food and pharmaceutical applications [12].

Finally, Godbillot, et al., 2005, studied the water-binding properties of the wheat starch film by determining the water vapor adsorption isotherms at 20°C, determining that the unplasticized starch film absorbs less water than native starch granules. Absorption by plasticized films depends on the equilibrium relative humidity (ERH) value and the glycerol content. When the ERH is equal to 44%, the plasticized film is less hygroscopic than starch, and above this value, the water absorbed increases with the glycerol content. Therefore, it is estimated that a maximum of 20% glycerol should be used to act as a plasticizer since, above this percentage, phase separation occurs and the amount of adsorbed water increases as it binds to the starch film, as well as to the "free" glycerol.

In conclusion, water vapor absorption is proportional to the number of hydrophilic sites (hydroxyl groups) in the plasticizer; the higher the hydrophobicity of the substituent, the lower the amount of water adsorbed [13].

### *1.2 Aim of this work*

Due to the need to develop new sustainable materials, this research focuses on developing biodegradable plastic films made from renewable materials that generally contain a high percentage of starch. Thanks to their production process, these plastics are biodegraded by microorganisms and introduced into the environment as an organic fertilizer beneficial for the soil [14]. Then, highlights for the development of biodegradable plastic films from cassava starch: 1) The utilization of cassava starch as a raw material for biodegradable plastic films offers an eco-friendly alternative to traditional plastics. These films can help reduce the environmental impact of plastic waste by degrading naturally and minimizing pollution. 2) Cassava is a renewable and abundant resource in many regions, making it an attractive source for biodegradable plastic production. This can contribute to sustainable agricultural practices and reduce dependence on non-renewable resources used in conventional plastics. 3) Biodegradable plastic films derived from cassava starch are designed to break down into environmentally benign components over time. This property is particularly valuable in applications where single-use plastics are common, such as packaging and agricultural films, and 5) Biodegradable films can find applications in various industries, including food packaging, agriculture, and more. Their versatility and environmentally friendly nature make them viable for industrial applications.

## 2 Materials and methods

### *2.1 Localization*

The Municipality of Aguachica is located in the South of the Department of Cesar, which has a latitude of 8.317 and a longitude of -73.617, between the Eastern Cordillera and the valley of the Magdalena River, with a territorial extension of 876.26 km$^2$, which occupies 3.8% of apartment area [15]. The municipality has two types of climates which are: Warm Thermal Floor, with temperatures greater than 24°C and heights between 50 and 1,000 masl. Temperate Thermal Floor, with temperature variations between 18–24°C and heights between 1,000 and 2,000±200 masl. The average annual temperature is 28°C, in July, the temperature reaches the highest values of up to 40°C, and in October, the lowest temperature occurs, reaching 22°C [16]. Thanks to the climate of the municipality of Aguachica, the economy revolves around the agricultural sector and agroindustry [17], where extractive energies, agriculture, livestock, and fishing have a GDP of 7.6% for the year 2018, being the Crops Cassava is the second most important crop (56,000) with a 12.7% share, after oil palm cultivation. On the other hand, it is highlighted that in the department of Cesar for 2018, 916,616.20 hectares were planted, with a production of 8,064,401.78 tons of cassava. On the other hand, for 2019, the municipality of Aguachica had a planted area of 120 hectares with a yield of 9 tons/hectare [18].

### *2.2 The cassava*

Cassava (Manihot esculenta) is characterized by developing laticiferous vessels composed of secretory cells or galactocytes that produce a milky secretion. The yucca plant grows in the warm, humid lowland tropics, in the subtropics with cold winters and summer rains, and in the mid-altitude tropics; its main advantage is the ability to grow with sporadic rainfall or long periods of drought and in acidic soils. Note that this plant does not tolerate saline soil conditions and waterlogging [19].

Cassava is divided into sweet and bitter cassava groups; this depends on the hydrocyanic acid content of the roots. Generally, the roots contain a glucose-cyanogen known as linamarin, which releases hydrocyanic acid when activated by the enzyme linamarin. The pulp contains a smaller amount of hydrocyanic acid than the peel. It is important to mention that the level of hydrocyanic acid is found in greater quantities in bitter cassavas and small quantities in sweet cassavas, and its presence varies according to the plant's physiological state and the humidity and fertility conditions of the soil [9]. As shown in Fig. 1, cassava is a perennial, woody, semi-shrub plant of variable size that reaches 1 to 4 meters in height, consisting of aerial and underground parts. The aerial part is made up of the stem (maximum height of 100 cm), leaves (length between approximately 14 and 17 cm), flowers, and fruits; while the underground part is composed of roots and radicals, although the roots are made up of an external part (bark or shell) corresponding to 12-20% of the root and the internal or central part (pulp) [16].

Because starch is needed as a raw material, it was decided to obtain starch from cassava (Manihot esculenta), planted in the municipality of Aguachica Cesar, taking advantage of this tuber characterized by its high starch content. In turn, it is highly perishable; it begins to deteriorate two or three days after harvesting if no treatment is developed. Consequently, chemical processes cause a color change inside the root, followed by microbial growth that accelerates damage. Cassava is made up of protein, fat, carbohydrates, fiber, and ash. Table 1 exposes the tuber-represented percentages in highly humid percentages with up to 72%.

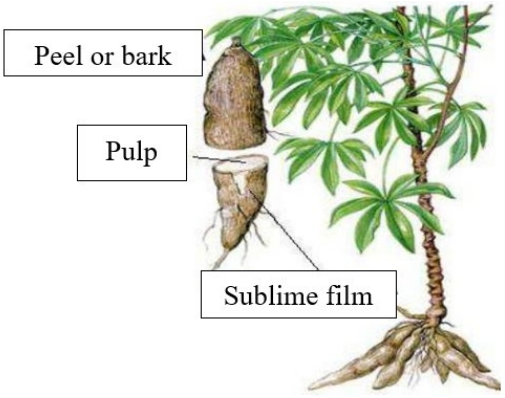


Figure 1. Parts of the cassava root.
Source: Obtained from [20].

Table 1.
Cassava composition.

| Fractions | Whole root | | Cortex | | Central cylinder | |
|---|---|---|---|---|---|---|
| | Wet | Dry | Wet | Dry | Wet | Dry |
| **Humidity** | 61.0 | - | 72.0 | - | 59.0 | - |
| **Protein** | 1.2 | 3.1 | 1.5 | 5.4 | 1.0 | 2.4 |
| **Fat** | 0.4 | 1.1 | 0.6 | 2.1 | 0.4 | 1.0 |
| **Carbohydrates** | 34.9 | 89.4 | 21.7 | 77.2 | 37.3 | 91.0 |
| **Fiber** | 1.2 | 3.3 | 2.1 | 8.9 | 1.1 | 2.7 |
| **ashes** | 1.3 | 3.3 | 1.7 | 6.1 | 1.2 | 2.9 |

Source: [21].

### *2.2.1 Cassava starch obtention:*

Starch is a polymer from natural sources, also known as starch, which is made up of granules that have a macromolecular configuration organized in layers whose particularity to its composition, its portion, and its appearance, which largely depend on the source of the starch that proceeds. The most abundant carbohydrate in nature is starch, and in plants, it is one of the main energy reserves and is found in sources as diverse as cereal seeds such as wheat, corn, and rice, in plant seeds, legumes of lentils, and beans, in the stem the sago palm, in leaves such as tobacco, in fruits such as apples, in tubers such as potatoes and bananas, and finally in roots such as sweet potatoes and cassava [16].

### *2.2.2 Starch structural properties:*

Starch is made up of two different polymeric structures: amylopectin and amylose, made up of glucose units, respectively. So, amylopectin is a branched polymer, while amylose is a linear polymer. The bond between amylopectin and amylose is an essential factor in the manufacture of films and dominates the physical and mechanical properties of the materials [22]. The property of interest in natural starch lies in its semi-crystallinity. For this reason, amylopectin is the element that contributes to the crystallization of most starches. The commercially significant properties of starch, which refer to its mechanical resistance and flexibility, those governed in nature by the strength and the crystalline zone, and the link between amylose and amylopectin, are also contemplated, molecular weight fraction, the structuring procedure of the components types in the polymer, the branching level and the plant type [23].

### *2.2.3 Starch extraction:*

Starch extraction can be carried out at an artisanal or technical level. Different methods exist to obtain starch from corn, cassava, potatoes, or bananas. The main methods are dry grinding and wet grinding. Although the usual process for extracting cassava starch is through wet milling, which consists mainly of fracturing the cell walls in order to release the starch granules through a grating, followed by the addition of water and filtration, which allows the separation of the starch particles suspended in the liquid medium of those that are relatively larger, such as fiber elements, then the water is removed, and the settled material is washed to remove the last different fractions of the starch to subject the purified starch to a drying finally; It should be noted that this method is considered a high-performance and economical process. On the other hand, obtaining starch by dry milling is proposed as an alternative to reduce water use, considering that washing and hulling, grating, pre-dehydration, pre-ground, dehydration, grinding, and sieving must be carried out [24].

### *2.2.4 Bioplastic production process from starch:*

Bioplastics are manufactured from renewable resources of natural origin, such as starch; they require chemical structures that allow the degradation of the material by microorganisms, such as fungi and bacteria [25]. Bioplastic is defined as “a plastic of biological origin produced by a living organism and with a biodegradable appearance, synthesized from renewable energy sources, such as starch (corn, cassava, and potato), so it hardly produces pollution” [26]. On the other hand, according to the American Society for Testing of Materials (ASTM) and the International Standards Organization (ISO), degradable plastics are polymers that can present changes in their chemical structure under specific environmental circumstances, causing a notable loss in their mechanical and physical properties. Considering the above, bioplastics could decompose with enzymes produced by microorganisms such as bacteria, fungi, and algae [27].

Fig. 2 shows the process of obtaining cassava starch, where initially, the root was washed, weighed, and peeled. When peeling, the rind and pulp were separated. Following this, it was grated, ground, or crushed with 350 mL of distilled water per kilogram of pulp to release the starch granules contained in the cells. Once the size was reduced, the mixture obtained was filtered through a filter, separating the fibers and impurities. Subsequently, a liter of water was added to the fiber obtained and filtered again; this step was carried out twice. The liquid obtained was left to stand in beakers for 4 h in sedimentation, where granules of various sizes settled to the bottom. Finally, the starch obtained was dried at 45°C for 24 h and then ground and sieved [28]. Note that, according to the FAO Agricultural Services Bulletin, the cassava starch extraction method which includes the following stages: collection, washing, shearing, grating and roots, extraction, sedimentation, drying, and adaptation; the latter includes the crushing, sieving, and packaging processes [16].

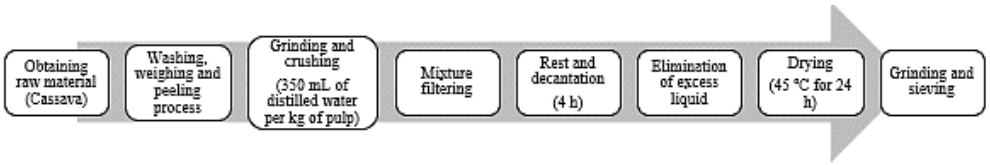


Figure 2. Starch diagram of the process.
Source: The authors.

The bioplastics process from starch has three stages: gelatinization (plasticizer and mechanical work), de-structuring of the granule, and film formation. First, there is gelatinization or initiation, defined as the loss of semi-crystallinity of starch granules in the presence of heat and high amounts of water. For this reason, it must be known that starch granules are insoluble in cold water because their structure is highly organized and presents great stability due to the multiple interactions that exist between the polysaccharides that constitute them. However, when they are heated, a slow process of water absorption begins in the amorphous intermecellar zones, which are the least structured and the most accessible; this is thanks to the fact that the hydrogen bonds are not as solid or numerous as in the crystalline areas. As the temperature increases, more water is contained, and the granule begins to bulge and increase in volume [27].

Gelatinization is generated in a tight range of temperatures that is altered depending on the source of the starch. Therefore, cassava starch gelatinizes in water at a temperature between 55 and 65 °C, which consists of swelling of the starch molecules because water penetrates its molecular structure. The unwinding of the molecules and their thermal mobility produced by swelling results in a decrease in crystallinity, breaking the structure. The behavior of the mixture is subject to the level of water absorption by the starch and the concentration. When gelatinization occurs, swollen starch granules occupy the empty spaces. The viscosity increases with temperature until the granules fragment, which disintegrates, and dissolves generates a decrease in viscosity. Secondly, there is destructuring, the transformation of the semi-crystalline starch grains into a homogeneous matrix of amorphous polymer, and the partial depolymerization of the molecules, on the one hand, and breaking the hydrogen bonds between the starch molecules. , of the other. The one that initially depolymerizes is amylopectin, then amylose, using greater energy. The increase in temperature increases the solubility of starch in water, leading to significant depolymerization around 150ºC. However, only above 190ºC can the increase in solubility be confirmed [25]. Finally, there is film formation, where the molding and drying of the sample are considered.

### *2.2.1 Starch films production:*

For the preparation of biodegradable films of cassava starch (pulp or commercial), the Solvent casting method was used, highlighting that the concentration of starch in the solution was 4% w/v and glycerol was 30% w/w, as shown in Fig. 3. Glycerin was pre-homogenized with distilled water at room temperature for 10 min with the help of a magnetic stirrer at 200 RPM. Note that the disadvantages of starches lie in their low tensile strength, deformation at the break, and, therefore, the functionality of the film as a function of time. The high intermolecular interaction can be reduced between the polymer chains of starch and plasticizers such as water, urea, glycerol, and sorbitol, among others, must be used to reduce its fragility. Also, these are hydrophilic, which increases the polymeric material's interaction. The above requires finding an alternative mixture, making it necessary to use a less hydrophilic biopolymer such as chitosan, whose function will reduce the hydrophilic character (water vapor) permeability of the biodegradable film obtained. However, its use is limited due to the high cost, so polyethylene-based films are still used in underdeveloped countries like Colombia.

After starch granule destructed was obtained, chitosan was added in concentrations of 0, 1, and 2% w/w concerning the mass of starch, previously diluted in 1% acetic acid. It was subsequently stirred at temperatures of 25°C for 45 min. Finally, the solutions obtained were added to Petri dishes for drying in a forced convection oven at 55°C for 24 h.

### *2.2.2 Determination and analysis process of the physicochemical properties, hydrophilicity, and biodegradability of the bioplastics obtained:*

The moisture absorption test was carried out to determine the moisture gain the films can obtain, which was reflected through the weight. For this reason, the films measuring 5x5 cm were cut into square shapes and dried in an oven at 100 °C for 24 h. Following this, they were exposed to the environment, and weight gain was monitored as a function of time using an analytical balance [29]. The percentage of moisture gain was determined by applying Eq. 1. Note that the thickness of the films was measured with a conventional vernier caliper.

**a)** Weighing the starch on the analytical balance. **b)** Addition of glycerin to the solution. **c)** Prehomogenization of glycerin. **d)** Solution temperature at 90 °C. **e)** Addition of starch.

Figure 3. Process of making starch films.
Source: The authors.

$$\% \text{ Weight gain} = \frac{\text{final weight} - \text{initial weight}}{\text{initial weight}} \times 100 \quad (1)$$

The density of the films was measured considering biopolymer samples measuring 2x2 cm and weighed on the analytical balance. Then, a 10 mL test tube was used, and 5 mL of distilled water was added. The biopolymer sample was carefully introduced until it was submerged entirely. It was recorded how much the water level rose; this is the plastic volume ($cm^3$), and the density was calculated with Eq. 2.

$$\text{Density} = \frac{\text{mass}}{\text{volume}} \quad (2)$$

On the other hand, the percentage of solubility of the films was determined according to the methodology proposed by Trujillo Rivera, 2014. First, the films were cut with dimensions of 2x3 cm and stored in a desiccator for 7 days at a relative humidity close to 0%. After this, the samples were weighed and placed in a 100 mL beaker with 80 mL of distilled water. The samples were kept under constant stirring for one hour at room temperature (25°C). After the stirring time had elapsed, the film pieces were dried at 60°C for 2 h, considering the percentage of soluble matter (% solubility) calculated according to Eq. 3.

$$\% \text{ Solubility} = \frac{\text{initial dry weight} - \text{final dry weight}}{\text{initial weight}} \times 100 \quad (3)$$

For the biodegradability analysis, the films measuring 5x5 cm were cut into a square shape and placed under environmental conditions, exposed explicitly to soil microorganisms, sunlight, and humidity for an exposure time of 15 days, as shown in Fig. 4, where weight loss was evaluated every 5 days using Eq. 4.

$$\% \text{ Weight loss} = \frac{\text{final weight} - \text{initial weight}}{\text{initial weight}} \times 100 \quad (4)$$

Figure 4. Biodegradation of plastic films.
Source: The authors.

Table 2.
Treatment's definition.

| | | B Factor - CC (%) | | |
|---|---|---|---|---|
| | | 0 | 1 | 2 |
| A Factor - (Type of starch) | Commercial | ACMG-Q0 | ACMG-Q01 | ACMG-Q02 |
| | Pulp | APG-Q0 | APG-Q01 | APG-Q02 |

Source: The authors.

### *2.1 Experimental design*

T the effect of the type of starch used and the effect of chitosan on the properties of the films was evaluated using a factorial design proposed with two factors for each of these and three levels per factor. For data analysis, ANOVA was applied, where the first factor corresponded to the type of starch used and the levels (starch) obtained with pulp and commercial starch. The second factor corresponds to the concentration of chitosan; the levels are 0, 1, and 2% w/w of the starch mass if there are significant differences for at least two means of the four treatments of each test, using the Tukey test [30].

For the evaluation of bioplastics according to the different response variables that will determine the hydrophilic and biodegradable characteristics, four replicas of the different treatments were developed to guarantee the statistical validity of the results [31]. The quantities of components to be used in general for the formulations without considering the type of starch was 4.2%, glycerol 1.8%, chitosan (0.042 and 0.084%), and the remaining water to complete 100%. Table 2 defines the 2 factors: starch type and chitosan concentration (CC).

## 3 Results and Discussions

### *3.1 Humidity absorption*

The humidity gain of the biodegradable films of the two types of commercial starch was carried out considering the weight monitoring of gain as a function of time. Based on the data, some general observations are raised in Fig. 5. As the concentration of chitosan increases (from 0 to 2%), there is a general trend of increasing weight in most cases (treatments 1, 2, 3, and 4). This behavior suggests that a higher chitosan concentration leads to higher weights. Then, within each chitosan concentration level, weight variations exist across different treatments. For example, for a chitosan concentration level 0%, the weights range from around 0.298 to 1.293, depending on the treatment [32].

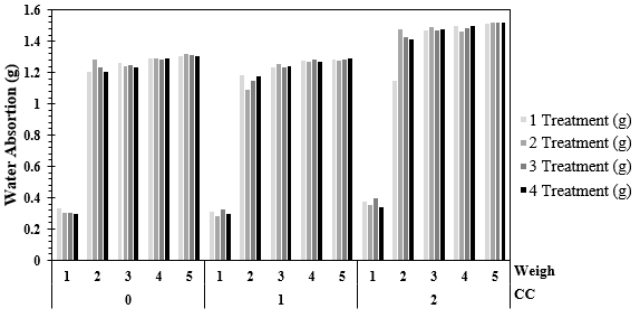


Figure 5. Humidity absorption for different treatments for commercial starch.
Source: The authors.

### *3.2 ANOVA for the humidity absorption*

After having evaluated the moisture adsorption expressed in percentage of weight gain, according to the statistical analysis carried out, it was evident that there were no significant differences (that is, P values>0.05) as shown in Table 3 for the differences between weighing. Therefore, it is deduced that for the three different concentrations of chitosan in the first 5 days, there was no effect on the moisture adsorption of the films, as evidenced by good statistical results [8].

The humidity gain of the biodegradable films of the two types of starch pulp and the following results were obtained according to the monitoring of the weight gain as a time function. The different percentages of weight gain of the biodegradable films with starch pulp with the three types of chitosan concentration are seen in Fig. 6. Note that the weighing values vary depending on the chitosan concentration and the treatment. In general, there is a decreasing trend in weighing as the concentration of chitosan increases; this suggests that, at higher concentrations of chitosan, weighing tends to decrease. Each treatment (1, 2, 3, and 4) shows differences in weighing, which may result from the interaction between the chitosan concentration and the specific treatment. Each weighing group (1, 2, 3, 4, and 5) seems to have slightly different behavior. Some groups show more constant weighing across different treatments and chitosan concentrations, while other groups show more marked variation [33].

According to the statistical analysis in Table 4, no significant differences (P≥0.05) existed between the second and third weighing of the four treatments of the biodegradable films with starch pulp. Therefore, it is deduced that the three different concentrations of chitosan in the first 10 days did not affect the moisture adsorption of the films. According to the statistical analysis, there were significant differences (P<0.05) between the pulp in the third and fourth weights of the four biodegradable films with commercial starch

Table 3.
ANOVA for the data of the weight gain percentage of the biodegradable films with commercial starch for the treatments.

| Variation origin | $R^2$ sum | DOF | $R^2$ | F | Probability | F-Value |
|---|---|---|---|---|---|---|
| --- | | | **Between 1 and 2** | | | |
| Between groups | 947.56 | 2 | 473.78 | 2.9 | 0.10 | 4.26 |
| Within the groups | 1455.12 | 9 | 161.68 | -- | -- | -- |
| **Total** | 2402.68 | 11 | -- | -- | -- | -- |
| **---** | | | **Between 2 and 3** | | | |
| Between groups | 0.4 | 2 | 0.2 | 0.4 | 0.68 | 4.26 |
| Within the groups | 4.46 | 9 | 0.5 | -- | -- | -- |
| **Total** | 4.85 | 11 | -- | -- | -- | -- |
| **---** | | | **Between 3 and 4** | | | |
| Between groups | 5.08 | 2 | 2.54 | 6.1 | 0.02 | 4.26 |
| Within the groups | 3.76 | 9 | 0.42 | -- | -- | -- |
| **Total** | 8.84 | 11 | -- | -- | -- | -- |
| **---** | | | **Between 4 and 5** | | | |
| Between groups | 0.661 | 2 | 0.331 | 6.1 | 0.02 | 4.26 |
| Within the groups | 0.491 | 9 | 0.055 | -- | -- | -- |
| **Total** | 1.152 | 11 | -- | -- | -- | -- |

Note: Where DOF are degrees of freedom and $R^2$ quadrate.
Source: The authors.

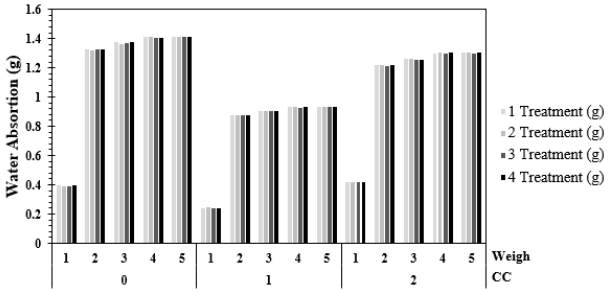


Figure 6. Humidity absorption for the different treatments for starch pulp.
Source: The authors.

treatments. Likewise, it is deduced that for the three different concentrations of chitosan in the first 15 days, there were differences between at least two of them in the moisture adsorption test of the films [10].

Once the Tukey test was carried out, it was possible to verify the differences in humidity adsorption of the biodegradable films with starch pulp between the first and second weighing of the four treatments. Chitosan concentrations were obtained from 0-1%, 0-2%, and 1-2%. According to the statistical analysis, there were significant differences (P≤0.05) between the third and fourth weighing of the four biodegradable films with commercial starch treatments [34]. Therefore, it is deduced that the three different chitosan in the first 20 days differed in at least two in the moisture adsorption test of the concentration films. The Tukey test was carried out to determine in which of the three concentrations there was a difference, where if the difference in the means is more significant than the value found in the Tukey test (Tα= 0.37, Tα= 0.62, Tα= 1.03 and Tα= 5.59).

Table 4.
ANOVA for the data of the weight gain percentage of the biodegradable films with pulp starch for the treatments.

| Variation origin | $R^2$ sum | DOF | $R^2$ | F | Probability | F-Value |
|---|---|---|---|---|---|---|
| --- | | | **Between 1 and 2** | | | |
| Between groups | 9775.58 | 2 | 4887.79 | 400.4 | 1.61E-09 | 4.26 |
| Within the groups | 109.86 | 9 | 12.21 | -- | -- | -- |
| **Total** | 9885.44 | 11 | -- | -- | -- | -- |
| **---** | | | **Between 2 and 3** | | | |
| Between groups | 0.3 | 2 | 0.15 | 1.33 | 0.312 | 4.26 |
| Within the groups | 1.017 | 9 | 0.113 | -- | -- | -- |
| **Total** | 1.317 | 11 | -- | -- | -- | -- |
| **---** | | | **Between 3 and 4** | | | |
| Between groups | 1.35 | 2 | 0.68 | 4.53 | 0.04 | 4.26 |
| Within the groups | 1.34 | 9 | 0.15 | -- | -- | -- |
| **Total** | 2.69 | 11 | -- | -- | -- | -- |
| **--** | | | **Between 4 and 5** | | | |
| Between groups | 0.192 | 2 | 0.096 | 3.21 | 0.089 | 4.256 |
| Within the groups | 0.27 | 9 | 0.03 | -- | -- | -- |
| **Total** | 0.462 | 11 | -- | -- | -- | -- |

Source: The authors.

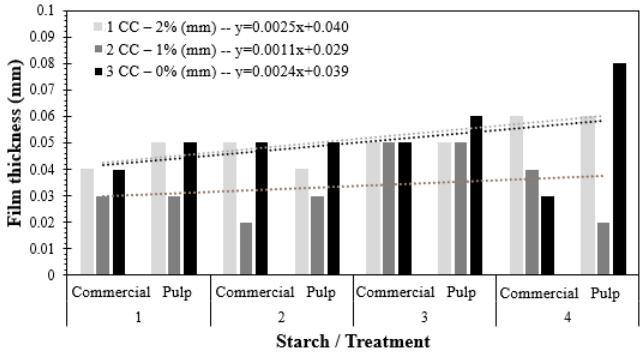


Figure 7. Thicknesses of biodegradable films corresponding to commercial starch and pulp.
Source: The authors.

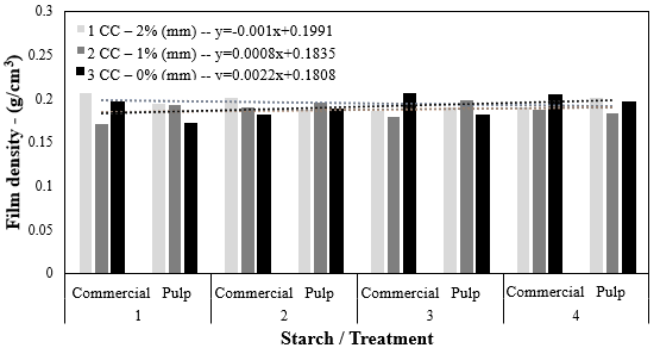


Figure 8. Densities of biodegradable films corresponding to commercial starch and pulp.
Source: The authors

### *3.3 Film thickness behavior*

According to the measurements made on the biodegradable films of the types of starch used in the research, the thicknesses shown in Fig. 8 were obtained, where the data on starch, treatments, and the concentration of chitosan at three levels can be observed, different (0, 1, 2%) with their respective millimeters (mm) measurements. Some notable trends and patterns were evident, and the data is divided into two types of starch: "Commercial" and "Pulp" in terms of treatment, four treatments (1, 2, 3, 4) are presented for each type of starch. For "Commercial" starch, as the concentration of chitosan increases (from 0 to 2%), the film thickness measurement tends to increase generally in all treatments based on the data; some general observations are raised from Fig. 7. This behavior suggests that, in this starch type, the addition of chitosan is associated with a significant increase. For "Pulp" starch, the relationship between chitosan concentration and measurement is more varied as observed. In some treatments, the increase in chitosan concentration is associated with an increase in film thickness; in other treatments, a decrease occurs. The variability indicates that the effect of chitosan on "Pulp" starch may be more complex and depends on the specific treatment [11].

Some treatments may be more sensitive to chitosan concentration than others, suggesting the importance of the interaction between treatment and chitosan concentration. In summary, the data indicate that chitosan concentration influences starch measurements, but the nature of this relationship varies depending on the type of starch and treatment. It is important to understand these relationships to determine how adding chitosan should be optimized based on improving starch properties or characteristics in particular applications. Likewise, a trend equation was established for each one that governs the behavior of each starch concerning the experimental conditions with the addition of chitosan.

### *3.4 Density behavior*

The density results are summarized in Fig. 8, exposing data on starch, treatments, and chitosan concentration at three different levels (0, 1, 2%) with their respective measurements in g/cm³. The data is divided into two types of starch: "Commercial" and "Pulp". In terms of treatment, four treatments (1, 2, 3, 4) are presented for each type of starch. For "Commercial" starch, as the concentration of chitosan increases (from 0 to 2%), the density (measured in g/cm³) tends to vary in all treatments. For "Pulp" starch, the relationship between chitosan concentration and density is more varied. In some treatments, the density increases with chitosan concentration, while in others, it decreases. This behavior suggests that the effect of chitosan on "pulp" starch may be more complex and depends on the specific treatment. Within each type of starch, different treatments show variations in density. Some treatments may be more sensitive to chitosan concentration than others, highlighting the importance of the interaction between treatment and chitosan concentration. Likewise, a trend equation was established for each one that governs the behavior of each starch concerning the experimental conditions with the addition of chitosan, evidencing a high correlation coefficient $R^2$ between the measured variables and the treatments, considering the value of the equation slope [33].

### *3.5 Percent solubility determination*

The results obtained from the percentage determination of solubility of the plastic films are shown in Table 5. Solubility of biodegradable films corresponding to commercial starch and pulp. The difference in dry weight between the initial and final state could be observed. The difference represents a change in dry weight during treatment. Overall, “Commercial Starch” appears to experience a greater dry weight difference than “Pulp Starch.” This suggests that the type of starch influences how it reacts to the treatment. As the concentration of chitosan increases (from 0 to 2%), the difference in dry weight generally tends to increase in both types of starch. This indicates that chitosan has a positive effect on dry weight change. The different treatments (1, 2, 3, 4) show variations in the difference in dry weight. Some treatments show significantly greater differences than others, suggesting that the specific treatment also has an impact. In some cases, the difference in dry weight is relatively small, while in other cases, it is more significant; this behavior could be related to specific factors of the treatments and the reaction of the starches to those conditions [8].

Table 5.
Weighing of biodegradable films corresponding to commercial starch.

| Treatments | Initial dry weight (g) | Final dry weight (g) | Difference | Initial dry weight (g) | Final dry weight (g) | Difference |
|---|---|---|---|---|---|---|
| | Commercial starch | | | Starch pulp | | |
| --- | | | CC - 0% | | | |
| 1 | 0.2875 | 0.1615 | 0.1260 | 0.3807 | 0.3166 | 0.0641 |
| 2 | 0.2357 | 0.1477 | 0.0880 | 0.5074 | 0.4817 | 0.0257 |
| 3 | 0.4015 | 0.2511 | 0.1504 | 0.3938 | 0.3362 | 0.0576 |
| 4 | 0.4174 | 0.2717 | 0.1457 | 0.4693 | 0.4371 | 0.0322 |
| --- | | | CC - 1% | | | |
| 1 | 0.2974 | 0.2123 | 0.0851 | 0.3092 | 0.2800 | 0.0292 |
| 2 | 0.3825 | 0.2805 | 0.1020 | 0.2118 | 0.1315 | 0.0803 |
| 3 | 0.291 | 0.1942 | 0.0968 | 0.3601 | 0.3518 | 0.0083 |
| 4 | 0.2607 | 0.1703 | 0.0904 | 0.2484 | 0.2023 | 0.0461 |
| --- | | | CC - 2% | | | |
| 1 | 0.3726 | 0.2288 | 0.1438 | 0.427 | 0.3325 | 0.0945 |
| 2 | 0.3829 | 0.2421 | 0.1408 | 0.4159 | 0.3298 | 0.0861 |
| 3 | 0.3806 | 0.2334 | 0.1472 | 0.3862 | 0.3294 | 0.0568 |
| 4 | 0.3536 | 0.2149 | 0.1387 | 0.4492 | 0.3545 | 0.0947 |

Source: The authors.

In Table 6, an analysis of the percentage of solubility of the films for commercial starch and pulp was carried out to determine the main changes between treatments and chitosan concentration. Likewise, chitosan concentration data (%) and 1-T (%), 2-T (%), 3-T (%), and 4-T (%) values are presented for two types of starch ("Commercial starch " and "Starch pulp") at three levels of chitosan concentration (0, 1, 2%). In commercial starch, as the concentration of chitosan increases, the 1-T, 2-T, 3-T, and 4-T values generally increase. This performance suggests that the chitosan concentration positively affects the values for this type of starch. For the other case (pulp starch), the relationship between chitosan concentration and values is more varied. In some cases, such as 1-T, the values increase with chitosan concentration, while in other cases, such as 3-T, they decrease. This behavior indicates that the effect of chitosan on pulp starch is more complex and depends on the specific treatment. On the other hand, the different treatments for both types of starch (1, 2, 3, 4) show variations in values. Some treatments may be more sensitive to chitosan concentration than others, highlighting the importance of the interaction between treatment and chitosan concentration.

Table 6.
Solubility percentage of biodegradable films corresponding to commercial starch and pulp.

| CC (%) | 1-T (%) | 2-T (%) | 3-T (%) | 4-T (%) |
|---|---|---|---|---|
| --- | | Commercial starch | | |
| 0 | 43.82 | 37.33 | 37.46 | 34.90 |
| 1 | 28.61 | 26.67 | 32.26 | 34.67 |
| 2 | 38.59 | 36.77 | 38.44 | 39.22 |
| --- | | Starch pulp | | |
| 0 | 16.84 | 5.06 | 14.63 | 6.86 |
| 1 | 9.44 | 37.91 | 2.30 | 18.56 |
| 2 | 22.13 | 20.53 | 14.70 | 21.08 |

Note: Where T is treatment.
Source: The authors.

### *3.6 Biodegradability analysis*

The results of the biodegradability determination of the commercial starch and plowing results were obtained according to the monitoring of weight loss as a function of time, as shown in Table 7. The data reveals that, in general, commercial starch exhibits higher CC percentages compared to starch pulp across all treatment levels and weighing conditions. Commercial starch consistently has values above 1.5, whereas starch pulp values are generally below 1.4; this value suggests that commercial starch contains more chitosan than starch pulp.

### *3.7 Properties comparison of bioplastics made of starch type and chitosan concentration*

For humidity adsorption, the differences obtained between commercial starch and pulp films for the 0% chitosan concentration were 37.6% in the first 5 days, 0.26% for the first 10 days. of 0.2% for the first 15 days and 0.3% for the

Table 7.
Weight loss of biodegradable films with commercial starch in the first weighing of the four treatments.

| CC (%) | 1-T (%) | 2-T (%) | 3-T (%) | 4-T (%) | 1-T (%) | 2-T (%) | 3-T (%) | 4-T (%) |
|---|---|---|---|---|---|---|---|---|
| --- | | | Commercial starch | | | | Starch pulp | |
| --- | | | | Weigh 1 | | | | |
| 0 | 1.5352 | 1.5320 | 1.5292 | 1.5382 | 1.7508 | 1.7543 | 1.7689 | 1.7525 |
| 1 | 1.3034 | 1.3034 | 1.3034 | 1.3034 | 1.3310 | 1.3343 | 1.3300 | 1.3319 |
| 2 | 1.3800 | 1.3800 | 1.3800 | 1.3800 | 1.3037 | 1.3040 | 1.3072 | 1.3024 |
| --- | | | | Weigh 2 | | | | |
| 0 | 1.5147 | 1.5126 | 1.5087 | 1.5174 | 1.7305 | 1.7276 | 1.7325 | 1.7342 |
| 1 | 1.2852 | 1.2832 | 1.2820 | 1.2871 | 1.3101 | 1.3115 | 1.3095 | 1.3127 |
| 2 | 1.3639 | 1.3609 | 1.3630 | 1.3659 | 1.2918 | 1.2950 | 1.2898 | 1.2876 |
| --- | | | | Weigh 3 | | | | |
| 0 | 1.4847 | 1.4790 | 1.4874 | 1.4860 | 1.6943 | 1.6931 | 1.6950 | 1.6939 |
| 1 | 1.2623 | 1.2598 | 1.2639 | 1.2645 | 1.2855 | 1.2875 | 1.2834 | 1.2840 |
| 2 | 1.3410 | 1.3403 | 1.3418 | 1.3420 | 1.2678 | 1.2656 | 1.2647 | 1.2688 |
| --- | | | | Weigh 4 | | | | |
| 0 | 1.4158 | 1.4201 | 1.4138 | 1.4145 | 1.6103 | 1.6094 | 1.615 | 1.6125 |
| 1 | 1.2091 | 1.2096 | 1.2106 | 1.2085 | 1.2303 | 1.2314 | 1.2285 | 1.2330 |
| 2 | 1.2803 | 1.2790 | 1.2823 | 1.2813 | 1.2146 | 1.215 | 1.2167 | 1.2138 |

Source: The authors. Note: Where T is treatment.

Table 8.
Averages of the percentages of weight gain between the weighing carried out in the four commercial starch and pulp treatments.

| CC (%) | Average weight gain percentage | | | |
|---|---|---|---|---|
| --- | Commercial starch | | | |
| --- | 1 and 2 weighing | 2 and 3 weighing | 3 and 4 weighing | 4 and 5 weighing |
| 0 | 274.24 | 3.96 | 2.85 | 0.67 |
| 1 | 294.20 | 3.88 | 3.55 | 0.48 |
| 2 | 276.69 | 3.54 | 1.96 | 1.04 |
| --- | Starch pulp | | | |
| 0 | 236.46 | 3.70 | 2.65 | 0.37 |
| 1 | 259.45 | 3.42 | 2.84 | 0.23 |
| 2 | 190.78 | 3.32 | 3.44 | 0.06 |

Source: The authors.

Table 9.
Average values for the response variables in the four commercial starch and pulp treatments.

| CC (%) | Commercial | Pulp | Commercial | Pulp | Commercial | Pulp |
|---|---|---|---|---|---|---|
| Average | Thickness | | Density | | Solubility | |
| 0 | 0.042±0.002 | 0.060±0.003 | 0.20±0.01 | 0.19±0.01 | 38.38±0.32 | 10.85±0.11 |
| 1 | 0.035±0.001 | 0.033±0.001 | 0.18±0.01 | 0.19±0.01 | 30.55±0.25 | 17.05±0.12 |
| 2 | 0.050±0.001 | 0.050±0.001 | 0.20±0.02 | 0.18±0.01 | 38.26±0.27 | 19.61±0.15 |

Source: The authors.

first 20 days, for the chitosan concentration 1%, were 34.75% in the first 5 days, 0.46% for the first 10 days, 0.71% for the first 15 days and 0.25% for the first 20 days and the chitosan concentration 2%, were 85.91% in the first 5 days, 0.22% for the first 10 days, 1.48% for the first 15 days and 0.98% for the first 20 days, which proves that commercial starch films have greater moisture adsorption than pulp starch films, thus being the one with 0% chitosan concentration the one with the greatest moisture adsorption, taking into account that chitosan It is used in plastic films to reduce the hydrophilic character [7,8], as was observed in Table 8.

For the thickness determination, the differences obtained between the films of commercial starch and pulp for the 0% chitosan concentration was 0.017 mm; for the 1% chitosan concentration, it was 0.002 mm, and for the 2% chitosan concentration, there was no difference. The data was obtained from the differences between Table 9, shown below. For the density's determination, differences were obtained between the commercial starch films and pulp; for the 0% chitosan concentration was 0.01 g/cm$^3$, for the 1% chitosan concentration, it was 0.01 g/cm$^{3,}$ and for the 2% chitosan concentration it was 0.02 g/cm$^3$.

For solubility, the differences obtained between commercial starch films and pulp for the 0% chitosan concentration was 27.53%; for the 1% chitosan concentration, it was 13.5%; and for the 2% chitosan concentration, it was 18.65%, from the above it can be confirmed that the films made with commercial starch have a greater solubility than those of pulp starch, considering the differences obtained from Table 9. For biodegradability, the differences obtained between commercial starch and pulp films, for the 0% chitosan concentration, were 0.13% in the first 5 days, 0.22% for the first 10 days, and 0.25% for the first 15 days. for the 1% chitosan concentration, they were 0.11% in the first 5 days, 0.28% for the first 10 days and 0.02% for the first 15 days and for the 2% chitosan concentration, they were 0.18% in the first 5 days, 0.26% for the first 10 days and 0.43% for the first 15 days, which proves that pulp starch films have greater biodegradability than commercial starch films, with the chitosan concentration being 0%.

## 1 Conclusions

Using the casting method, the mixture of cassava starch (pulp or commercial) with glycerol and chitosan generates a biofilm with good properties. Within each type of starch used, the different treatments show variations in the density and thickness of the films. Some treatments may be more sensitive to chitosan concentration than others, highlighting the importance of the interaction between treatment and chitosan concentration. Likewise, a trend equation was established for each one that governs the behavior of each starch concerning the experimental conditions with the addition of chitosan, evidencing a high correlation coefficient ($R^2$) between the measured variables and the treatments, considering the value of the slope of the equation.

It was observed that the plastic films that produced more bubbles at the time of production contained chitosan at a higher percentage. Likewise, the films made with pulp starch have the same colorless tone as the films made with commercial starch; in the end, what caused them to take on an opaque tone was the amount of chitosan in those that contained it.

The different tests carried out in the research determined that using commercial starch to produce biodegradable plastic films favors greater moisture adsorption, solubility, and biodegradability compared to starch extracted from cassava by hand. Regarding the most appropriate concentration of chitosan in the formulation of the films, the potential use of biofilms must be considered, and in this way, the appropriate concentrations and percentages for their industrial application must be established.

Bioplastic films with chitosan offer a potential application in the food industry, considering the environmental sustainability that this type of biomaterials can offer. Bioplastic films incorporating chitosan, especially when combined with cassava starch, present great potential for application in the food industry. These biomaterials stand out for their ability to address environmental and sustainability challenges. Some key benefits they offer include their renewable origin, biodegradability, and the ability to reduce dependence on traditional petroleum-based plastics. The combination of chitosan and cassava starch in bioplastic films can not only improve moisture and fat barrier properties but can also extend the shelf life of food, reducing food waste. These biodegradable films can reduce plastic pollution and relieve pressure on landfills and the environment.

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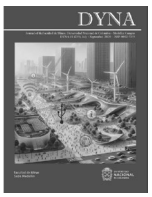

UNIVERSIDAD NACIONAL DE COLOMBIA

# Conceptual design of tailings dam and stability assessment

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**Abstract**
This work aims to present and discuss a conceptual project of mining tailings dam. Therefore, specific topics on tailings dams are visited and the characterization of materials constituting such structure is reviewed in the literature. Based on parameters available in the literature, a hypothetical dam was schematized and its stability was assessed via computational analysis (limit equilibrium and finite element flow analysis). Assessing eventual design changes (additional dam heightening) and hypothetical situations (collapses in the internal drainage), it is concluded that the schematic conceptual design presents itself viable and stable given the proposed geometry and the properties of materials considered. The importance of the internal drainage system for the dam´s stability was also identified.

*Keywords*: tailings dam; conceptual design; stability analysis.

# Diseño conceptual de la presa de colas y evaluación de estabilidad

**Resumen**
Este trabajo tiene como objetivo presentar y discutir un proyecto conceptual de presa de relaves mineros. Por lo tanto, se abordan temas específicos sobre presas de relaves y se revisa la caracterización de los materiales que constituyen dicha estructura en la literatura. Con base en parámetros disponibles en la literatura, se esquematizó una presa hipotética y se evaluó su estabilidad mediante análisis computacionales (equilibrio límite y análisis de flujo de elementos finitos). Al evaluar posibles cambios en el diseño (aumento de altura de la presa) y situaciones hipotéticas (colapsos en el drenaje interno), se concluye que el diseño conceptual esquemático se presenta viable y estable dada la geometría propuesta y las propiedades de los materiales considerados. También se identificó la importancia del sistema de drenaje interno para la estabilidad de la presa.

*Palabras clave:* presa de relaves; diseño conceptual; análisis de estabilidad.

## 1 Introduction

Tailings dams are considered some of the largest man-made geotechnical structures. They have the purpose of disposing tailings from mining. Kossoff et al. [1] define tailings as the mixture of comminuted rock and fluids from the beneficiation process, presenting as a physical characteristic fine grain size and angular shape, and chemical composition dependent on the composition of the rock matrix and the reagents used in the process.

Typically, three basic construction methods are identified: upstream, downstream or centerline. These methods refer to the lifting technique and direction used. In the methods of raising the centerline and upstream, the upgrades are carried out partially over already disposed tailings. Although it generates significant savings with earth movement (less volume of material is used to the construction of the dam), it brings some complexity regarding the constructive control of the dam and the execution and control of drainage.

Azam and Li [2] present a worldwide history of failures in mining dams, where according to the authors' review, about 1.2% of mining dams presented some type of failure, against 0.01% of civil dams, in the last hundred years. In view of the aforementioned, the need for a full understanding of all the contours related to tailings dams and the correct conceptualization of the project to be developed is implicit. Curretly, several authors have attributed failures in tailings dams to construction and design problems, causing a generalized rupture [2–7].

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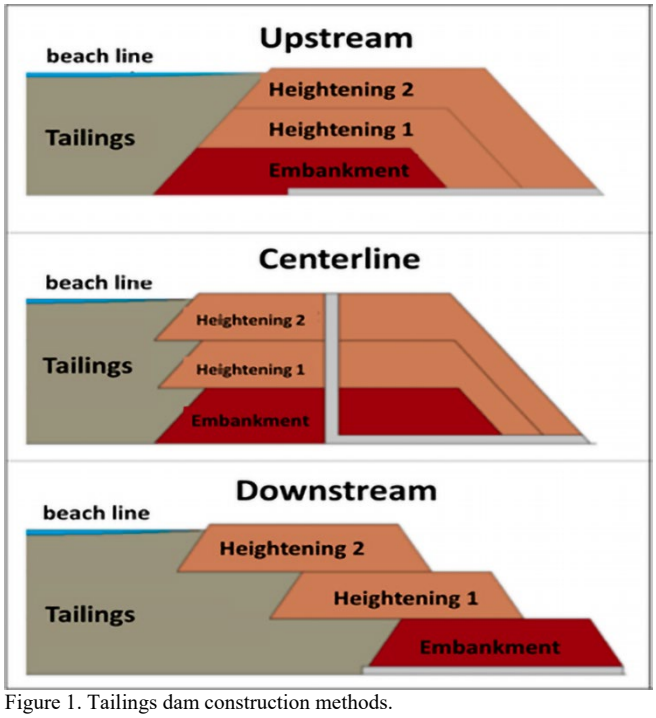


Figure 1. Tailings dam construction methods.
Source: Author

In this sense, considering the complexity of the theme and the latest incidents, the present work aims to evaluate the safety of a tailings dam executed by the upstream raising method.

### *1.1 Construction methods for tailings dams*

There are three basic construction methods for tailings dams, although a combination of two or all three methods is common. These methods refer to the raising technique and direction used, whether upstream, downstream or along a centerline. These dams can be built with material from borrow areas or with the tailings from processing, provided they have been treated and meet the geotechnical specifications of the project. To this end, this tailings can be subjected to additional processes such as cycloning, for desliming, and is then called a hydraulic embankment [7]. De Araújo [8] comments that in the use of hydrocyclones, in his case study, the underflow (outlet with coarser material) has a percentage of 78% solids by weight and the overflow has 35%. As it is the portion with the lowest humidity and is typically more granular, the product from the underflow is destined for use as construction material for the elevations.

Fig. 1 shows the construction methods typically used in tailings dams.

As Fig. 1 shows, different from the downstream heightening method, in the centerline and upstream heightening methods, the heightening is carried out partially on tailings that have already been disposed of. Although this generates significant savings in earthmoving (there is a smaller volume of material used to build the dam), it brings a certain complexity in terms of constructive control of the dam and the execution and control of drainage.

## 2 Conceptual project

A conceptual study of a gold mine [9] was taken as a basis, where the systematic development from geological modeling, mine planning, processing and final configuration is presented. However, the disposal of tailings is not addressed. Thus, based on the study by Bicca et al. [9], there is a need to design technology for the disposal of generated tailings typically disposed in dams, in order to minimize the area impacted by this disposal. According to this study, due to the type of ore and beneficiation process (gold), practically all the tonnage of mined ore (which has gold content that makes it possible to process it) is processed and finally disposed of in the tailings dam. Considering an average gold content of 2.1 ppm (or grams of gold per ton of ore), it is clear that from each ton benefited only 2.1 grams on average will be product and will not be destined to the tailings dam. The rocks with no mineable content are destined directly into the sterile pile, without undergoing beneficiation.

Considering the mining planning, which aims at the best use of mineral resources and optimization of production processes, including the optimization of beneficiation, it is aimed a uniform production throughout the operation (life of the mine), and also the supply of ore at a relatively uniform rate to the beneficiation plant. Thus, except for anomalous situations (production failures, shutdowns, among others), there is a continuous annual generation of 1.45 million tons of tailings, with an average annual increase of 2.6 million tons, over the 13 years of operation.

The processes of beneficiation and concentration of gold ore are mainly comminution (crushing and grinding), physical-chemical (flotation), hydrometallurgy (leaching) and liquid-solid separation (thickening). The grinding process is more responsible for reducing the particle size and other processes by the addition of water, and finally the leaching and flotation processes (by the addition of reagents) are also responsible for changing the physicochemical properties of the generated waste.

### *2.1 Dam conceptualization*

In the absence of data to adequately size the dam height, which should be sized according to the disposal rate and the elevation according to the topography of the site chosen for disposal, also in the absence of characterization of the materials to be used, for the conceptual design, parameters based on literature were adopted. In a conceptual way, in the absence of a specific dam location, which due to the topography would allow the dam height to be determined according to the occupied area. Table 1 presents an estimate of the occupied area and dam height, considering hypothetically a dam on flat terrain (which increases considerably the area occupied by the tailings).

Table 1.
Relationship between occupied area, average terrain slope and dam height.

| Occupied Area (ha) | Dam Height (m) |
|---|---|
| 60,57 | 30 |
| 45,43 | 40 |
| 36,34 | 50 |

Source: Author

As for geometry and properties of the dam, a range of case studies is available in the literature. Regarding to material characterization (beneficiation tailings) and geometries adopted, works of Silva et al. [8], Albuquerque Filho [10], Naeini and Akhtarpour [11], Rafael and Romanel [4], and Rout, Sahoo and Das [6] were consulted. Such works present characterizations of tailings from different ores (iron, copper and aluminum) and dam geometries. It should be noted that none of the studies listed above is explanatory as to the filter and/or drainage system used and its dimensions, however several textbooks [12,13] present options for drainage design configurations for earth dams (applicable to tailings dams) and filter sizing (referring to particle sizes).

It is also observed that the same materials (tailings), from mines of the same ore, have variability of geotechnical parameters, a fact that goes against the different beneficiation processes, which are responsible for giving the materials different geotechnical and hydraulic characteristics, such as demonstrates the work of Silva et al. [8]. This is due to the different processing routes, which comminute an ore in different particle sizes and use different reagents in the physical-chemical concentration processes.

To determine the hydraulic parameters of the materials that make up the structure (heightening and tailings), an option to laboratory tests or field tests, is the use of mathematical models for indirect determination of the parameters (kh, kv and/or kh/ratio) as presented by Shamsai et al. [14].

### *2.2 Parameters and assumptions adopted*

Although most of the studies listed above deal with metal ore tailings, it was decided to use them as a basis for the development of the project, above all regarding the geometry and scale magnitude for the geotechnical properties of the design materials. It was decided to adopt, in a conservative way, geotechnical parameters with values close to the lowest values verified in the bibliography, since these referred to iron ore and copper tailings.

For the project, it was decided to consider dams made up of five materials (foundation, soft clay, landfill, disposed tailings and dense tailings) with properties according to Fig. 2, so that the parameters considered do not differ from the reality presented by real materials, although, for simplification, it was decided to consider isotropic materials.

As a construction method, due to its greater relevance (greater use for tailings dams) and economy (constructive, requiring less earth movement), as previously mentioned, the Upstream method of raising was chosen. Using elevations of 10 (ten) meters interspersed with benches of 10 (ten) meters, the slopes being considered with an inclination of 25°. As a preliminary project, a dam with 4 elevations was considered, totaling a global dam of 40 meters high. For the configuration of the tailings beach, the design parameters were used according to Silva [8] and Araújo [15], who based on empirical and observational models, considered in their studies the existence of two distinct phases, where the submerged portion presents greater inclination in relation to the emerged portion. This phenomenon is well described in works such as those by Araújo [15] and Machado [16], where they cite Vick apud Araújo [15].

| Material Name | Color | Unit Weight (kN/m3) | Strength Type | Cohesion (kN/m2) | Phi | KS (m/s) | K2/K1 | K1 Angle |
|---|---|---|---|---|---|---|---|---|
| landfill | | 19 | Mohr-Coulomb | 10 | 36 | 1e-007 | 1 | 0 |
| filter/drain | | 20 | Mohr-Coulomb | 0 | 37 | 0.001 | 1 | 0 |
| dense tailings | | 18 | Mohr-Coulomb | 0 | 32 | 3.47e-006 | 1 | 0 |
| disposed tailings | | 18 | Mohr-Coulomb | 0 | 20 | 3e-005 | 1 | 0 |
| foundation | | 20 | Mohr-Coulomb | 19 | 35 | 5e-006 | 1 | 0 |
| soft clay | | 15 | Mohr-Coulomb | 18 | 0 | 5e-006 | 1 | 0 |

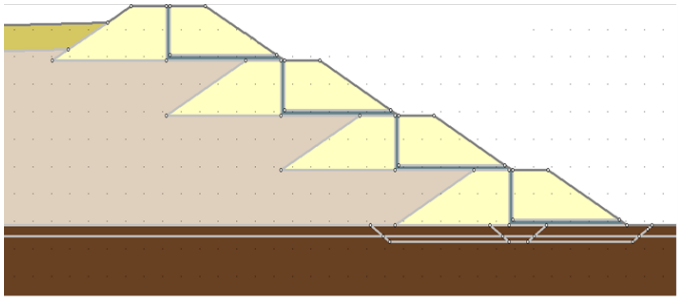

Figure 2. Dam layout and construction materials (software Slide).
Source: Author

As for the configuration of the tailings disposal, a tailing beach of 150 meters in length was considered between the theoretical pivot point of the tailings, at the dam, and the water line over which the tailings are submerged, typically with greater angulation as discussed by Silva [8]. As for the slopes adopted, a slope (i) of 0.5% was considered for the emerged tailings and 3.0% for the submerged tailings. Subsequently, the hypothesis of a water line under the tailings was observed, that is, a situation of greater risk and greater requirement for a filter/drainage system.

Regarding to the filter/drainage system, a chimney drain with a blanket was used in the project, in order to cover half of the foot and the entire central extension of the elevation, thus enabling its continuity during the elevations. The use of foot filters was also analyzed, as well as the option without a filter (hypothetical, system collapse). Fig. 1 shows the configuration of the proposed dam and a table with the constituent materials of the model.

## 3 Stability analysis

For the stability analysis of the dam project and design variations, limit equilibrium analyses were carried out using the software Slide 6. The piezometric line, hydraulic gradients and pore pressure distribution were determined in the same software, by numerical method, and later used in the analytical analysis, where they are influential in determining the Safety Factors (SF). For all analyzes, the Mohr-Coulomb rupture criterion was used. For the calculation of all safety factors, the Morgenstern-Price method was used, using a 50-slices discretization. This method was chosen because it is considered a rigorous method that adapts to different rupture surfaces and complex cases with different materials.

Regarding to the determination of parameters associated with the water flow, these were determined by considering a

discretization by 4000 nodes and triangular elements, for all analyzes. These hydraulic parameters are determined by the software.

### *3.1 Project options*

A dam project has several options and geometry solutions that can change the dam performance in different ways, typically the most evaluated aspect is the Safety Factor (SF), however other aspects such as the percolation of water by the massif (dam), pore pressure stresses and hydraulic gradients, must also be evaluated and may be of extreme interest when evaluating the piping and liquefaction phenomena.

To the project in question, it was decided to evaluate the variation of the water line or "tailings beach" position, and its influence on the stability of the dam; as well as the internal drainage system of the dam, by foot drain system and by its hypothetical failure. The hypothesis of an additional elevation and the existence of a low resistance layer on the foundation was also evaluated.

### *3.2 Analysis results*

#### *3.2.1 Ideal conditions*

Ideal situations were considered as a reference model, without the need for foundation treatment, systems and an internal drainage connected to the foot and center of the slope, and mainly the "tailing beach" 150 meters away from the last slope. In such a situation we have an S.F. of 2.246. Fig. 3A shows the rupture surface and piezometric line, and Fig. 3B shows the pore pressure distribution.

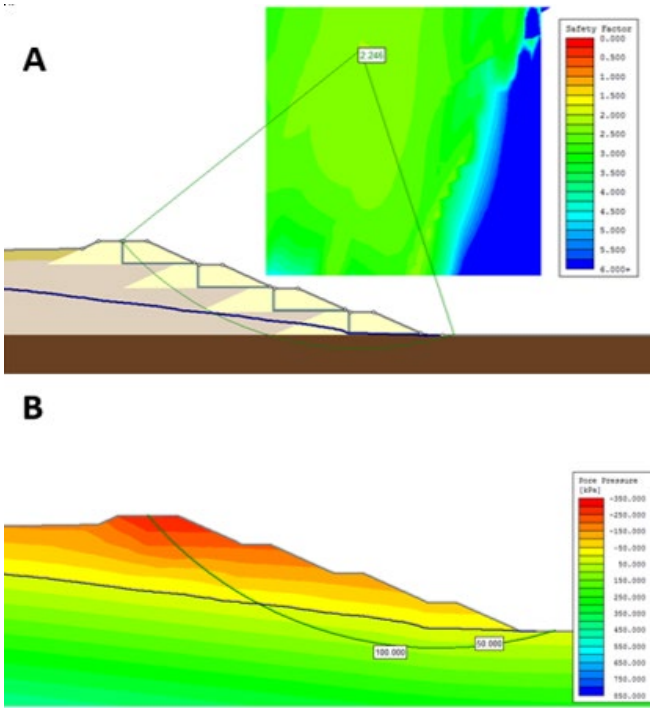


Figure 3. (A) Rupture surface in the dam in ideal situation and, (B) corresponding pore pressure distribution.
Source: Author

#### *3.2.2 Scenario with water line under the tailings*

For the analysis of the limit situation, the hypothesis of eliminating the tailings beach and raising the water level in the dam to 1.5 meters upper the tailings was evaluated (Fig. 3A). This hypothesis, as shown in Fig. 4, moves the piezometric line to the internal side of the dam. Fig. 4A shows the rupture surface, with 2.054 S.F., and Figs. 4B and 4C show the pore pressure distribution and hydraulic gradient at the base of the dam, respectively. This hypothesis is maintained in the following analyzes since it represents a risky scenario in comparison with the adequate distance from the "tailings beach" of the dam.

#### *3.2.3 Scenario with water line under the tailings and hypothesis of drainage system collapse*

In addition to the previous situation, a hypothetical collapse of internal drains was considered. This situation is considered to be the limit. In such a situation, an S.F. of 1.767 is estimated, as shown in Fig. 5A, however, such configuration represents concentration of hydraulic gradient and upward flow of water, as shown in Fig. 5C, situations that generate piping and liquefaction.

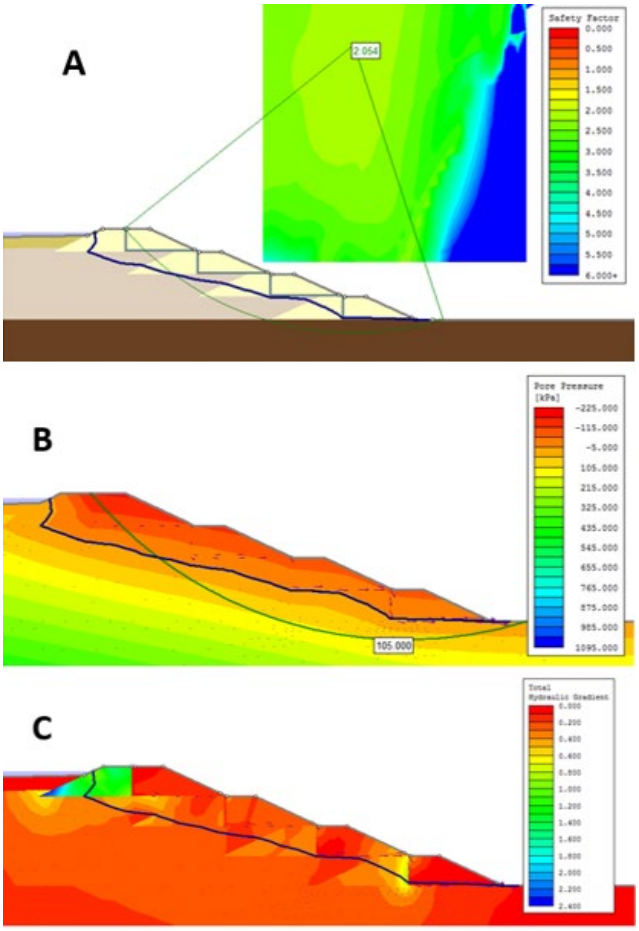


Figure 4 - (A) Rupture surface in the hypothesis of water level above 1.5 meters, (B) respective pore pressure distribution and (C) hydraulic gradient in the first dam.
Source: Author

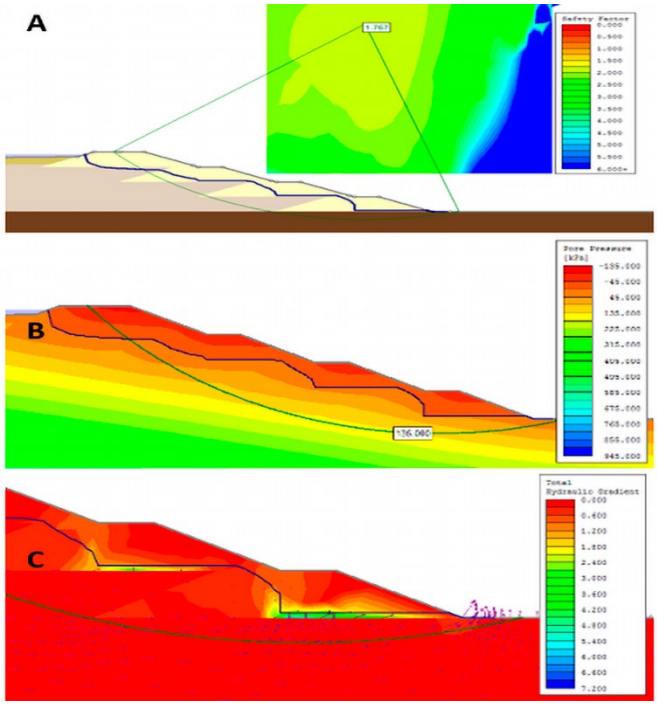


Figure 5 – (A) Rupture surface in hypothesis of collapse of internal drainage system and water level above the tailings, (B) respective pore pressure distribution and (C) accumulation of hydraulic gradient and internal water flow.
Source: Author

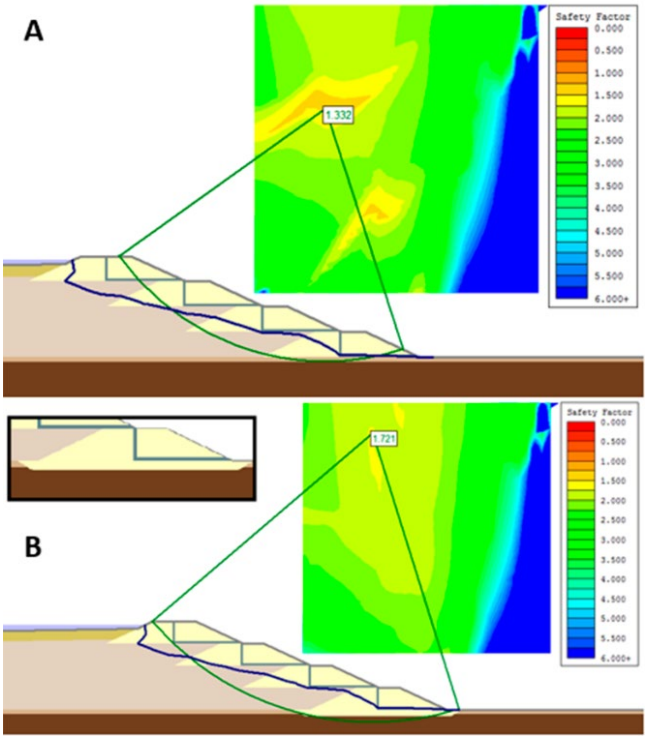


Figure 6. (A) Rupture surface and S.F. in the scenario of occurrence of "soft clay" layer under the dam and (B) Rupture surface and S.F. after treatment of the initial dike foundation.
Source: Author

### 3.2.4 *Scenario with dam foundation under soft clay and subsequent foundation treatment (by partial layer replacement)*

In this scenario, the hypothetical occurrence of a soft clay layer (low strength) in the foundation of the dam, dike and tailings was considered. The hypothetical layer presents a thickness of 2 meters, considering it in the analysis we would have an S.F. of 1.332 and a rupture surface that would pass exactly through it (Fig. 6A). Considering a certain treatment of the foundation, by removing and replacing the layer under the initial dike, and advancing 1 meter under it, that is, crossing the layer. Fig. 6B shows the situation with the treatment of the foundation and its S.F. of 1.721.

### 3.2.5 *Blanket drainage system with water line under the tailings (1.5 meters above the tailings)*

This scenario was analyzed as an alternative configuration of drainage/filter system inside the dam, in order to evaluate both as a design option and as a hypothesis of eventual impairment of the vertical portion of the drainage/filter system. For that, in the model, only filter/drain of the "bar foot" type was considered. The hypothesis of a water level above the tailings was maintained. Fig. 7A shows the rupture surface and the piezometric surface line of the dam, where an S.F. of 1.994 was calculated. In Fig.s 7B and 7C, the pore pressure and hydraulic gradient distribution in the dam are represented.

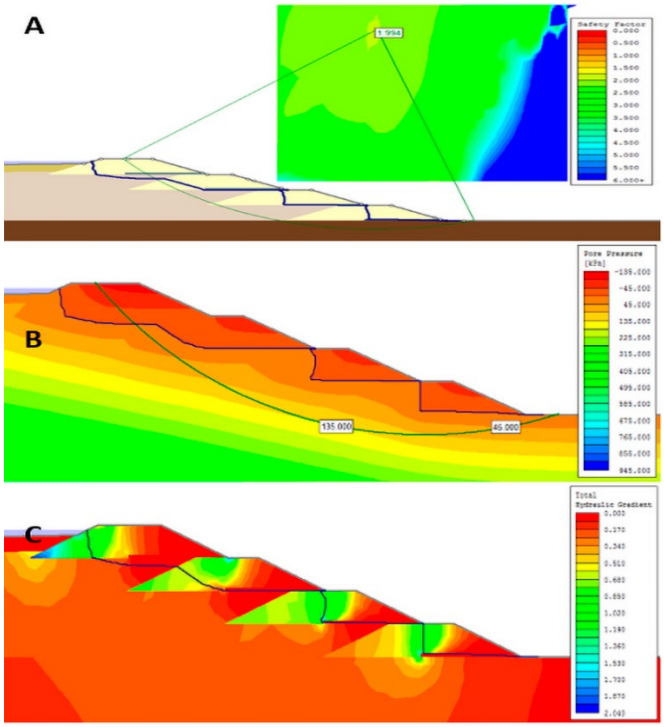


Figure 7. (A) Rupture surface in blanket drainage option and water level above the tailings, (B) respective pore pressure distribution and (C) hydraulic gradient accumulation.
Source: Author

### 3.2.6 *Blanket drainage system only on initial dike and water line under the tailings (1.5 meters above the tailings)*

In this scenario, the option for an internal drainage/filter only in the initial dam was analyzed. The hypothesis of a water level above the tailings was maintained. Fig. 8A shows the rupture surface and piezometric line of the dam, where an S.F. of 1.942 is calculated. In Figs. 8B and 8C, the pore pressure and hydraulic gradient distribution in the dam are represented.

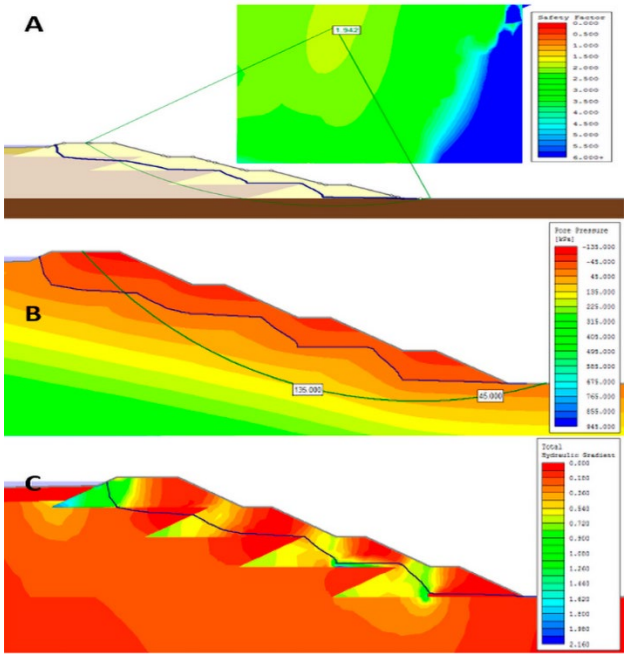


Figure 8. (A) Rupture surface in blanket drainage option only in initial dike and water level above the tailings, (B) respective pore pressure distribution and (C) hydraulic gradient accumulation.
Source: Author

### 3.2.7 *Project Scenario considering additional heightening (5 heightening) and with a waterline under the tailings (1.5 meters above the tailings)*

In this scenario, the hypothesis of an additional heightening of the dam and its impact on stability was analyzed. The hypothesis of a water level above the tailings was maintained. Fig. 9A shows the rupture surface and piezometric water line of the dam, where an S.F. of 1.899 is calculated. In Figs. 9B and 9C, the pore pressure and hydraulic gradient distribution in the dam are represented.

### 3.2.8 *Project Scenario considering additional heightening (5 heightening) and with a water line at 150 meters from the dam*

In this scenario, the hypothesis of an additional heightening of the dam and its impact on stability was analyzed. In this analysis, the "tailings beach" was located 150 meters from the dam.

Fig. 10A shows the rupture surface and piezometric line of the dam, where an S.F. of 2.105 is calculated. In Figs. 10B and 10C, the distribution of pore pressure and hydraulic gradient in the dam are represented. There is a reduction in pore pressure compared to the previous situation.

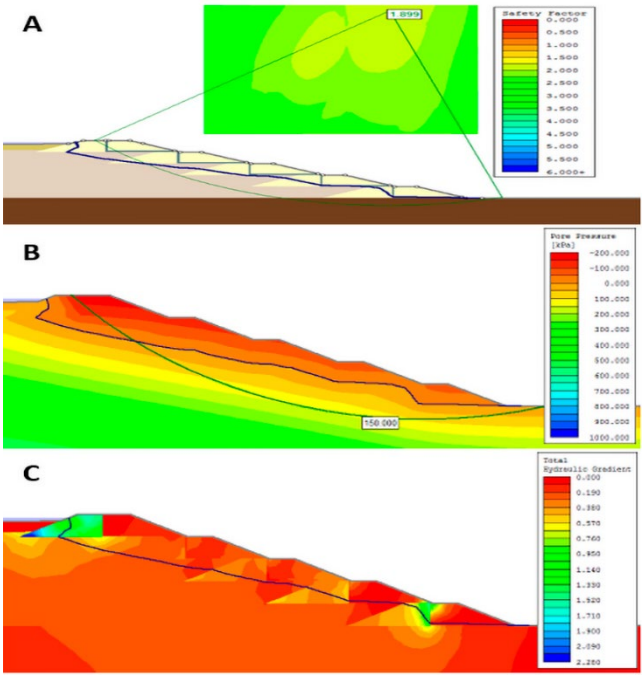


Figure 9. (A) Rupture surface in the event of additional heightening and water level above 1.5 meters, (B) respective pressure distribution and (C) hydraulic gradient.
Source: Author

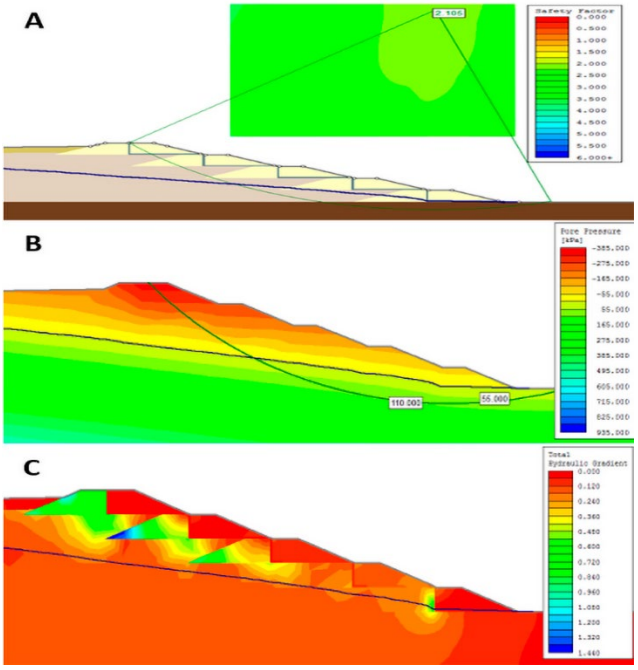


Figure 10. (A) Rupture surface in the hypothesis of additional heightening and water line at 150 meters from the dam, (B) respective pore pressure distribution and (C) hydraulic gradient.
Source: Author

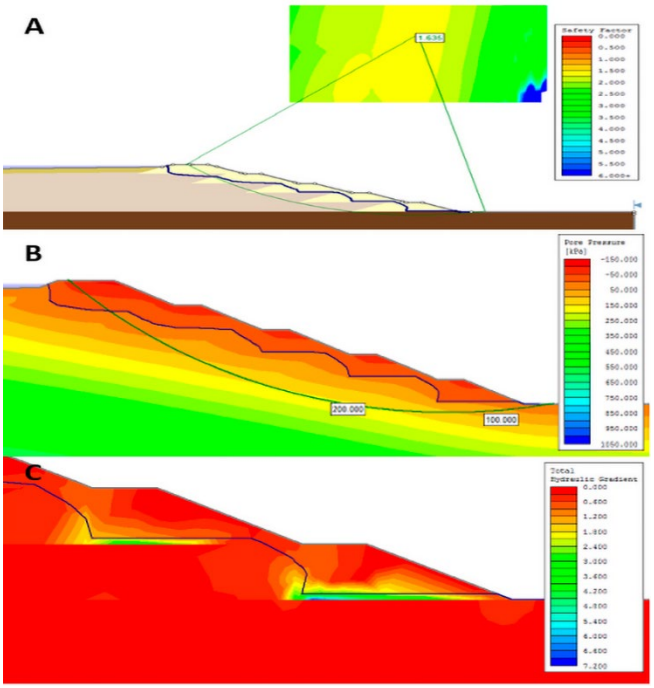


Figure 11. (A) Rupture surface under the assumption of internal drainage system and water level above the tailings, (B) respective pore pressure distribution and (C) accumulation of hydraulic gradient and internal water flow.
Source: Author

#### *3.2.9 Project Scenario considering additional heightening (5 heightening), with water line at 150 meters from the dam and hypothesis of drainage/filter system collapse*

In this analysis, besides the additional heightening and water level above the tailings, a hypothetical internal drainage collapse was considered. This situation is considered to be the limit.

In this situation, an S.F. of 1.635 is estimated, according to Fig. 11A; however, configuration represents hydraulic gradient concentration, as shown in Fig. 11C.

### *3.3 Analysis of results*

The suggested tailings dam project met the safety requirements by the analytical method used, Limit Equilibrium. Under ideal operating conditions, water line at 150 m from the dam and internal drainage/filters in the proper configuration, the project presents a Safety Factor (S.F.) of 2.2; while under adverse conditions (collapse of internal drainage system and elevation of the water level), it still presents an S.F. of 1.8.

Although considering that the values obtained in the S.F.'s are above those recommended by standard (S.F. between 1.2 and 1.5), and thus the project is considered acceptable, other factors must be taken into account. First, since it is a hypothetical dam, several variables (topography, geology, materials, among others) are uncertainties. In this study, all parameters were estimated from the literature, while a real tailings dam project will certainly have laboratory test data to support the proposed solutions and access to greater resources for analysis.

Regarding to the analyzed scenarios, as expected, impacts on the S.F.'s, concentration of hydraulic gradients and pore pressures were verified; with variations in water level and position (tailing beach) and according to the internal drainage configuration. A scenario with an additional heightening (for a total of five heightening) was analyzed, raising the dam to a final relative height of 50 m. In this case, there is an S.F. of 2.1 in an ideal situation and an S.F. of 1.6 under adverse conditions, still within the safety limits.

Regarding to hydraulic gradients and pore pressures, it appears that these were sensitive to the changes tested. The lower dams and the internal filters are the most critical positions. As for pore pressure, it can be seen that in the proposed scenarios there was a variation along the critical rupture surface. These scenarios could (in the case of critical hydraulic gradients) cause triggers that lead to a dam rupture.

Based on the above analyses, it appears that the best measure to be taken to ensure the safety of the project is to move the water line away from the dam, which not only increases the dam's safety factors, but also reduces the pore pressures and hydraulic gradients. As for the internal filter/drainage systems, three options were evaluated: chimney drain with blanket, horizontal blanket drain and blanket drain only in the initial dike. According to the analysis carried out, a chimney drain with a blanket not only guarantees the highest safety factor, but also results in the smallest pore pressures within the dam slope and, is therefore, the most recommended option. The last analysis to be made would refer to safety due to liquefaction and piping; however, considering the design using a chimney drain with a blanket system in all heightening, and the respective hydraulic gradients (lower than the other options), which reduces the risk of landfill liquefaction; the dam can be considered stable at the level of the conceptual design.

## 4 Conclusion

The work showed the design of a tailings dam at the end of the mine operation, considering four heightening in ideal operating conditions (150 m away from the tailings beach and proper operation of the filters). In this condition, the dam has a S.F. of 2.25. Throughout the work, the effect of different variants that can occur during the operation of the dam was shown, including: (a) the increase of the water level almost to the crest of the dam, (b) problems with malfunctioning filters, (c) occurrence of soft clay in the foundation not detected in the design phase, (d) execution of a heightening level more than initially projected. All the analyzed conditions are responsible for the reduction of S.F. and may even reach values lower than those established by the standards. In this sense, it should be noted that such constraints must be taken into account in the project, as well as it is essential to ensure the proper functioning of all devices of a tailings dam (for example: filters), combined with an adequate periodic inspection (for example: measurement of piezometric levels).

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# Identification of short term Fast-Slow patterns using the Nasdaq-100 future through a technical analysis application

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**Abstract**
In recent decades, the analysis of atypical behavior in asset prices has become relevant, since participants in financial markets recognize that the idea of perfect markets is distanced from reality. The purpose of this research is to present a trading strategy through the identification of short-term chart patterns, based on anomalies in the future price of the Nasdaq-100 index. The historical backtesting methodology will be used in the technical analysis of the asset to quantify the performance of the identified patterns. It will be verified that the anomalies in the stock index are not temporary; rather, they persist and recur on a recurring basis, especially in intraday events. Additionally, the best performing trading session will be determined. This work will provide retail traders with trading guidelines to approach the markets with a statistically profitable strategy.

*Keywords*: Nasdaq-100; market anomalies; futures market; technical analysis.

# Identificación de patrones Fast-Slow de corto plazo empleando el futuro del Nasdaq-100 a través de una aplicación de análisis técnico

**Resumen**
En las últimas décadas, ha tomado relevancia el análisis de comportamientos atípicos en los precios de activos, ya que los participantes en los mercados financieros reconocen que la idea de mercados perfectos se distancia de la realidad. El propósito de esta investigación es presentar una estrategia de negociación a través de la identificación de patrones gráficos a corto plazo, basados en anomalías en la cotización del futuro del índice Nasdaq-100. Se empleará la metodología de backtesting histórico en el análisis técnico del activo para cuantificar el rendimiento de los patrones identificados. Se comprobará que las anomalías en el índice bursátil no son pasajeras; más bien, persisten y se repiten de forma recurrente, especialmente en eventos intradía. Además, se determinará la sesión bursátil de mejor rendimiento. Este trabajo brindará a los traders minoristas pautas de negociación para abordar los mercados con una estrategia estadísticamente rentable.

*Palabras clave*: Nasdaq-100; anomalías de mercado; mercado de futuros; análisis técnico.

## 1 Introduction

Traditionally, investors in the financial markets base their investment decisions on two main lines of analysis, with the objective of correctly selecting assets and determining the best time to do so: fundamental analysis and technical analysis. Fundamental analysis is in charge of the study of macro and micro economic forces that can affect the behavior of an economy to a greater or lesser extent, as well as the behavior of industries and sectors, including the analysis of the financial results of companies (Abarbanell and Bushee, 1997). Technical analysis, on the other hand, is responsible for the study of price movements, analyzes and identifies repetitive events in the history of the price with the objective of establishing future behaviors in price trends, the study is based mainly on analyzing historical charts [1]

The formation of chart patterns or chartism is one of the branches of technical analysis, on which this study will be developed. A chart pattern is a formation that builds the historical price of an asset and according to the fulfillment of

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certain criteria can generate a buy or sell signal. Patterns are classified into two groups, which in turn contain multiple variations: continuation and reversal formations. The continuation pattern signals that the previous trend will continue and that the strength of the movement in that direction is in place. The reversal pattern signals that once the pattern has been fully formed, the direction of the market will change, i.e., it will take the opposite trend to the one it had before formed [2]. The graphic pattern under study, given its characteristics and according to the scenario in which it is formed, can confirm a trading signal for continuation or reversal of the asset's movement; likewise, it generates reliability in contexts of high and low volatility.

Graphical patterns and other events observed in asset prices reflect behaviors or phenomena that are considered anomalous, Grossman and Stiglitz spoke of a series of events that make no apparent sense and cannot be demonstrated by traditional theory, these events that have no initial foundations and that are considered abnormalities open a wide spectrum of possible findings that the present study intends to explore [3]. These authors are the main exponents of financial anomalies, they consider that markets are informationally inefficient, this due to the fact that the various agents live with a clear asymmetry of information with respect to other actors, Grossman and Stiglitz oppose classical theories such as that of Fama with the Efficient Market Hypothesis (EMH) where he states that the market price of assets is traded at fair value and reflect with a good estimate their intrinsic price at a given time [4].

Recent decades have seen the awakening of a strong interest in the research field in deciphering the reasons why these unknown events are generated. The importance of these trends makes sense when the impact they have on the behavior of agents in the stock market is measured. The financial markets are made up of two large groups of participants that inject liquidity into the continuous dynamics of buying and selling assets. These two groups are institutional traders and retail traders; the latter group has clear disadvantages with respect to the former because they have limited capital, infrastructure and information, and mostly low efficiency investment and speculation strategies, thus being at the mercy of large investors who have more information and investment capacity [5].

In the speculative field, the main difference between the two groups refers to the fact that the institutional trader can resist a movement against the market without releasing or liquidating his positions, that is to say, he can remain in the market without having to materialize the associated losses and have the balance of his open operations temporarily in the red. This is unthinkable for the retail trader, because for him any moderately deep movement made by the market against his position can mean a great loss of his account, so he designs strategies to cut losses relatively soon. Another aspect to consider and that opposes against the group of retail investors and has a strong impact, reducing their account balances, are the transaction costs [6]. Institutional and retail have similar transaction costs and no difference is made between the size of their accounts [7].

In addition to the above, there is a lack of an investment strategy that allows them to compete. Thus, the retailer buys and sells assets with diverse motivations that in many cases do not have a structured decision-making process. Contrary to this, the institutional ones have professionalized, robust and complex investment systems [8], which allow them to participate in the markets with profitable strategies and favorable conditions. This does not necessarily lead retailers to fail, on the contrary, it is a window that opens and that this study wishes to take advantage of.

For the above reasons, this research is important because it focuses on reducing the gap between the two types of participants, it wants to provide a contribution to retailers, specifically it tries to fill the void that exists in terms of ways or forms of negotiation of this type of traders, that is, through the identification of technical analysis patterns for trading in the short term (understood as the 24 hours that make up a trading day, divided into three major sessions, the Asian, European and American) and under a series of defined rules, the retail trader may have a trading strategy with a proven statistical advantage.

The analysis of the strategy will be done through the construction of a historical backtesting applied to the future of the Nasdaq-100 index, where the behavior of the graphic patterns will be simulated in an established time frame in order to quantify its profitability, confirm the optimal trading session and determine whether these phenomena could be classified as a technical anomaly. The patterns that the study proposes to identify have not been found in similar academic research, and empirically it can be said that this is an unusual and unconventional way of approaching trading in financial markets.

The document is divided into three parts. The first part deals with the efficient market hypothesis regarding market anomalies and their different types, as well as the variables that make up the strategy based on graphic patterns. The second stage describes how the identification and interaction between the variables that form the patterns under study is generated and in the third stage, the results obtained from the identification, its global profitability and its disaggregated profitability for the different stock market trading sessions are presented, and it is determined whether it can be considered a technical market anomaly and, finally, some conclusions are presented.

## 2 Theoretical Framework

### *2.1 The efficient markets hypothesis*

Eugene Fama, proposed the EMH [4], suggesting that markets are rational and informationally efficient when the interaction among participants leads to an equilibrium situation where asset prices reflect all available information and quickly incorporate new information as it emerges into the price. These ideal trading conditions assume that no investor can beat the market by generating returns that could be considered unusual. Fama divides his hypothesis into three categories. Weak efficiency" is based entirely on the historical series of prices, where each asset sees reflected in its value all available information without the possibility of predicting future price behavior. The "semi-strong efficiency", in addition to the historical information, has the capacity to reflect all the new relevant information that

becomes public. Finally, "strong efficiency", in addition to historical and public information, involves private information, which indicates that as efficiency goes from weak to strong, the possibilities of obtaining extraordinary and continuous returns over time are exhausted.

Now, in the stock markets there is evidence that asset prices do not follow the principles of efficient and rational markets, the three degrees of efficiency are not fully met as mentioned by Fama, the day-to-day stock market reflects those prices draw deviations to the guidelines previously proposed [9]. Such deviations are known as market anomalies since they are abnormalities that occur within perfect markets.

### *2.2 Market Anomalies*

The EMH is antagonized by the model developed by Grossman and Stiglitz, which suggests that informationally efficient markets can never be efficient, i.e., that they are inefficient. This condition is the result of the imbalance generated by an asymmetry in information, which indicates that the flow of information does not reach all investors in the same way [3]. This means that not all participants are well informed and therefore prices reflect partial information, causing the profitability of each individual to vary according to the degree of advantage obtained in decision making. The model also clarifies that information travels with a lag from informed individuals to uninformed individuals, which means that the first can make more intelligent investment decisions.

Now, anomalies are the indicator of inefficient markets, everything that is not explained by the efficiency hypothesis is considered an anomaly, i.e., deviations that occur and do not follow the rules of perfect markets, some of them occur once, or a few times and disappear, while others are identified and recurrently remain over the years. According to Kuhn [10], an anomaly is systematic evidence of prolonged episodes with a regularly recurring structure and does not respond to isolated events, however, it does not find consistency with the basic theory. For their part, Tversky & Kahneman (1986) defined an anomaly as a deviation to currently accepted paradigms, which is too widespread to be ignored, too systematic to be dismissed as a random error and too fundamental to be accommodated at the cost of weakening the normative framework [11].

Therefore, if an unknown phenomenon occurs once or very rarely, even if it is initially classified as an anomaly, this condition is only ratified if it meets certain characteristics. According to Tua [12], for an anomaly to be considered an inefficient market sample, it must meet two requirements: persistence and opportunity to be exploited. Anomalies are classified into three categories, fundamental, calendar and technical. A fundamental anomaly is an irregularity where the return on the securities differs from the actual valuation of the asset. Calendar anomalies are those where the occurrence of certain events is directly related to specific times of the year and technical anomalies correspond to phenomena that are identified mainly through asset price charts where the aim is to predict future behavior based on events that have occurred with historical prices.

Classical authors have shared the research carried out in different stock markets delving into the subject of market anomalies and agree that the series of phenomena observed and analyzed in the different trading parks cannot be explained by market efficiency since they are unusual occurrences of prices. From these authors some early research emerge, from the calendar line we find Gultekin and Gultekin [13], Tversky and Kahneman [11], Ariel [14], Agrawal and Tandon [15], Smirlock and Starks [16]. For fundamental anomalies, Fama and French [4] and for technical anomalies, Brock, Lakonishok [17] stand out.

Gultekin and Gultekin [13] in their study found the existence of seasonality in the main stock markets of industrialized countries. Seasonality refers to the fact that there is a clear difference in average returns measured on a month-to-month basis. They used parametric and non-parametric methods for testing, but since the result between the methods was similar, they decided to report them with the non-parametric tests. The seasonality anomaly found was generally reflected in a significantly large average return at the end of the fiscal year.

Ariel has a direct impact on calendar anomalies [14], determining anomalous behavior for stocks, since they exhibit positive average returns only during the first half of the months, and show zero returns during the second half. His study focused on the U.S. stock market from 1963 to 1981. In turn, Agrawal and Tandon found two calendar anomalies, known as "the turn-of-the-month effect" and "the turn-of-the-year effect" [15]. In the first, during these four days that mark the change from one month to another, the yield is higher overall than that of the remaining days of the month. For the second anomaly describes the increase in stock prices in the last week of December and the first week of January.

From the point of view of technical anomalies, two of the most well-known technical analysis strategies, the moving average and the trading range breakout [18]. Applied to the Dow Jones between 1897 and 1986, they performed a statistical analysis with the bootstrap technique. They applied these tests on four models: the random walk, the AR (1), the GARCH-M and the exponential GARCH, concluding that the returns obtained when applying these two trading strategies with these models were not consistent. Sullivan took other popular analysis techniques, such as channel breaks, moving averages, supports and resistances, trading volume, chose measurement parameters for each, the objective was to establish as many rules as possible and determine which was the most profitable over a 100-year time span (1897-1996), and used the Dow Jones index [19]. They used Bootstrap to obtain the data that allowed them to quantify the performance of about 7,850 variables. The five-day moving average was the best rule with a 17.2% average annual return.

### *2.3 Nasdaq-100 Index*

The technology Nasdaq-100 (NDX) is one of the three most representative stock indexes of the North American stock market, along with the SP500 and the Dow Jones. It brings together 100 of the largest non-financial companies in terms of market capitalization, both domestic and international [19]. No company in the index can have a weighting of more than 24%. The Nasdaq-100 is an index

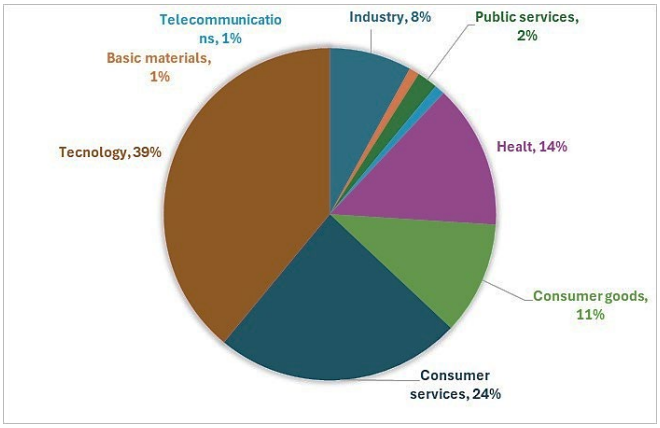


Figure 1. Nasdaq-100 Index Composition by Industry.
Source: Own Elaboration with data from Bloomberg (2020).

concentrated in the technology sector and it is there where the world's largest companies shine, it is also integrated by other large industries such as healthcare and consumer services. It is the world's fastest growing stock index by large capitalization, and since the 2008 crisis it has outperformed the SP500 index with higher annual returns and volatility (Nasdaq website). Observing that technology presents accelerated growth in the world and that its influence on companies is being decisive in obtaining better results and confirming through volatility calculations, the future of the Nasdaq-100 index is chosen to develop this research. Fig. 1 shows the composition of the Nasdaq-100 index by industry, a marked participation of technology companies is evident, which currently weigh 39%, and also shows an outstanding collaboration of the companies that make up the technology industries such as consumer services, health and consumer goods with weights of 24%, 14% and 11% respectively.

### *2.4 Strategy based on the Fast-Slow Pattern*

The graphic pattern under study arises from the continuous observation of the price behavior of various financial assets, and it is through constant analysis that rules or guidelines have been defined that the retail trader must abide by and execute in order to obtain results close to or similar to those that the research will reveal. The pattern is also the response to the non-institutional trader's need to have a competitive advantage when positioning himself ahead of the market. The operator will have in front of him a future price chart of the Nasdaq-100 in the form of Japanese candlesticks, which will take direction to make investment decisions through the guidelines that will be detailed below, these allow the trader to begin the construction of his work chart that will be interpreted as he identifies that the rules of his action plan are being created.

The trader who wishes to use the strategy based on the short-term Fast-Slow Pattern (hereinafter PFS), should identify and execute the purchase or sale of the Nasdaq-100 index future at the moment when the following three rules occur strictly and in order:

1. Identification and marking on the chart of the trading zones, which correspond to: the maximum and minimum price of the most recent Asian, European and American sessions, as well as the highest and lowest price of the trading day of the immediately previous day.
2. Formation of the Fast-Slow pattern over at least one of the established trading zones (rule 1).
3. Formation of one of the established Japanese candlestick patterns, which will be the trigger for market entry.

It is important to emphasize that the essence of the strategy is the formation of the Fast-Slow pattern, however, this will only be important when it is formed over one of the established trading zones, therefore the zones are the first element (rule 1) to be identified and marked on the asset's price chart.

### *2.5 Trading Zones and Trading Sessions*

Any price set by the financial asset can be negotiated (buy or sell), but a trader and especially a retailer cannot participate in the market at any price, that is to say, he cannot afford to buy and sell at the slightest variation in the quotation. Any trader using technical analysis will establish "his zone(s)" where he will seek to benefit from the fluctuations of the asset of his choice and from this choice derives much of his success. A trading zone (base zone) refers to a range of prices (several consecutive prices) and not to a specific one, this means that the final signal for the trader to participate in the market can occur at any price in the range. The size of the range is discretionary chosen by the trader. This study proposes to consider trading zones of which no previous research was found, and according to empirical evidence has an interesting potential to be explored.

Traditionally, the strategies that have within their components the identification of supports and resistances use the "price" factor for their plotting, that is, they will find for a certain reason a negotiation zone (price range) that allows them to define their entry to the market. The proposal presented in this document uses the price variable in a secondary place, the "time" variable has the leading role, since it is the time of the stock market day that will set the initial guideline for the drawing of the zone.

A trading day starts at 00.00 GMT and is divided into three trading days, the Asian, the European and the American. The Asian trading day starts and closes between 00.00-7.00 GMT, which is the trading hours when most of the stock exchanges of that continent are actively trading, and the other two sessions work in the same way, followed by the European stock exchanges from 7.00-13.30 and the American stock exchanges, with United States at the top, that start at 13.30 (summer time) or 14.30 (winter time), finishing operations at 20.00 or 21.00 depending on the time of the year. The period from 20/21.00-24.00 is considered a "dead" time as there is little or no trading activity. Each trading session is of high importance as it involves frantic competition between all types of participants. The listed time slots correspond to general trading ranges for each continent and to the opening and closing times of most stock exchanges, although there are some that, depending on their time of day, share activity with stock exchanges on other continents.

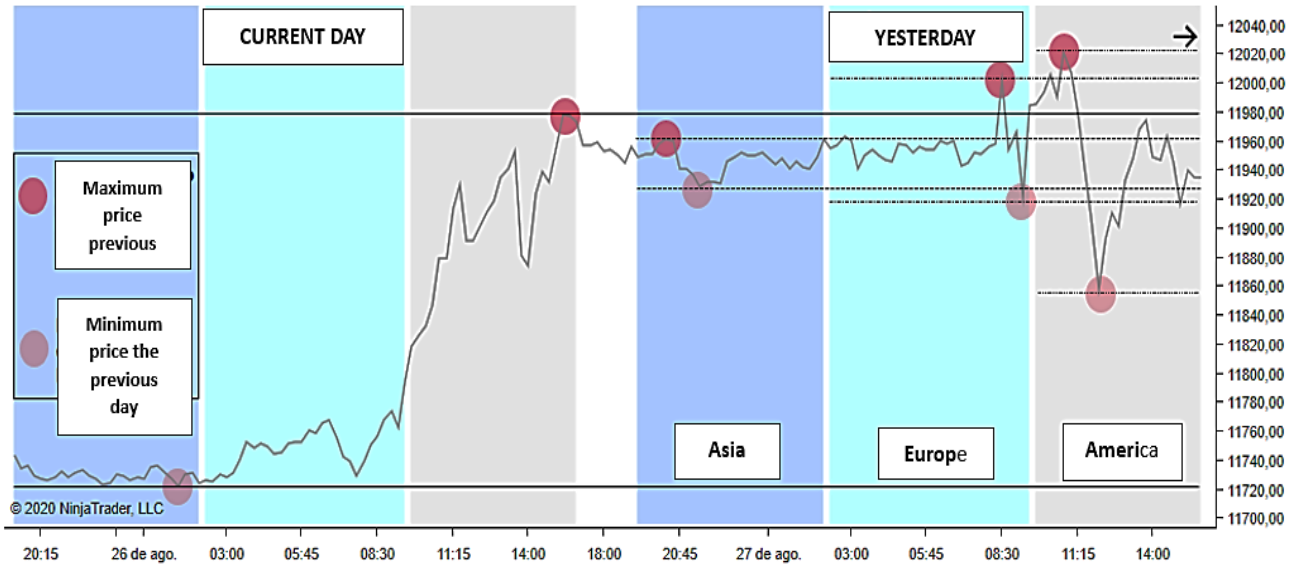


Figure 2. Trading Zones and Trading Sessions.
Source: Own Elaboration with Ninja Trader 8 Platform.

Fig. 2 shows the fluctuation of the price of the asset within the schedules of each of the sessions, which will mark and define clear and objective levels that will be used as trading zones, which correspond to the maximum and minimum prices of each band, i.e., each session will mark two zones. Also, the highest and lowest quote of the previous trading day are taken into consideration. According to the above, the trader will have eight potential objective trading zones in every moment, four tops (dark circles in the figure) and four bottoms (light circles in the figure). The most recent session of each time frame will always be used.

Having stated the above, the first rule of the strategy will be to have the potential trading zones defined at all times, and it will be on them that the observation of the price of the Nasdaq-100 index futures will be focused.

### *2.1 Fast-Slow Pattern (PFS)*

The essence of the PFS focuses on the "time" that the price takes to develop the movements that make it up. For a correct understanding of the graphical pattern under study, it is important to clarify that the historical price chart of a financial asset is composed of two variables, time (X-axis) and price (Y-axis). Their characteristics are described below:

1. It is composed of two movements, which will always be comparable to each other and which go in opposite directions, that is a first upward movement (A-B) and a second downward movement (B-C), the order of which can be reversed, bearish-bullish.
2. The formation and identification of the PFS must necessarily take place over a trading zone, that is to say, it starts (point A) and ends (point C) its formation over a base zone and it is there where its validity to be traded is determined. It will not be valid when it is formed in zones other than those indicated.
3. In relation to the time variable, the displacement or segment B-C must be formed at least twice as long as it takes for the segment A-B to be formed. For example: A-B one hour, B-C two hours or more.
4. In relation to the price variable, the two advances will be of similar sizes.

In Fig. 3, the dynamics of the bullish and bearish PFS is observed, each scheme originates from point A which is located in a base zone, then moves in one direction until reaching the highest or lowest point (B), and thus concludes the first advance, finally it moves in the opposite direction to C, in at least twice the time it took the first journey, if it is triple or more, the empirical evidence shows a tendency to better results. So, in this way, the second rule of the proposed strategy is configured.

### *2.2 Japanese Candlestick Formation*

The Japanese candlestick (consisting of body and shadow) is one of the many ways to graphically represent the price of financial assets and the most popular among technical analysis traders. Since the focus of the research is the short term, the analysis of this rule will be performed on a chart with a periodicity of two minutes, i.e. each time this period elapses, a new candlestick will be drawn. The various price fluctuations determine the shape and size of each candlestick; therefore, it is essential to define the variants to be used in the strategy. A candlestick by itself does not transcend, that is why in the first two rules it is assigned a specific context.

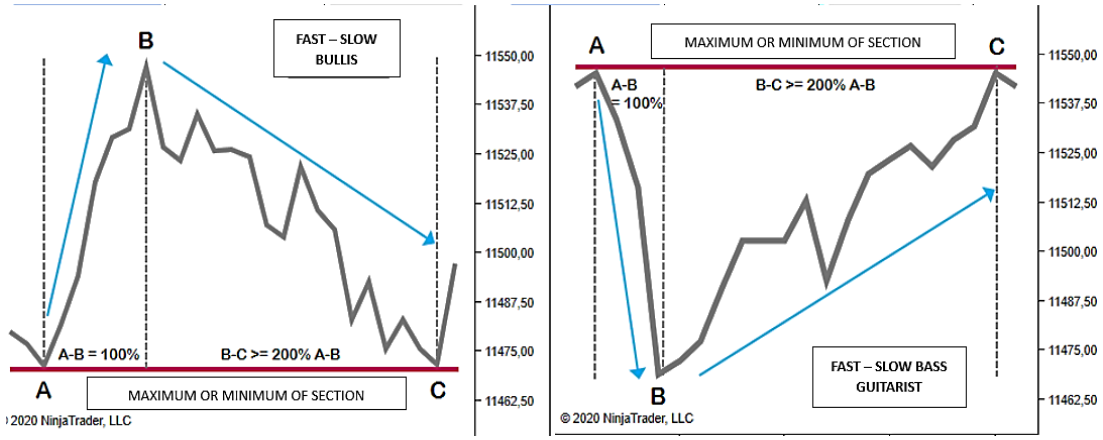


Figure 3. Fast-Slow Pattern Bullish and Bearish.
Source: Own Elaboration with Ninja Trader 8 Platform.

The Japanese candlesticks constitute the third guideline of the strategy. These become the "trigger" that determines the "ideal" moment to execute the plan. The candles will only have protagonism when the two initial rules have been fully complied, that is, they must be formed in a trading zone and when the PFS is completed at point C, it is just at that moment that one of the formations must be drawn, if it is achieved, the trader must enter the market according to what the strategy determines, in case the first two patterns are generated and the candlestick pattern is not obtained, the entry will be canceled.

The most influential characteristic for identifying an adequate candle formation is its dimension or length, it means that this aspect is decisive for the validity of rule three. In general terms, the triggers are patterns that are characterized by outstand due to their size with respect to the preceding candles, when they do not stand out they are considered invalid. The study proposes formations with variants for the two directions that a market can take, when reference is made with respect to a bullish pattern it is indicated that the direction that is intended to be projected is ascending and the opposite is the case in a negative one. This document present three types of patterns: Envelope, Star and Pin Bar.

Enveloping Pattern: Consisting of two candles. It is characterized because the length of the body of the second candlestick wraps the body of the previous candlestick in its entirety. The two candles must have opposite directions.

Star Pattern: It is formed by a minimum of three candles and a maximum of five. It is characterized because the first and last candles go in opposite directions and their sizes are significant, the intermediate one(s) are generally of small length.

Pin Bar Pattern: It is composed of a candlestick. It is characterized by having a large shadow (upper in bearish pattern and lower in bullish) and a generally small body.

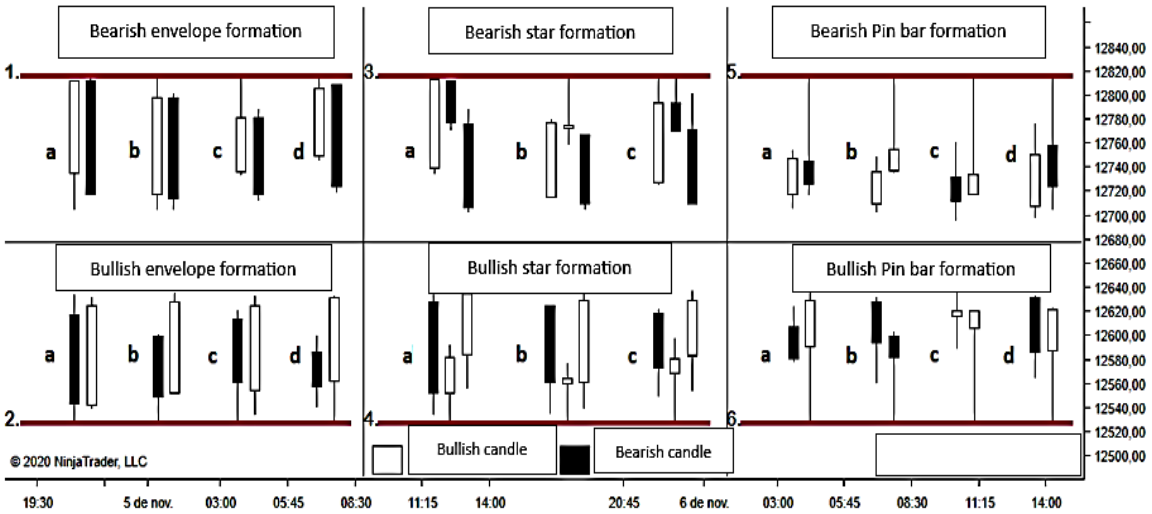


Figure 4. Japanese Candlestick Patterns, Bullish and Bearish.
Fuente: Own Elaboration with Ninja Trader 8 Platform.

With the candlestick formation, regardless of which type occurs, what the trader projects is that the market generates a "twist" point, that is, in the context that the market goes in a downward direction and reaches point C of the PFS, when the candlestick pattern is drawn in that area, it causes a turn in the direction and from that moment begins a bullish path, likewise, it applies to a change from bullish to bearish. Fig. 4 illustrates the three types of formations for bullish and bearish market turns, equally, several examples are observed for each variant, the above plurality is important sinc markets are dynamic and small changes do not indicate that a formation is distorted.

### *2.1 General Rules of the Strategy*

In addition to the three main rules that make up the proposed strategy, there were other general rules that were used in the development of the strategy, which are listed below:

- Stop Loss: For buy/sell transactions the stop loss was placed four ticks (minimum price variation) below/above the minimum/maximum price of the candlestick pattern that generated the entry. Dynamic stops were not considered.
- Take Profit: The minimum profit ratio over risk that was handled in the totality of transactions is 1, i.e., profits of less than one unit are not accepted when the risk assumed is one unit.
- Entry at End of Session: No transactions were opened thirty minutes or less before the end of any of the trading sessions analyzed.
- News or Events: No trades were taken when there were sixty minutes or less to the release of U.S. unemployment rates or interest rates, as well as speeches of the nation's and Federal Reserve´s presidents. For other macroeconomic releases of lesser impact, no trades were taken when there were fifteen minutes or less before their release.

## 3 Methodology

The data set used during the development of the short trading strategy was obtained from the US Nasdaq-100 stock market, the professional electronic trading platform Ninja Trader 8 was used for historical observation of price behavior. The graphical visualization of the asset price was carried out in a two-minute time frame, that is to say, each Japanese candlestick on the chart represents this time unit and based on defined rules the interaction between the opening, closing, minimum and maximum prices is interpreted. The observation window for the research is from the beginning of October 2019 to the end of September 2020. The Nasdaq-100 index as underlying asset was selected because it lists the world's largest companies by market capitalization, mainly from the technology sector, and because it has a higher average annual volatility than the S&P 500 index. To establish the above, there were taken the daily returns of the futures of these indexes from October 2018 to September 2019 and the standard deviation of these returns was calculated, then annualized and the result shows that the Nasdaq-100 derivative during this period had an average annual volatility of 23% compared to 17% for the SP500 derivative. Volatility is of great importance to the intraday trader as it represents greater trading opportunities.

## 4 Backtesting

One of the most recurrent methodologies to evaluate the development of a trading strategy in a given time window is "historical backtesting". It consists of performing a simulation using historical data in order to establish what would have been the result of applying an investment strategy in that selected period [20]. One of the main advantages of backtesting is the possibility of creating multiple scenarios that can be analyzed quantitatively and qualitatively. This analysis tool takes on an important meaning when applied in an honest, meticulous and realistic manner, reflecting reasonableness and logic in the results.

Computational progress has allowed the implementation of new backtesting methodologies such as the one proposed by Seda [21], who through algorithmic configurations automatically incorporates recent data to the multiplicity of assets and variables, with the purpose of selecting and incorporating into its portfolio the best investment instruments of the moment. The most usual methodology and the one used in this study is the one that selects the period to be measured and the data remains static, it means that it does not incorporate new data. Investment funds, portfolio managers and retailers use the statistics of their backtests to choose their trading strategies and allocate capital. In order to obtain the results, it was imperative to create a database that would allow the historical data to be stored in an orderly and coherent manner. The first step consisted of determining the variables according to the proposed objectives, among the main ones the following were selected:

Trading Session and day of the week: Seeks to determine in which of the trading sessions the greatest number of operations are generated, as well as the most effective and profitable. Also, to know the day in which the strategy showed the best performance.

Candlestick formation or pattern: This is a determining variable, it is wished to know which of the proposed patterns was the greatest trigger of income in the registered operations, as well as to know its effectiveness and profitability.

Maximum Displacement in Favor (MDF) and Against (MDC): This variable is ideal to establish an adequate amount of maximum loss allowed per operation (stop loss), as well as the profit taking (take profit).

Once the analysis variables were determined, data collection was performed using the Ninja Trader 8 electronic trading platform. The observation window was established, and the trading strategy was strictly simulated on each day. Finally, it was proceeded to quantify the variables. Tables 1, 2 and 3, contain the total of the variables of the database required to perform the backtesting, each observation gathers all the information of row one in the three tables (operation # 1).

Table 1
Backtesting data reported for each observation or scenario. Part 1

| Operation # | Date | Day | Session (*) | Time | | Duration | Price | C / V |
|---|---|---|---|---|---|---|---|---|
| | | | | Entry | Exit | (Minutes) | | |
| **1** | 03/10/19 | Thursday | American | 10:56 | 12:48 | 112 | 7594,00 | C |

Source: Own Elaboration (2020)

Table 2
Backtesting data reported for each observation or scenario. Part 2

| Operation # | Pattern (*) | Level 1 | Level 2 | Level 3 | Operation Type (*) | MDF (*) | MDC (*) | Stop |
|---|---|---|---|---|---|---|---|---|
| **1** | Star | Max Eur Ant | Max Asi Ant | | Cont | 241 | -49 | -53 |

Source: Own Elaboration (2020)

Table 3
Backtesting data reported for each observation or scenario. Part 3

| Operation # | Trend in M2 | Route | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **1** | Yes | -49 | 67 | -10 | 241 | 112 | 239 | |

Source: Own Elaboration (2020)

The backtesting is composed of main variables (*) that are analyzed in this research, it also reviews secondary variables that are not the object of study, however, they are included because they may arouse the interest of analysis in other traders

## 1 Data and Results

The collection period showed 541 observations generated during the three trading sessions. The study aimed to quantify and establish the best Risk-Reward Ratio (hereinafter RRR) of the strategy, it was proposed to examine from the 1 to 1 relationship, to the 7 to 1, the above allows us to find a sensible relationship between the level of risk and take profit.

Fig. 5 shows the scheme of each of the proposed RRRs, starting at 1 to 1. This indicates that for each unit of risk (stop) that is decided to assume, at least one unit of reward (profit) will be obtained, the measurement covers up to the ratio 1 to 7. It is considered that as the RRR increases, the probabilities of obtaining it decrease.

According to Table 4, it can be established that short-term PFS is a profitable strategy in six of the seven ratios proposed. The highest effectiveness is recorded in the 1 to 1 RRR, where 71.72% of the transactions recorded profits and only 28.28% losses. However, in terms of profitability, the RRR that gives the best performance in this measurement is the 1 to 2, where over the period covered a return of 91.10% would have been obtained, higher if compared to the 63.40% of the 1 to 1. The last ratio shows a total deterioration of the measurements, which suggests that the 1 to 7 ratio should not be taken in any scenario. The profitability found is free of commissions.

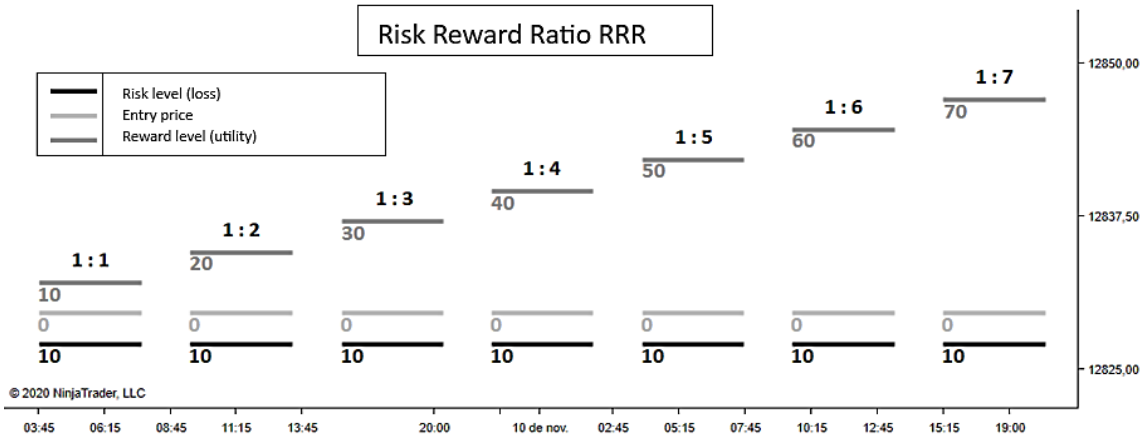


Figure 5. Risk-Reward Ratio Scheme.
Fuente: Own Elaboration with Ninja Trader 8 Platform.

Table 4
Effectiveness and Profitability of the Fast-Slow Pattern by Risk-Reward Ratio.

| RRR | 1 : 1 | 1 : 2 | 1 : 3 | 1 : 4 | 1 : 5 | 1 : 6 | 1 : 7 |
|---|---|---|---|---|---|---|---|
| **N° Total Trades** | 541 | 541 | 541 | 541 | 541 | 541 | 541 |
| **% Profit** | **71,72%** | 52,68% | 38,26% | 29,57% | 22,18% | 17,19% | **6,84%** |
| **% Stop** | **28,28%** | 47,32% | 61,74% | 70,43% | 77,82% | 82,81% | **93,16%** |
| **Net profit (%)** | 63,40% | **91,10%** | 79,31% | 67,36% | 44,36% | 37,25% | **-61,79%** |

Source: Own Elaboration (2020)

Table 5
Effectiveness and Profitability of the Fast-Slow Pattern per Trading Session.

| Session | Europe | America | Asia |
|---|---|---|---|
| **N° Trades** | 189 | **230** | 122 |
| **Participation** | 34,94% | **42,51%** | 22,55% |
| **% Profit** | 52,38% | **55,65%** | 47,54% |
| **% Stop** | 47,62% | **44,35%** | 52,46% |
| **Net profit (%)** | 22,07% | **57,28%** | 11,75% |

Source: Own Elaboration (2020)

Table 6.
Effectiveness and Profitability of the Fast-Slow Pattern by Japanese Candlestick Formation.

| Candlestick formation | Pin Bar | Enveloping | Star |
|---|---|---|---|
| **N° Trades** | 130 | 171 | **240** |
| **Participation** | 24,03% | 31,61% | **44,36%** |
| **% Profit** | **56,15%** | 47,95% | 54,17% |
| **% Stop** | **43,85%** | 52,05% | 45,83% |
| **Net profit (%)** | 16,19% | 25,14% | **49,77%** |

Source: Own Elaboration (2020)

Table 7
Effectiveness and Profitability of the Fast-Slow Pattern per Trading Day.

| Trading Day | Monday | Tuesday | Wednesday | Thursday | Friday | Sunday |
|---|---|---|---|---|---|---|
| **N° Trades** | 93 | **124** | 117 | 92 | 98 | 17 |
| **Participation** | 17,19% | **22,92%** | 21,63% | 17,01% | 18,11% | **3,14%** |
| **% Profit** | 51,61% | 54,84% | 41,88% | 58,70% | **59,18%** | 47,06% |
| **% Stop** | 48,39% | 45,16% | 58,12% | 41,30% | **40,82%** | 52,94% |
| **Net Profit (%)** | 14,12% | 23,38% | 9,81% | 17,21% | **26,09%** | **0,50%** |

Source: Own Elaboration (2020)

Table 5 shows the performance of the PFS strategy from the variable of trading sessions. The results are convincing in favor of the performance that occurred during the American session, 42.51% of the events were registered in this session with a total of 230, likewise, the effectiveness of the session is superior to the others with 55.65% of successful operations and 44.35% of stops. Additionally, it is interesting the profitability generated; this session alone contributed 57.28% of the 91.10% of the overall result of the RRR 1 to 2.

Table 6 shows the behavior of the PFS measured by the triggers of the Japanese candlestick formations, where the pattern that detonated the most trades was the Star, with 240 events corresponding to 44.36% of the total number of observations. It also contributed with the best performance of the measurement, providing 49.77% of the total of 91.10% of the best overall RRR. However, it was not the most effective training; this item is attributed to Pin Bar, which contributed 56.15% of successful cases.

Numerous studies have been based on the behavior that the price could perform on a specific day of the week, Table 7 shows the dynamics of the PFS per stock market day analyzed, Tuesday is observed as the day with the highest trading activity, generating 22.92% of the events, corresponding to 124 cases of the total, however, it is not the day that contributes the best performance to the strategy, Friday leads the ranking of effectiveness and profitability where it participates with 59.18% and 26.09% respectively.

## 1 Conclusions

The financial markets in recent decades have developed new approaches to the traditional ones, the large traders continue to be at the vanguard in the development of investment methods, the retailer on the other hand participates in the different markets thanks to technological advances, low initial capital requirements and the development of strategies with statistical backing. The results of this study provide the retail trader with a strategy of defined parameters and positive profitability generation, which is favorable given the accentuated divergence at all levels that exists between the two groups of stock market agents, from the most informed, capitalized and sophisticated

to those who lack practically all of the above or have them in a very limited form, which evidences a gigantic asymmetry of resources between the two groups. The results of the research place the strategy based on the identification of the PFS as a recurrent imperfection of the market, that is to say, it has been established that the behavior of the graphic pattern under study is classified as a technical anomaly, in the year of observation using an intraday time frame, it has not been an ephemeral behavior of the price but a repeated formation with positive results that can be systematically exploited.

It is confirmed that a high RRR is not required to obtain profitability, on the contrary, it deteriorates as profit increases. The research showed a good performance of the American session, this was the time zone that produced the most market entry signals and at the same time the most profitable. It can be established that this is not an isolated result; the Yankee session is characterized by producing the most severe fluctuations in asset prices. Likewise, the European session, which is characterized by a volatility historically lower than the American and higher than the Asian, showed results in line with this tradition. As far as candlestick patterns are concerned, the Star formation is the one that showed the most, however, the three variables show similar positive results, that is to say, they have an acceptable reliability in the RRR 1 to 2.

The Nasdaq-100 index future is an asset that is characterized by a great speed and extension in its movements, this vehicle is proposed to investors who have tolerance to high volatilities, otherwise, the trader could be overwhelmed by the rapidity of the movements it performs. Furthermore, given the empirical evidence, operators are advised to manage a single asset for purely speculative purposes; if the objective is to invest in the medium and long term, the creation of a portfolio with multiple instruments would be the best scenario. Based on the foregoing, it is suggested to implement the proposed strategy in different assets in multiple markets, in different time frames and observation windows in order to know its coverage and behavior in different contexts. Additionally, it is worth considering that the PFS can be identified on alternative trading zones, in such a way that the potential of the short-term pattern can be validated in other areas of the price chart.

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# Documentary analysis on productivity in enterprises

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**Abstract**
Productivity is a key indicator for the sustainable growth of enterprises. However, small and medium-sized enterprises (SMEs) often do not measure it; therefore, there is a need to develop a greater understanding of this concept as a subject of study. A study was conducted with a qualitative approach using a documentary analysis technique based on a documentary record instrument. The research objective is to locate, analyze, and synthesize scientific evidence on business productivity to strengthen the theoretical and methodological foundations for further analysis and application in future studies. The results are presented in the following categories: Productivity concepts, efficiency, effectiveness, and competitiveness; variables or factors affecting productivity; productivity techniques and tools; case studies on productivity; and productivity and human talent. The findings of this research can contribute to promoting the measurement of productivity in SMEs.

*Keywords:* documentary analysis; productivity in enterprises; productivity techniques.

# Análisis documental sobre la productividad en las empresas

**Resumen**
La productividad es un indicador clave para el crecimiento sostenible de las empresas. Sin embargo, las PYMES no suelen medirla; por lo que, se requiere desarrollar un mayor entendimiento de este concepto como objeto de estudio. Se desarrolló un estudio con un enfoque cualitativo con una técnica de análisis documental basado en un instrumento de registro documental. El objetivo de la investigación es localizar, analizar y sintetizar evidencia científica sobre la productividad de las empresas para fortalecer las bases teóricas y metodológicas para profundizar su análisis y aplicación en futuros estudios. Los resultados se presentan en las siguientes categorías: Conceptos de productividad, eficiencia, eficacia y competitividad; variables o factores que afectan la productividad; técnicas y herramientas de la productividad; casos de estudio sobre la productividad; y, productividad y talento humano. Los hallazgos de esta investigación pueden contribuir a promover la medición de la productividad en las PYMES.

*Palabras clave*: análisis documental; productividad en las empresas; técnicas de productividad

## 1 Introduction

The competitiveness of a country is the ability of its economy to provide its population with a high and growing standard of living, as well as high levels of employment on a sustainable basis [1]. Additionally, it is the set of institutions, policies, and factors that determine the level of a country's productivity [1].

Thus, competitiveness is the ability of an institution to generate effective strategies aimed at maintaining and increasing its presence in the market, enhancing its productivity, negotiating capacity with other enterprises in a competitive environment determined by the market, government policies, and regional, national, and international economic alliances [2].

Productivity in a country is crucial for its sustainable and inclusive growth, which must include three fundamental pillars: strengthening human capital, improving logistical infrastructure, and fostering a business-friendly climate to encourage private investment. These three pillars should be operating within a framework of macroeconomic stability [2].

Therefore, it can be inferred that an alternative to sustain

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competitiveness in these enterprises is through productivity. This concept relates to the production of goods and services in relation to resources such as labor, materials, energy, machinery, and other factors [3]. Productivity involves being both efficient and effective. In this sense, efficiency means that having many resources is not enough; it is about using available resources timely and appropriately [4].

Consequently, the measurement of productivity is an excellent way to assess a country's ability to enhance the standard of living for its population. Only through increased productivity can the standard of living be improved [5]. However, it is observed that currently, small and medium-sized enterprises (SMEs) do not employ tools to enhance production and process management because they are not aware of their importance and necessity, as well as their complexity [6]. Thus, it is relevant to delve into the topic through available scientific evidence to trigger understanding as a subject of study and provide references for offering solutions to enterprises.

Therefore, this research is proposed and justified in terms of criteria suggested by Hernández-Sampieri [7]. Firstly, considering that it will contribute to understanding the factors influencing organizational productivity (theoretical value). Secondly, the study's results will help reveal the forms of productivity in enterprises (practical implication). Lastly, through the research findings, a model will be developed to understand and enhance productivity through the study's variables (methodological value).

As a result, to provide a perspective on the subject of study, a synthesis of theory and concepts associated with productivity is presented with the intention of providing answers to the following questions: How is productivity measured? What are the main productivity tools?

In this context, Juez [8] mentions that productivity aims to measure the result of a process or processes within an organization. Therefore, an important aspect is the analysis of efficiency concerning resource utilization; the fewer resources invested to produce the same or greater number of profits, the better the efficiency. Productivity is observed by the ratio between the output obtained and the resources used. To calculate a country's productivity, the Gross Domestic Product (GDP) is divided by the hours worked. It is important to note that factors affecting productivity include the quantity and quality of human resources, the quantity and quality of natural resources, capital invested in the industry, the macroeconomic and microeconomic environment, technological level, and industry configuration.

As a means to increase productivity, various methodologies and tools have been studied, including Lean Manufacturing. Vargas-Crisóstomo and Camero-Jiménez [9] define lean manufacturing as a model of excellence and continuous improvement in management, involving the elimination of waste that does not add value to the product and comprises various tools.

In this sense, lean manufacturing has become an alternative to enhance productivity and develop manufacturing competencies that impact competitiveness. The lean manufacturing tools that have the greatest impact on enterprises' productivity include 5S, Total Productive Maintenance, Just-in-Time (JIT), Kaizen, Kanban, Single-Minute Exchange of Die (SMED), and Value Stream Mapping (VSM). The indicators that best measure productivity are those related to efficiency, effectiveness, and internal factors [10].

Meanwhile, according to Socconini [11], lean manufacturing tools are defined as the systematic and continuous process of identifying and eliminating excesses or waste. Excess refers to any activity in the process that does not add value but involves work and cost. Therefore, lean manufacturing should be understood as a set of tireless and uninterrupted activities to create innovative, effective, and efficient enterprises. Given this premise, it is considered important to explore the most relevant ones.

**5S:** The primary benefit of implementing the 5S methodology in enterprises is the increase in productivity. This results from having fewer defective products, fewer accidents, reduced unnecessary movements, less time spent on tool changes, improved quality, and ultimately, creating a conducive work environment [12].

**Kaizen:** As proposed by Vargas-Crisóstomo and Camero-Jiménez [9], the word Kaizen means improvement directed towards the satisfaction of functional and cross-cutting goals such as quality, costs, and human potential. All with the aim of achieving greater customer satisfaction.

**TPM** (Total Productive Maintenance): TPM is defined as a set of techniques aimed at eliminating breakdowns through the participation and motivation of all employees [13]. This methodological work strategy is aimed to create an operating system that increases the efficiency of all the equipment involved in the company's production process to guarantee its correct functioning, thus avoiding waste due to loss of time when equipment fails, which would lead to non-compliance with customers and higher costs for the company [14].

**Kanban**: Kanban focuses on limiting work in progress and visualizing the development value stream, leading to a reduction in cycle time [15]. Krishnaiyer [16] defines Kanban as a visual tool for monitoring and controlling resource consumption and production of an enterprise. It is responsible for managing inventory levels, continuous material flow, and is used to track progress in the production process [17]. The Kanban methodology seeks to achieve a productive, organized and efficient process. Its main objective is to ensure sustainable production to avoid excess final product, bottlenecks and delivery delays. Work in progress must be organized according to the capacity of work centers and teamwork. The system requires real-time communication about capacity [18].

**VSM** (Value Stream Mapping): Value Stream Mapping is a lean tool implemented to explore the current scenario of the enterprise and information flow [19].

**SMED** (Single-Minute Exchange of Die): SMED reduces setup time by changing internal tasks to external tasks during this operation [20]. SMED is a methodology for analyzing and improving time lost in production series changes due to running setups. Its original definition argues that tool changes to make on a production line should be completed in less than 10 min. It focuses on the analysis, systematization and standardization of tasks performed by the machine operator or the line crew [21].

**Just-in-Time:** According to Fory [22], continuous process improvement is a crucial theme for enterprises, leading them to implement strategies to reduce economic losses, time, and resources.

In this context, it is confirmed that a tool for productivity is lean manufacturing. This is essential in enterprises because it is composed, in turn, of a set of tools that help eliminate all signs of waste in the production system, with the aim of optimizing the profits, product quality, and satisfying customer needs and demands [17]. In this sense, lean manufacturing practices are not only about implementing them, but also about the development of people and the transformation of the culture of enterprises [23].

On another note, it is recognized that enterprises seek to offer more and better services at attractive prices to customers without affecting their profits. One strategy to achieve this is by minimizing production costs through process standardization, as it reduces failures, waste, and increases productivity [24]. In this regard, enterprises should use methodologies and tools to diagnose their processes, identify critical points, and invest in strategies that optimize the operations of their value chain, the use of their resources, and the quality of their products, in order to consistently exceed customer expectations and achieve differentiation in the market [25].

On their part, Quijia-Pillajo [25] indicate that the characteristics of enterprises that most significantly drive productivity are: trained human capital, relationships with other enterprises through a business group, commercial openness through exports, and foreign capital investment. These factors generate productivity benefits such as increased availability of intermediate goods, access to new technologies, technical consultancy, and the dissemination of knowledge. Meanwhile, Agudelo [27] mentions that the variables with the greatest impact on labor productivity are job satisfaction, teamwork/cohesion, and organizational climate. On the other hand, the dimensions with less impact on labor productivity are competencies and employee participation.

Given all the above, the objective of the present research is to locate, analyze, and synthesize information on the productivity of enterprises to delve into its study through a documentary analysis. Therefore, the research results will be presented in the following analysis categories: (a) category 1. Concepts of productivity, efficiency, effectiveness, and competitiveness in enterprises, (b) category 2. Identifying the variables or factors that affect productivity in enterprises, (c) category 3. Identifying the techniques and tools of productivity in enterprises, (d) category 4. Case studies on productivity in enterprises, and (e) category 5. Productivity and human talent.

## 2 Methodology

### *2.1 Study type*

The present research was conducted through a qualitative approach, which, according to Vega-Malagón [28], is based on data collection methods without numerical measurement, such as description and observation of the phenomenon. The authors also assert that the process is flexible and moves between events and their interpretation. Additionally, it relies on a logical and inductive process to explore, describe, and generate theoretical perspectives by evaluating the natural development of events without manipulation or stimulation of reality [7].

On the other hand, the applied analysis technique is documentary analysis, which is a form of technical research. It involves a set of intellectual operations aimed at describing and representing documents in a unified and systematic manner to facilitate their retrieval and interpretation [29]. Martinez-Corona and Palacios-Almon [30] consider documentary analysis as a recognized scientific procedure characterized by a systematic process to investigate, collect, organize, analyze, and interpret information related to a research topic in the context of documentary research.

Table 1.
Analysis of categories for the study

| Analysis category | Main question |
|---|---|
| Concepts of productivity, efficiency, effectiveness and competitiveness in enterprises. | What is the meaning of productivity, efficiency, effectiveness and competitiveness in an enterprise? |
| Variables or factors affecting productivity in enterprises. | What are the variables or factors that affect productivity in enterprises? |
| Techniques and tools for productivity in enterprises. | What are the techniques and/or tools of productivity in enterprises? |
| Case studies on productivity in enterprises. | What are the case studies of productivity? |
| Productivity and human talent. | What is the relationship between productivity and human talent? |

Source: Own elaboration

### *2.2 Data collection instrument and analysis categories*

The instrument for gathering information was documentary recording. This refers to the set of strategies and methods for retrieving information documented in physical or digital documents, which, through certain tools, enable the consultation of the sources from which information is obtained [31]. The collected information possesses the characteristic of contributing to answering the central questions of the study, as outlined in Table 1.

### *2.3 Documentary analysis procedure and document selection criteria*

The present study revolved around the subject of study called the productivity of enterprises. Therefore, this work allowed the search, retrieval, and analysis of documentary sources using fixation techniques, data localization, and content analysis guided by logical procedures for this type of research, such as reading, synthesis, and deduction [32].

In the documentary record, initially, it contains excerpts (verbatim quotes) from articles in indexed journals. Subsequently, if deemed necessary, it is supplemented with academic books and other documents that contribute to the study topic. This way, the consolidation of documents serves as a strategy to carry out the analysis of documents with the aim of systematizing, building, and communicating concepts and theories of high academic relevance based on established categories [33].

Table 2.
Documents included in the documentary record

| Aspect | Latin-American | From other countries |
|---|---|---|
| On the subject | 9 | 4 |
| Contextual | 5 | 7 |
| Total | 14 | 13 |

Source: Own elaboration

In this context, based on the proposal by Martinez-Corona and Palacios-Almon [30], the development of the present study will deepen the understanding of the subject of study and contribute elements for future research studies to be conducted with scientific rigor, thus obtaining relevant and quality results. Consequently, the procedure proposed by the same authors, which also represents the document selection criteria, was developed, consisting of four phases:

1. Documents such as scientific articles, books, or book chapters were located in databases such as WoS, Science Direct, Scielo, Redalyc, Scopus, Latindex, and Google Scholar.
2. A combination of essential and complementary keywords was used.
3. The time range for document search was determined, considering updated information from the year 2019. Only in exceptional cases and considering the document's relevance were elements from previous years considered for inclusion.
4. Documents addressing at least one category determined for the study, considering one or more elements, were integrated into the analysis.
5. The selected articles are written in Spanish or English.

### *2.4 Analyzed documents (sample)*

To integrate the analysis of the categories, searches were conducted in scientific databases using the following keywords: "productivity, efficiency, and effectiveness", "productivity factors", "techniques and tools of productivity", "case studies on productivity" and "productivity and human talent." Once located, the documentary record was compiled. Out of a total of 120 located documents, in the screening process under the selection criteria, a total of 27 documents were included as the unit of analysis, which are summarized in Table 2.

## 3 Results

Next, once all the steps of the methodological process have been completed, the results of the documentary analysis on the topic of productivity in enterprises are presented, in accordance with the established categories.

### *Category 1: Concepts of productivity, efficiency, effectiveness, and competitiveness in enterprises*

To initiate the study on enterprises' productivity, some concepts of great importance will be defined. Thus, Gómez-Gómez [4] indicates that efficiency is related to the intelligent management and use of available resources, avoiding waste, and contributing to the generation of value. In this sense, it involves using the few or many available resources opportunistically and appropriately; that is, when needed and for what they are needed. On the other hand, effectiveness is understood as the achievement of objectives, which can be attained regardless of the resources used, sometimes at any cost, whether for customer satisfaction, achieving production goals, and/or meeting sales quotas. Under the author's logic, it can be inferred that a concept of productivity not widely explored is as follows: achieving objectives with the intelligent use of resources or, in other words, productivity is being both efficient and effective simultaneously. In other words, efficiency and effectiveness are two interdependent concepts that, when managed together and interrelated, result in what is known as productivity.

In another context, it is known that a large number of enterprises have ceased to be competitive due to low productivity, often linked to inefficient process management, failures in information traceability, and processes that hinder the functioning of the enterprise. This scenario has created the need for enterprises to achieve a global change in their processes, aligning them based on market demands through the application of radical improvement methodologies. This involves Process Reengineering, seeking to restructure enterprises to achieve more effective results [34]. Consequently, the alternative to sustain competitiveness in enterprises is through productivity. This concept relates to the production of goods and services in relation to resources used, such as labor, materials, energy, machinery, or other factors [3].

Additionally, it is relevant to consider that, according to Momeni and Ni [35], quality and productivity are key factors after a crisis to gain competitive advantages and economic recovery. Therefore, economic development is currently reflected in an enterprise success; hence, the planning of any process is closely related to the productivity with which progress is made. When discussing productivity, it encompasses both elements and activities that come together to achieve a single result. The authors mention that improvements in measuring productivity are reflected in the fact that, with the use of fewer resources and/or activities, better results can be obtained [36].

### *Category 2: Variables or factors affecting productivity in enterprises*

The globalization of markets has led enterprises to make constant decisions aimed at improving their competitiveness in uncertain environments. This pursuit typically focuses on reducing costs and increasing quality. The latter is reflected in the product and delivery times, especially because enterprises seek to enhance their processes, including the production process and its planning. Hence, the Master Production Schedule (MPS) involves establishing organizational decisions in advance to optimize the use of resources within a timeframe convenient for the enterprise. Simultaneously, it determines the quantities and dates at which the enterprise's distribution inventories should be available.

In this regard, the MPS is only concerned with products and components subject to external demand from the production unit, while Material Requirement Planning (MRP) is a detailed

plan specifying the specific quantity and exact dates of product manufacturing, considering the foundations for shipping times and delivery to the customer. This contributes to achieving the enterprise's strategic objectives and resolves negotiations between manufacturing and marketing by effectively utilizing plant capacity [37].

Quijia-Pillajo [26] indicate that an analysis of the determinants of productivity in Ecuador shows that the characteristics of enterprises that most significantly drive productivity are: trained human capital, relationships with other enterprises through a business group, commercial openness through exports, and foreign capital investment. These factors generate productivity benefits such as increased availability of intermediate goods, access to new technologies, technical consultancy, and knowledge dissemination. Therefore, to boost the productivity of enterprises based on these results, it is recommended that they focus on incorporating employees with high levels of education. This is because such personnel possess a broader knowledge domain that would influence productivity. Additionally, fostering interaction between enterprises in any form, whether through exports or alliances, is crucial to generate new knowledge and innovation.

Under this argument, Agudelo-Orrego and Escobar-Valencia [27] mention that when descriptively analyzing the variables with the most significant impact on labor productivity, both managers and employees agree that job satisfaction is crucial. Therefore, it is important to clearly define tasks and distribute them according to the capabilities of the collaborators. Another important factor is teamwork/cohesion, which should be encouraged through cooperation and the clear definition of objectives to be achieved. Similarly, organizational climate plays a significant role, promoting the establishment of a positive work environment represented by feedback, communication, and integration. On the other hand, the dimensions with less impact on labor productivity are competencies and employee participation.

Now, according to Uemura [38], when discussing productivity with workers and plant managers, mentions efficiency given the current workspace considered as a (active) production asset. It is desirable to save not only processing time but also workspace to improve asset efficiency. Particularly, when there is a significant difference in orders due to the season, and sales during the peak season must cover fixed costs during the off-season, it is necessary to maximize asset productivity during the peak season. From this perspective, the effective use of space is an important issue because not only can the process time be shortened by consolidating excess space and shortening the production line, but also, if another production equipment can be placed in the vacant space, the production volume will increase dramatically.

### *Category 3: Techniques and tools for productivity in enterprises*

The modern state of the global economy shows that a nation cannot proceed in isolation. For effective development, there must be a connection between the economies of different nations. This interconnected global economy has led to strong competition among industries. Because of this, ensuring quality, cost, and production technology has become crucial. This is where the concept of lean manufacturing seems to be suitable [39].

Under this reasoning, when considering the objectives pursued by the enterprise, the most suitable tools for this strategy can be selected. These actions, accompanied by other methodologies such as job standardization and other tools, not only impact the improvement of the manufacturing process but also generate a better understanding of the process by both technical staff and factory workers [40].

To achieve an increase in competitiveness, enterprises can choose different innovative management strategies that help improve various parameters of this function. One such strategy that has been proven with favorable results worldwide is lean manufacturing [41]. Additionally, industrial enterprises currently face the challenge of identifying and implementing new organizational and production techniques that allow them to compete in a global market. Thus, the lean manufacturing model has become an alternative to increase productivity and develop manufacturing competencies that impact competitiveness. However, the effect that each of the lean manufacturing tools contributes to achieving productivity is unknown [10].

In this sense, lean manufacturing becomes a strategic tool that involves all areas of an enterprise, not only due to its various applications within an organization but also because it has the potential for application in any type of enterprise; moreover, it can be adjusted to different scenarios with excellent results. This was demonstrated in a project through the review of various lean tools that can be applied in Occupational Safety and Health and simultaneously impact process optimization [42].

The above becomes relevant since the manufacturing industry in Mexico is a key element for the country's development. This is considering that, in a highly competitive environment, enterprises seek to offer more and better services at attractive prices to customers without affecting their profits. One strategy to achieve this is to minimize production costs through process standardization, as it reduces failures, waste, and increases productivity [24].

In this regard, manufacturing enterprises implement lean manufacturing tools to maintain their competitiveness against competitors by improving the productivity of the system. It is noteworthy that Value Stream Mapping (VSM) is a fundamental tool for implementing the lean approach and can be used in many sectors of the industry [19].

As cited in Sosa-Solano and Zeña-Ramos [36], they report the analyses and tests conducted in an enterprise where the aim was to improve the productivity of the working area using the lean manufacturing concept. The authors identified the main problems affecting productivity in the production area of the product. The authors used time studies during the evaluation, yielding data that showed a significant improvement in production and product realization after the application of lean manufacturing, along with a reduction in process time.

In this context, lean manufacturing is a method that focuses on organizational improvement; thus, applying it in the

enterprise will eliminate any activity or input that hinders productivity. In addition, it provides feasible solutions that focus on the growth of the enterprise [36].

Finally, lean manufacturing improves the quality and productivity of the product, minimizes taks time, manufacturing waste and inventory, and eliminates activities that do not add value [43].

***Category 4: Case studies on productivity in enterprises***

An example of the consequences of not having measures to ensure quality and productivity can be found in the scientific literature. In this regard, it is worth mentioning that, according to Flores-Meza [6], there is a significant percentage of small and medium-sized enterprises (SMEs) in the Peruvian textile market that incur economic losses due to penalties paid to customers, mainly related to delays in delivering order batches. The authors argue that this is due to poor production management and a lack of focus. It is also important to note that the manufacturing sector is crucial for its substantial contribution to the country's gross domestic product. This is because SMEs do not employ methodologies to improve production and process management, as they are unaware of the importance and necessity of such methodologies, as well as how complex they can be. Thus, these models will help enterprises avoid incurring economic losses due to penalties for orders not delivered on time.

The authors propose a model, and to validate it, a time simulation was conducted in the manufacturing area of the mentioned textile enterprise. In particular, the Lean Production Management Model integrates knowledge and change management along with 5S and Kanban techniques to achieve better implementation results. It is essential to consider the human factor as a primary factor for success.

Now, in the competitive, dynamic, and changing environment in which enterprises operate today, new challenges are posed to grow and sustain over time. Therefore, aspects such as customer satisfaction, innovation, and social responsibility are increasingly used objectives by enterprises. However, elements like quality and productivity continue to be critical factors in the sustainability of the business. To achieve this, enterprises must use methodologies and tools to diagnose their processes, identify critical points, and invest in strategies that optimize the operations of their value chain, the use of their resources, and the quality of their products. All with the aim of consistently exceeding customer expectations and achieving differentiation in the market [25].

In this sense, the use of tools from the Toyota Production System, also known as Lean Manufacturing, plays a fundamental role in eliminating waste and continuously improving industrial production levels. It can also be implemented in various sectors of the enterprise, as well as in any industry area, enabling continuous improvement of production processes [44].

Related to the above, it is asserted that lean is recognized as one of the most effective methodologies for improving production processes. This can be observed in a study in the packaging labeling sector [45]. Where the idea of optimizing first and then automating is followed. This approach contributed to the following: reduced operation times, increased production rates, and better use of human resources. From this perspective, it is an improvement method through which production problems and methods of operation are examined to find a solution that ensures quality and greater efficiency; with this approach, there is a constant search to use fewer resources.

Another case is proposed by Veres [46], aiming to help enterprises take the initial steps in the lean implementation project. A conceptual model was developed to simplify the process and define specific steps to follow. The four phases are: Planning, Training, Development, and Coaching. The model was tested in the healthcare environment, in the Romanian public sector, and the results showed increased productivity, improved employee workplace perception, reduced time loss, reduced movement, and other enhancements.

It is important to mention that Juan de Dios-Pando [17] state that organizations tend to generate the need to implement lean manufacturing tools (TPM, 5S, SMED, Kanban, Heijunka, among others); these tools are useful for competing and excelling efficiently in their industry. In the authors' study, it is revealed that lean manufacturing is essential in the footwear industry because it consists of a set of tools that help eliminate all signs of waste in the production system with the aim of optimizing the enterprise's profits, product quality, and meeting customer needs and demands.

In another study, the practice of the 5S principles in the manufacturing of small and medium-sized enterprises (SMEs) has been widely discussed in scientific studies related to critical success factors (CSF) and challenges for improving organizational performance. The importance of performance measurement for sustaining 5S becomes a strategic value in the improvement process and waste elimination [47].

In this context, there are several examples of successful lean practices in manufacturing and service; to reduce costs, achieve quality, and increase competitiveness. However, some enterprises still do not adopt lean practice. Lean practices are not just about implementing tools but also about developing people and transforming the enterprise culture [23].

***Category 5: Productivity and human talent***

The independent variables, climate, and job satisfaction, although two distinct topics, are related. The former refers to the attributes of the entity, while the latter focuses on the attitudes of its workers in their job [48]. In relation to these variables, it is considered that they are subdivided into the dimensions of leadership and motivation for work climate, while commitment is related to job satisfaction [49].

Therefore, for Ramírez-Torres [50], it is of utmost importance to invest in intellectual capital through knowledge management to increase productivity, competitiveness, and the overall capacity of the enterprise to perform in context. Thus, managerial management in the current globalization framework implies a high level of adaptation to changes for enterprises, in addition to planning, direction, coordination, and control in resource management to enhance their competitive capabilities. Hence, it is important to enhance human behavior at work, increasing people's ability to be efficient and effective by

incorporating and/or appropriating the philosophy, values, and corporate culture of the enterprises. This aims to raise awareness of occupational activity with a socially responsible sense concerning learning, goal achievement based on assigned functions, relationships, and interpersonal and professional growth, among others.

In addition to the above, it is mentioned that there are enterprises that consider human talent a fundamental part of the organization and, therefore, focus on providing workers with training in social areas relevant to their work. This approach aims to create a trustful environment with appropriate instructions for their employment, allowing them to contribute maximally to the enterprise. This leads to the conclusion that the productivity of human talent goes hand in hand with training, as it can have a positive impact on workers, making them more committed to their work. In this way, they navigate smoothly within their workspace without any issues and feel motivated by the effort the enterprise puts into creating an environment of trust, providing suitable knowledge to achieve short and long-term objectives set by the enterprise as a whole [51].

In light of all the above, [52] warns that enterprises should invest and develop in the following areas: research and development (R&D) processes, topics related to human capital, managerial skills, the application of ICTs, healthy virtual workspaces, hybrid work (in-person and virtual), technical competencies, emotional salary, professional development plans within the enterprise, friendly physical and operational infrastructures, social responsibility, creativity and innovation, added value to the job position, motivational leadership, emotional intelligence, among other topics. It is also crucial to observe their impact on personal and team performance. Therefore, it is essential for enterprises to genuinely and comprehensively link the human component of collaborators in the administrative and strategic management of the business as a key success factor. This is driven by the vigor, effort, intellect, ability, and attitude that only the workforce of people can make possible in relation to all the mission processes of enterprises.

## 4 Discussion and conclusions

As a result of the documentary analysis, it is highlighted that efficiency and effectiveness are two interdependent concepts, and when managed together and interrelated, it leads to what is known as productivity. On the other hand, competitiveness refers to the ability of an enterprise or individual to compete in a market, involving the capacity to offer quality products or services at competitive prices. Competitiveness is based on productivity, effectiveness, and efficiency, as a more productive, effective, and efficient enterprise tends to be more competitive in the market.

Therefore, in the business context, the concepts of productivity, efficiency, effectiveness, and competitiveness are fundamental for the success and growth of an enterprise. For this purpose, proper strategic planning, clear task allocation, and effective work organization, along with the correct standardization of processes, can optimize productivity.

Additionally, the use of technologies provides appropriate tools and well-maintained equipment, factors that can enhance productivity in enterprises. Likewise, training, motivation, job satisfaction, and the competence of personnel can influence an enterprise's productivity, underscoring the importance of having trained and motivated employees while fostering teamwork. Similarly, a positive and well-organized work environment, with a collaborative culture and good working atmosphere, can significantly impact productivity.

Moreover, the economic environment, government regulations, competition, changes in market demand, and other external factors can affect an enterprise's productivity. It is important to note that these variables may vary depending on the industry type, enterprise size, and other specific factors in each case.

Implementing productivity techniques and tools in enterprises can help improve efficiency and performance. Identifying and addressing issues affecting productivity and promoting business growth through the development of human talent and integrating the human component into administrative and strategic business management are crucial.

Enterprises should use methodologies and tools to diagnose their processes, and the use of tools from the Toyota production system plays a fundamental role in waste elimination and continuous improvement. To achieve an increase in competitiveness, enterprises use various tools to minimize production costs through process standardization, reducing errors and waste.

Enterprises select specific tools to increase their competitiveness, and one tool they have adopted for continuous improvement is lean manufacturing, transforming it into a strategic tool that involves all areas of the enterprise. Applying this tool in the enterprise eliminates any activity or input that may cause delays in productivity while providing feasible solutions focused on the enterprise’s growth.

Ensuring that responsibilities are evenly distributed and that each team member understands their role and responsibilities promotes greater efficiency and prevents duplicated efforts. Similarly, fostering a culture of continuous improvement, where employees identify and propose ways to optimize existing processes and procedures, encourages team members to provide regular feedback and implement improvements when necessary.

Investing in the training and skill development of employees is also essential. This helps improve their effectiveness and quality of work, as well as their ability to implement new productivity techniques and tools.

Various case studies on productivity in enterprises were analyzed, where some authors implemented a production management model that integrates knowledge and techniques such as 5S or Kanban, highlighting the importance of the human factor. In the case study of the packaging labeling sector, it is stated that the lean methodology has been one of the most effective for improving production processes. Other lean implementation projects, where a model of planning, training, development, and coaching was developed, showed an increase in productivity, an improvement in the perception of the workplace, and a reduction in time and movements.

Adding to the above, we can observe that enterprises that

have applied some lean model or practice have achieved a reduction in waste, time, and streamlined processes, moving towards a culture of continuous improvement.

Productivity and human talent are intrinsically related in an enterprise. Human talent refers to the skills, knowledge, and competencies of the members of a workforce. The effective management of human talent can have a significant impact on the productivity and overall performance of an enterprise.

It is crucial to recruit and select candidates with the right skills for the job. Identifying and hiring talented individuals with potential can increase long-term productivity and ensure a better cultural fit. Investing in employee development and training is essential to harness their talents and skills to the fullest. Providing professional development programs and training opportunities enhances employees' competencies and knowledge, which can boost their productivity.

Effective communication among team members promotes a collaborative work environment and encourages the exchange of ideas and knowledge. Recognizing and rewarding employees' achievements can increase their motivation and commitment. Intrinsically motivated individuals are often more productive and willing to make an effort to achieve results.

Promoting a healthy work-life balance helps employees maintain high levels of energy and commitment. This can prevent burnout and improve job satisfaction, ultimately translating into higher productivity.

In conclusion, with the results of this study, a better understanding of the study object, namely productivity in enterprises, has been achieved. In this regard, further analysis can be conducted in future studies or approaches on the same topic.

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# Reliability prediction for automotive electronics

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**Abstract**
Reliability prediction for electronic products is a fundamental activity for automotive industry for several reasons: 1) understanding if a reliability goal is met, 2) comparing among alternative designs, or 3) evaluating reliability improvements. Reliability prediction is defined by the computation of the failure rates of all system/product electronic components. In the automotive field there are several guides designed for reliability prediction of electronic components, where the Siemens SN 29500 is well accepted by automotive industry. However, the Siemens SN 29500 standard, as well as other standards, gives the basis for failure rate calculation assuming constant environmental conditions, but not a step-by-step process when products are operating under different environments during their field life. Thus, in this article we present a step-by-step process to fully understand the implementation of the Siemens SN 29500 standard, when environment is not constant to obtain the failure rate/reliability value of a product, following an automotive electronic application.

*Keywords*: reliability prediction; failure rate; SN 29500; mission profile; failure in time.

# Predicción de confiabilidad para electrónica automotriz

**Resumen**
La predicción de confiabilidad de productos electrónicos es una actividad fundamental en la industria automotriz por diferentes razones: 1) entender si se cumple con un objetivo de confiabilidad, 2) comparar entre diseños alternativos, o 3) evaluar mejoras de confiabilidad. La predicción de confiabilidad queda definida por el cálculo de la taza de falla de todos los componentes electrónicos que constituyen un sistema/producto. En el campo automotriz existen diferentes guías diseñadas para la predicción de confiabilidad de componentes electrónicos, donde el estándar Siemens SN 29500 es bien aceptado en la industria automotriz. Sin embargo, el estándar Siemens SN 29500, así como otros estándares, da las bases para el cálculo de la taza de falla asumiendo condiciones ambientales constantes, pero no muestra un proceso paso a paso cuando el producto opera en el campo bajo diferentes condiciones ambientales. De esta manera, en este artículo se presenta un proceso paso a paso, para el entendimiento de la implementación del estándar Siemens SN 29500, cuando las condiciones ambientales no son constantes, para obtener un valor de taza de falla/confiabilidad de un producto, siguiendo una aplicación electrónica automotriz.

*Palabras clave*: predicción de confiabilidad; taza de falla, SN 29500; perfil vida; fallas en tiempo.

## 1 Introduction

Automotive electronics industry demands high reliability in field applications, for this reason, it is required to predict the hardware failure rates on early development stages. This knowledge allows us to understand the ability of the product to operate in reliable form under given operation conditions [1], as well as to evaluate designs, compare design alternatives, support test planning, and track reliability improvements [2].

Automotive electronics products can have from hundreds to thousands of components, where the failure rate for each individual component represents its reliability of it and must be predicted. For this purpose, there are several standard-based methods, which categorize components and identify a set of parameters to predict their failure rates. In this sense, predictive models have been developed for electronic components, however, a disadvantage is that the models are not being updated according to the development of new

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technologies [2-5]. Even though, there are many options in automotive field. One of the most preferred standards is the Siemens SN 29500 [6]. Moreover, the standard ISO 26262, used for Functional Safety analysis, recommend its use in Part 5: Product development at hardware level [7].

Additionally, there are a set of software that cover the reliability prediction and include the most frequently used standards [2, 8], however, if there is not a well understanding of the standard, the use of the software or the standard by itself does not facilitate its application. Likewise, training and standards are expensive, and it is difficult to find manuals for application in literature. Then, due to the applicability of the SN 29500 standard for the reliability prediction, this paper provides a step-by-step process for failure rate calculation using this standard in a practical study case. This process could be used as a reference for practitioners in this field.

## 2 Siemens SN 29500 standard

As stated on SN 29500 standard, Siemens standard is mainly used by Siemens AG and Siemens companies as a uniform basis for reliability prediction [9]. Last update was done in November 2016, and it is composed for a total of 12 parts that are shown in Table 1.

Reliability prediction is calculated through failure rates, where failure rate is defined as the proportion of the failures that can be expected on average under given environment and functional operation conditions in a time interval [6]. The SN 29500 standard is recognized as representing a conservative approach to determining failures rates [10], and it specifies the failure rate values in FIT (failures in time), where one FIT corresponds to one failure in $10^9$ component hours.

In first instance, the SN 29500 standard provides reference failure rates ($\lambda_{ref}$), which mean the corresponding component failure rate when it operates under the standard defined reference conditions (time interval, operating voltage, mean ambient temperature, environment, etc) i.e., when the product operates at 40°C degrees.

Since reference condition will not always be the same, the SN 29500 standard also provides conversion models to calculate failures rates depending on stress operating conditions as voltage, current, temperature, among others. For example, eq (1) represents a conversion model to calculate a failure rate under operating conditions:

$$\lambda = \lambda_{ref} \; x \; \pi_U \; x \; \pi_I \; x \; \pi_T \quad (1)$$

where $\lambda_{ref}$ is the failure rate under reference condition, $\pi_U$ is the voltage dependence factor, $\pi_I$ is the current dependence factor, and $\pi_T$ is the temperature dependence factor.

There are several conversion models to be used, the chosen conversion model will depend on the type of component being evaluated as will be seen on section 3.2.

Next section shows the step-by-step process for reliability prediction based on SN 29500 standard through a study case.

Table 1.
SN 29500 standard parts

| Part | Last update | Name |
|---|---|---|
| 1 | 01-2004 | Expected values, general |
| 2 | 09-2010 | Expected values for integrated circuits |
| 3 | 06-2009 | Expected values for discrete semiconductors |
| 4 | 03-2004 | Expected values for passive components |
| 5 | 06-2004 | Expected values for electrical connections, electrical connectors, and sockets |
| 7 | 11-2005 | Expected values for relays |
| 9 | 11-2005 | Expected values for switches and buttons |
| 10 | 12-2005 | Expected values for signal and pilot lamps |
| 11 | 04-2015 | Expected values for contactors |
| 12 | 02-2008 | Expected values for optical components |
| 15 | 11-2016 | Expected values for electromechanical protection devices in low voltage network |
| 16 | 08-2010 | Expected values for electromechanical control pushbuttons, signaling devices and position switches in low voltage networks. |

Source: Siemens SN 29500 standard, 2016.

## 3 Automotive electronic study case

In this paper, a monitor used on a vision system is used as an engineering application example, reliability prediction is calculated by part stress analysis based on field life profile, temperature mission profile, and Siemens SN 29500 standard.

### *3.1 Inputs for the analysis*

Key inputs for a reliability prediction based on a part stress method are Bill of Materials, temperature mission profile, life profile, schematics, and components data sheets.

Bill of Materials (BOM) is the main input, since it shows the components that build all the system. Therefore, it shows the components that must to be evaluated and their reliability to be determined. BOM must have clearly identified the type of component and enough information to track main characteristics of each component as the supplier's name and supplier part numbers.

Study case: Fig. 1 shows the quantity of components for the monitor under analysis, where capacitors and resistors represent more than the 80% of the components in the product.

Temperature mission profile has a direct impact in the components failure rate. Failure rate calculation for some components is dependent on the stress generated by temperature. As temperature increase, the failure rate increase, therefore reliability decrease. Additionally, failure

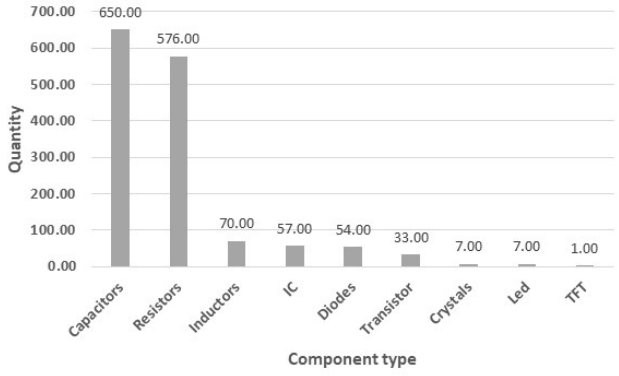


Figure 1. Components distribution by type.
Source: The author, 2024.

Table 2.
Temperature mission profile

| i | Ambient temperature (°C) T | % of expected active life length $\%L_i$ | Tau $\tau_i$ |
|---|---|---|---|
| 1 | -30 | 0.0001% | 0.00000 |
| 2 | -25 | 0.0083% | 0.00003 |
| 3 | -20 | 0.0339% | 0.00013 |
| 4 | -15 | 0.1858% | 0.00073 |
| 5 | -10 | 0.5918% | 0.00232 |
| 6 | -5 | 3.2056% | 0.01256 |
| 7 | 0 | 7.1742% | 0.02811 |
| 8 | 5 | 12.4835% | 0.04891 |
| 9 | 10 | 12.0191% | 0.04709 |
| 10 | 15 | 17.4888% | 0.06852 |
| 11 | 20 | 18.0311% | 0.07064 |
| 12 | 25 | 14.7121% | 0.05764 |
| 13 | 30 | 8.3714% | 0.03280 |
| 14 | 35 | 4.3508% | 0.01705 |
| 15 | 40 | 1.1150% | 0.00437 |
| 16 | 45 | 0.2286% | 0.00090 |
| | **Total** | 100% | 0.39178 |

Source: The author, 2024.

rate will be lower if the distribution of the percentage of expected active life length is centered on the mean ambient temperature. If expected active life length is skewed on high temperatures, it will represent a higher failure rate.

**Study case:** Table 2 is the temperature mission profile for the monitor under analysis. Monitor is expected to operate on environments between -30°C to 45°C, where the 75% of the operating time is concentrated between 5°C to 25°C.

Life profile is the factor used at the end of the analysis and represents the estimated operation time (in hours) of the product when it works in the field. Reliability prediction will be calculated by using the total failure rate and the estimated operation time as seen on section 3.4.

**Study case:** Table 3 is the life profile for the monitor, where it is designed to operate 10 years, for a total of 34,320 hr on operation.

Where Tau is the annual ratio of time for the product in permanent working mode, and based on Table 2 and Table 3 data, is given by

$$\tau_i = \left(\frac{T.op.time}{T.op.time + T.non\ op.time}\right) x\ \%L_i \qquad (2)$$

Finally, the schematic and data sheets are used for the correct calculation of the operational parameters to be defined in section 3.3. Schematic is used to define, among other things, component location, operation voltages, relationship with other components, etc. On the other hand,

Table 3.
Life profile

| | |
|---|---|
| Years of operation | 10 |
| Weeks operation per year | 52 |
| Days operation per week | 6 |
| Hours operation per day | 11 |
| Average driving speed [km/h] | 45 |
| Operation per year [h] | 3,432 |
| Total operation time [h] ($t_{op}$) | 34,320 |
| Total non-operation time [h] ($t_{non\ op}$) | 53,280 |

Source: The author, 2024.

Table 4.
Failure rates for resistors

| Resistors | | $\lambda_{ref}$ in FIT | $\theta_l$ in °C |
|---|---|---|---|
| Carbon film | ≤ 100 kOhm | 0.3 | 55 |
| | > 100 kOhm | 1 | 55 |
| Metal film | | 0.2 | 55 |
| Network per resistor element | | | |
| | Standard | 0.1 | 55 |
| | Custom design | 0.5 | 55 |
| Metal-oxide | | 5 | 55 |
| Wire-bound | | 5 | 55 |
| Variable | | 30 | 55 |

Source: Siemens SN 29500 standard, 2016.

data sheets are used to get components key parameter as rated power dissipation (W), maximum temperature (°C), temperature at the break point of the power derating curve (°C), rated voltage (V), etc.

### *3.2 Components classification*

Based on the BOM, types of components need to be identified as seen on Fig. 1. Then, the first step is, depending on the type of component, identify the corresponding part of the SN 29500 standard as per Table 1.

Next, look for the table related to the component and select the classification of the component that best match with the component characteristics. As example for a resistor, each of the 576 resistors that are part of the Monitor shall be classified according to Table 4. This procedure should be repeated for all components based in the corresponding part of the standard SN 29500 and the table related to the component, each type of component has its own table for classification.

Classification will define the reference failure rate ($\lambda_{ref}$), the corresponding equation for the failure rate calculation of each component and the constant values to be used in the calculation.

Once that each component has been classified, next step is to apply a conversion from reference to operating conditions as explained in next section.

### *3.3 Conversion models*

Classification of each component define the equation for failure rate calculation, in other word, classification define the corresponding conversion model.

Failure rate for each component should be estimated based on equations from Table 5. Where failure rate is given for a reference failure rate and multiplication factors that represent different types of stresses as temperature. Depending on the type of component and the classification, standard SN 29500 should be reviewed to determine the correct equation, Table 5 shows the general equations for each type of component, but depending on the classification some stress factor may not apply. As example, for Capacitors eq. 4 apply as it is in Table 5. For Resistors and Inductors eq. 4 apply but considering only reference failure rate and temperature dependence factor ($\pi_T$). For other passive components only reference failure rate is considered.

Table 5.
Conversion models

| Components | Reliability general conversion model | Equation number |
|---|---|---|
| Integrated circuits and discrete semiconductors | $\lambda = \lambda_{ref} \times \pi_U \times \pi_T \times \pi_D$ | (3) |
| Passive components | $\lambda = \lambda_{ref} \times \pi_U \times \pi_T \times \pi_Q$ | (4) |
| Relays | $\lambda = \lambda_{ref} \times \pi_L \times \pi_E \times \pi_T \times \pi_K$ | (5) |
| Switches and buttons | $\lambda = \lambda_{ref} \times \pi_L \times \pi_E$ | (6) |
| Signal and pilot lamps | $\lambda = \lambda_{ref} \times \pi_U$ | (7) |
| Contactors | $\lambda = \lambda_{ref} \times \pi_S \times \pi_U \times \pi_I \times \pi_T \times \pi_E$ | (8) |
| Optical components | $\lambda = \lambda_{ref} \times \pi_U \times \pi_T \times \pi_I$ | (9) |
| Protection devices | $\lambda = \lambda_{ref} \times \pi_U \times \pi_I \times \pi_T \times \pi_S \times \pi_E$ | (10) |

Source: Siemens SN 29500 standard, 2016.

In Table 5, $\lambda$ is the operating failure rate, $\lambda_{ref}$ is the reference failure rate, $\pi_U$ is the voltage dependence factor, $\pi_T$ is the temperature dependence factor, $\pi_D$ is the drift sensitivity factor, $\pi_Q$ is the quality factor, $\pi_L$ is the load dependence factor, $\pi_E$ is the environment dependence factor, $\pi_K$ is the failure criterion factor, $\pi_S$ is the switching rate factor, and $\pi_I$ is the current factor.

It is important to mention, that every stress factor ($\pi$) is represented by a stress model, and the inputs for the stress model are the constants given by the SN 29500 standard and the operational parameters, that are the factors that the standard is unable to define and need to be calculated based on normal/nominal field operation of the product, i.e. power dissipation of a component.

Model $\pi_T$, as example for resistors, is given by Eq. (11)

$$\boldsymbol{\pi_T} = \frac{\boldsymbol{A\ x\ exp(Ea_1\ x\ z) + (1-A)\ x\ exp(Ea_2\ x\ z)}}{\boldsymbol{A\ x\ exp(Ea_1\ x\ z_{ref}) + (1-A)\ x\ exp(Ea_2\ x\ z_{ref})}} \quad (11)$$

With

$$\boldsymbol{z = 11605\ x\ \left(\frac{1}{\theta_{U,ref} + 273} - \frac{1}{\theta_2 + 273}\right)\ in\frac{1}{eV}} \quad (12)$$

Where

$$\boldsymbol{\theta_2 = \theta_U + \Delta\theta\ \ in}\ ℃ \quad (13)$$

$$\boldsymbol{\Delta\theta = P + R_{th}} \quad (14)$$

and

$$\boldsymbol{z_{ref} = 11605\ x\ \left(\frac{1}{\theta_{U,ref} + 273} - \frac{1}{\theta_1 + 273}\right)\ in\frac{1}{eV}} \quad (15)$$

where A, $Ea_1$ and $Ea_2$ are constants given by the standard, $\theta_1$ is the average reference surface temperature in °C from Table 4 and $\theta_2$ is the average actual surface temperature. Then, $\theta_2$ is a key parameter, because the field calculations will be reflected in it. $\theta_2$ is dependent on $\theta_U$, that is the average actual ambient temperature, and this value comes from the mission temperature profile. $\Delta\theta$ represents the temperature rise due to self-heating of the component and is given by the thermal resistance ($R_{th}$) in K/W and the operating power dissipation (P) in watts (need to be calculated).

Similar process must be repeated for the component corresponding stress factor, where elements as the operating power dissipation (P), operating voltage (U), must be calculated, and the elements as rated power dissipation ($P_{max}$), maximum temperature ($\theta_{max}$), temperature at the break point of the power derating curve ($\theta_{br}$) must be consulted on components data sheets, as part of the inputs for the analysis.

### *3.4 Failure rate*

Failure rate is the number of failures per unit time that can be expected to occur for the product and is denoted by $\lambda$. Calculations for failure rate in the SN 29500 standard are given in Failure in Time (FIT), that represents one failure per $10^9$ component hours. Then, FIT calculation for each component will be dependent on the temperature mission profile, the corresponding conversion model and the applicable operational parameters, where the calculation for each component is given by

$$\lambda_{comp} = \frac{\sum_{i=1}^{n}(\lambda_i\ x\ \%L_i)}{\tau_{total}} \quad (16)$$

Study case: Table 6 shows the process to calculate the component failure rate where a resistor has been taken as example. Resistor under analysis has been classified, according to Table 4, as a "Metal oxide" resistor, then conversion model is given by $\lambda = \lambda_{ref} \times \pi_T$. For the application of the conversion model, it is considered that $\Delta\theta$ is not significant (equal zero), this due to measurements in the printed circuit board (PCB) while operating.

Once that failure rate (in FIT) has been calculated for each mission profile temperature from Table 2, eq. 16 is applied, then, from Table 6, FIT value for the resistor under analysis is $\lambda_{comp}$ = 0.4044 / 0.3918 = 1.0322. This process must be followed for each single electronic component.

Table 6.
FIT value for a resistor

| i | Ambient temperature (°C) T | % of expected active life length $\%L_i$ | Tau $\tau_i$ | FIT $\lambda_i$ | $\lambda_i$ x $\%L_i$ |
|---|---|---|---|---|---|
| 1 | -30 | 0.0001% | 0.00000 | 0.2816 | 0.0000 |
| 2 | -25 | 0.0083% | 0.00003 | 0.3292 | 0.0000 |
| 3 | -20 | 0.0339% | 0.00013 | 0.3828 | 0.0000 |
| 4 | -15 | 0.1858% | 0.00073 | 0.4428 | 0.0003 |
| 5 | -10 | 0.5918% | 0.00232 | 0.5099 | 0.0012 |
| 6 | -5 | 3.2056% | 0.01256 | 0.5847 | 0.0073 |
| 7 | 0 | 7.1742% | 0.02811 | 0.6679 | 0.0188 |
| 8 | 5 | 12.4835% | 0.04891 | 0.7604 | 0.0372 |
| 9 | 10 | 12.0191% | 0.04709 | 0.8630 | 0.0406 |
| 10 | 15 | 17.4888% | 0.06852 | 0.9770 | 0.0669 |
| 11 | 20 | 18.0311% | 0.07064 | 1.1036 | 0.0780 |
| 12 | 25 | 14.7121% | 0.05764 | 1.2441 | 0.0717 |
| 13 | 30 | 8.3714% | 0.03280 | 1.4005 | 0.0459 |
| 14 | 35 | 4.3508% | 0.01705 | 1.5745 | 0.0268 |
| 15 | 40 | 1.1150% | 0.00437 | 1.7685 | 0.0077 |
| 16 | 45 | 0.2286% | 0.00090 | 1.9851 | 0.0018 |
| | Total | 100% | 0.39178 | | 0.4044 |

Source: The author, 2024.

After completion of above activity, the failure rate of the product is calculated by summing up the failure rates of each component in each category, this is based on the assumption that a failure of any component leads to a system failure

$$\lambda_{sys} = \sum_{i=1}^{n} \lambda_{comp} \quad (17)$$

On the other hand, there are situations where other sources have to be followed to obtain the component FIT value. Situations as:

- Standard SN 29500 defines little operating experience for a specific condition.
- Classification by the SN 29500 does not completely match with the component. This situation is given by new technologies in components that are not included in the last revision of the standard.
- Component supplier already has reliability data.

### 3.4.1 Manufacturer reliability datasheet

A simple way to obtain reliability data, when available, is to review the components data sheets that can be found on suppliers' portal, sometimes referenced as Reliability or MTBF or FIT estimator.

### 3.4.2 Accelerated life testing

Accelerated life testing is performed generally by the component supplier, where the failure rate of the component is given by the model

$$\lambda_{comp} = \frac{\chi^2/2(r, CL)}{Device\ hours} \quad (18)$$

where $r$ is the number of failures and $CL$ is the confidence level. $\chi^2/2$ (r,CL) value can be obtained using Table 7 .

And

$$Device\ hour = sample\ size\ x\ test\ duration\ x\ AF \quad (19)$$

Sample size is the total amount of components under test, test duration is the sum of test time of all components, and AF is the acceleration factor that is given by the Hallberg-Peck model

$$AF = AT\ x\ AH \quad (20)$$

where

$$AT = e^{\frac{Ea}{k}\left(\frac{1}{K_n} - \frac{1}{Ks}\right)} \quad (21)$$

and

$$AH = \left(\frac{RH_s}{RH_n}\right)^m \quad (22)$$

Table 7.
$\chi 2/2$ (r,CL)

| Failures | Confidence level (%) | | | |
|---|---|---|---|---|
| | 50 | 60 | 90 | 95 |
| 0 | 0.6 | 0.93 | 2.31 | 2.96 |
| 1 | 1.68 | 2 | 3.89 | 4.67 |
| 2 | 2.67 | 3.08 | 5.3 | 6.21 |
| 3 | 3.67 | 4.17 | 6.7 | 7.69 |
| 4 | 4.67 | 5.24 | 8 | 9.09 |
| 6 | 5.67 | 6.25 | 9.25 | 10.42 |
| 7 | 6.67 | 7.27 | 10.55 | 11.76 |
| 8 | 7.67 | 8.33 | 11.75 | 13.16 |
| 9 | 8.67 | 9.35 | 13 | 14.3 |
| 10 | 9.67 | 10.42 | 14.2 | 15.63 |

Source: Vishay, 2008

*AT* is the Arrhenius model, *Ea* is the activation energy in eV, *k* is the Boltzman constant, *Kn* is the reference temperature, *Ks* is the test temperature. *AH* is the Humidity model, *RHn* is the reference humidity, *RHs* is the test humidity and *m* is the humidity acceleration factor.

### 3.4.3 Field data

Some components have not data from testing to determine the failure rate, but instead, there is field warranty data to estimate it. Then, failure rate, based on exponential distribution, is obtained as:

$$F(t) = 1 - e^{-\lambda t} \quad (23)$$

then

$$\lambda = -\left[\frac{ln(1 - F(t))}{t}\right] \quad (24)$$

where

$$F(t) = \frac{Functional\ field\ faults}{Produced\ samples} \quad (25)$$

and

$$t = \frac{Operating\ time\ per\ day\ (hr)}{Operation\ days} \quad (26)$$

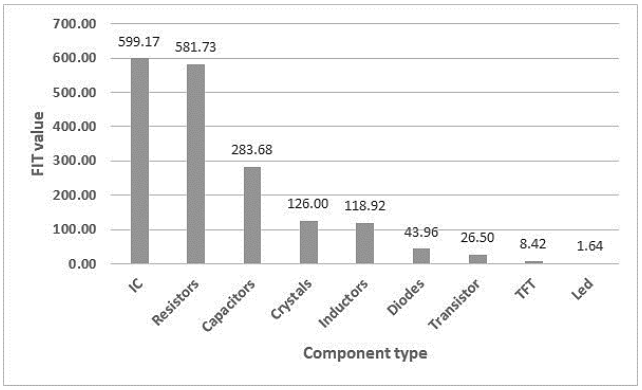


Figure 2. FIT values distribution by component type.

Source: The author, 2024.

**Study case**: Monitor FIT values distribution by component type is shown in Fig. 2. Total FIT value for the monitor is FIT = 1790.03, where the ICs, resistors and capacitors represents the 80% of the FIT value.

Finally, FIT value for the system in conjunction with the life profile will result in the system reliability as explained in next section.

### *3.5 Reliability prediction*

For reliability prediction based on SN 29500, the failure rate is assumed to be a constant, then the distribution of the failure time is exponential. In this way, the reliability for the system is given by:

$$\boldsymbol{R(t) = e^{-\lambda_{sys}\, x\, t_{op}}} \tag{27}$$

where $\lambda_{sys}$ is the system failure rate as per sec. 3.4 and $t_{op}$ is the total operation time from Life profile on Table 2.

Study case: Reliability for monitor is given by the exponential distribution, $\lambda_{sys}$ = 1790.03 and total operation time $t_{op}$ = 34,320 hr. Then, Table 8 summarize calculations for reliability based on eq. 27.

Table 8.
Reliability prediction

| Parameter | Value |
|---|---|
| FITs | 1,790.03 |
| Lambda (λ) | 1.790E-06 |
| MTTF=1/λ | 558,650.25 |
| $t_{op}$ | 34320 |
| $\lambda * t_{op}$ | 6.14E-02 |
| Reliability=e^(-λt) | 0.9404 |
| Unreliability = 1-Reliability | 0.0596 |

Source: The author, 2024.

After analysis is completed, it can be concluded that reliability for the system is 94.04%.

## 4 Conclusions

Reliability prediction is a useful tool on automotive industry that can be used since the beginning of any product design, were the calculation of a reliability value will provide basis to define if a target for the project is met, if a design is better than other one or simply, to evaluate any design improvement to be made.

For reliability prediction based on Siemens SN 29500 standard, this paper provides a guide for practitioners with valuable information for the implementation when it is known that a product is subjected to a variable and changing environment during its useful life.

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# Integrative approach for formation damage diagnosis in a Colombian brownfield: a comprehensive methodology

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**Abstract**
Formation damage is the reduction of a well's productivity due to the alteration of the permeability of the subsurface rock, leading to economically inefficient operations. This research established a methodology to diagnose such damage, which is divided into: 1) Identification of operational problems, 2) Field sampling and analysis of geological and engineering data, 3) Adaptation of API standards for the study of fluid-fluid and rock-fluid interactions, 4) Identification of damage mechanisms and recommendations. This methodology was applied to two depleted wells in a brown oilfield with reduced productivity to address scale deposition and casing corrosion issues. Finally, the application of control and stimulation fluids must satisfy technical and environmental requirements, with the objective of inducing destabilization of the identified formation damage mechanisms.

*Keywords*: formation damage diagnosis; workover; rock-fluid interaction; fluid-fluid interaction; emulsion.

# Enfoque integrador para el diagnóstico de daño de formación en un campo maduro colombiano: una metodología integral

**Resumen**
El daño de formación es la reducción de la productividad de un pozo debido a la alteración de la permeabilidad de la roca subsuperficial, conduciendo a operaciones económicamente ineficientes. Esta investigación estableció una metodología para diagnosticar dicho daño, la cual se divide en: 1) Identificación de los problemas operativos, 2) Toma de muestras de campo y análisis de datos geológicos e ingenieriles, 3) Adaptación de las normas API para el estudio de las interacciones fluido-fluido y roca-fluido, 4) Identificación de los mecanismos de daño y recomendaciones. Esta metodología se aplicó a dos pozos depletados en un yacimiento con baja productividad para abordar los problemas de deposición de incrustaciones y corrosión. Finalmente, la aplicación de fluidos de control y estimulación deben cumplir los requisitos técnicos y medioambientales, con el objetivo de inducir la desestabilización de los mecanismos de daño a la formación identificados.

*Palabras clave*: diagnóstico de daños en la formación; reacondicionamiento; interacción roca-fluido; interacción fluido-fluido; emulsión.

## 1. Introduction

In relation to the energy demand levels of the year 2020, it is expected that global energy demand will escalate by 14% in the more moderate scenarios to as much as 53% in the more ambitious scenarios by the year 2050. Nevertheless, despite the incorporation of renewable energies, the energy matrix will remain reliant on fossil fuels such as coal, oil, and

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natural gas [1]. The rate of discovery of giant reservoirs reached its zenith in the late 1960s, among which approximately thirty account for half of the world's reserves, with the majority classified as brown fields. Consequently, the efficient development of these fields needs the application of economically practical techniques, alongside proper reservoir management [2]. Prevention and diagnosis of formation damage are imperative in well operations, as the economic viability of any project hinges upon the capability to produce hydrocarbon volumes at proper rates [3,4]. Technically defined, formation damage encompasses any process responsible for inducing localized alterations in the initial permeability characteristics, resulting in diminished performance of productive or injector wells [3-8], potentially leading to the complete shutdown of wells [9]. Formation damage can occur at any stage of a well's lifecycle, whether during drilling, completion, stimulation, or workover/service operations [4,8].

The comprehension of formation damage mechanisms and their origins holds paramount significance, as the formulation of strategies and remediation treatments for achieving the restoration of original or near-original well productivity hinges upon them. Various methodologies have been proposed for the assessment and determination of formation damage mechanisms affecting reservoir operability [10-12]. Nevertheless, no single test or tool exists that can comprehensively supply the necessary information for identifying and evaluating formation damage, underscoring the value of a systematic approach [5]. The rationale behind the paramount importance of the know & how of professionals conducting formation damage diagnosis.

In line with the context, the purpose of this study is to present a systematic methodology for the evaluation and diagnosis of formation damage within a brownfield situated in the Middle Magdalena Valley Basin, Colombia. The study aims to document the identified formation damage mechanisms after each intervention process in two designated wells, referred to as A and B, located within the study field. Furthermore, the study aims to supply recommendations for the remediation of the encountered formation damage in a brownfield.

## 2. Experimental section

Identification of causes behind well injection or production decline, known as formation damage diagnosis, requires a multidisciplinary approach [13], integrating geological and engineering information [7,10,14], as well as the incorporation of various knowledge fields, such as organic/inorganic chemistry, physicochemistry, colloid and interfacial sciences, chemical kinetics, mineralogy, diagenesis, and porous media flow [8].

Initially, formation damage was detected through a reduction in the water injection rate or oil well productivity index. Subsequently, well samples were collected, including crude oil, formation water, precipitates (carbonate, asphaltene, wax), injection water and fluids used in operations. Additionally, a pre-diagnosis was performed by analyzing available geological and engineering information, encompassing lithostratigraphy, reservoir structural configurations, facies analysis, diagenetic processes, reservoir fluid properties, petrophysical properties, drilling history, well service and intervention records, well logs, production history, and pressure analysis results. After that, laboratory tests were done, adapted from API-RP 42B and API-RP 13B standards, which were categorized into basic fluid and rock characterization, and the study of rock-fluid and fluid-fluid interactions [15,16]. Finally, the formation damage was diagnosed based on the pre-diagnosis analysis and laboratory results obtained in the earlier steps.

To comprehensively diagnose formation damage, it was essential to have well-specific information such as petrophysical data, geological context, mechanical conditions, intervention history, production history, and prior studies. Additionally, knowledge of rock mineralogy and basic characterization of reservoir and external fluids was vital. This collective information yields an overarching perspective on potential formation damage mechanisms [3,7,10,17].

### *2.1 Materials and reagents*

For compatibility and emulsion tests, it was necessary to have samples of native reservoir fluids taken at the wellhead. In the absence of formation water, it was possible to synthesize it in the laboratory based on physicochemical characterization results, following standard methods for the examination of water and wastewater (methods: S.M 2540 D, S.M 2540 C, and S.M 2540 B).

### *2.2 Geological and engineering information*

Formation damage assessment requires a systematic approach encompassing research, planning, and comprehensive analysis of all available information [3,18]. This information may encompass geological and engineering data such as lithostratigraphy, structural configurations, facies analysis, and diagenetic processes [7,10,18], reservoir fluid properties, petrophysical characteristics, well history, production records, well logs, and pressure analysis results [7,11,21,17]. In this study, geological, petrophysical, reservoir, and fluid characteristics data were compiled and interpreted. The well's life history, including mechanical status, drilling logs, completions, and intervention history, was also scrutinized.

### *2.3 API gravity*

The API gravity of the examined crude oil samples was determined following the procedures outlined in the ASTM standard D287 – 22, employing the hydrometer method [19].

### *2.4 Micrograph acquisition*

High-quality microscopic images were captured using a Nikon SMZ445 C-PSC stereoscope, enhancing the precision and detail of crude oil-in-water, water-in-crude, and mixed emulsions, as well as in exploring their destabilization dynamics.

### *2.5 Basic Sediment and Water measurement (BSW)*

The estimation of water and sediment content was done using the centrifuge method by the procedure outlined in ASTM standard D4007–22 [20].

### *2.6 Viscosity*

Viscosity measurements were assessed using a Brookfield DV2T® viscometer adapted to a temperature-controlled circulating bath with a propylene glycol solution. Each viscosity measurement used 50 mL of the sample to assess the temperature effect between 25 to 80 °C.

### *2.7 Cation Exchange Capacity (CEC)*

The test procedure for determining the CEC was modified from the API RP 13B-1 2014 standard for field evaluation of water-based drilling fluids and is described as follows [21]: A 0.01 N methylene blue (MB) solution was prepared with deionized water. After that, 10 g of rock was mixed with 30 mL of deionized water. The rock suspension was then treated with methylene blue (MB) solution in 0.5 mL increments. Following each 0.5 mL addition of MB, the rock mixture underwent magnetic stirring for 1 minute and a small aliquot was extracted and deposited onto Fisher brand filter paper. The development of a persistent blue halo around the rock aggregate spot on the filter paper signified the displacement of cations in the double layer by MB, coating the entire surface.

The cation exchange capacity was calculated using eq. (1), where CEC is the cation exchange capacity, $C_h$ is a volumetric constant equivalent to 100, $V_m$ is the volume of methylene blue solution in mL, $C_m$ is the concentration of methylene blue (0,01 meq/mL), and $W_s$ is the weight of the rock sample used.

$$\mathrm{CEC} = \frac{C_h \times V_m \times C_m}{W_s} \quad (1)$$

### *2.8 X-ray diffraction*

Rock samples were analyzed using powder X-ray diffraction (XRD) technique. For this purpose, the sample was homogeneously ground using a mortar and pestle until a grain size capable of passing through a 400-mesh sieve was achieved. Subsequently, the prepared sample was placed onto a sample holder and positioned in the Bruker D8 Advance® diffractometer.

The analysis covered a 2θ measurement range from 3.5° to 70°, with a sampling time of 0.6 s, using CuKα1 radiation. The resulting diffractogram was processed and analyzed using the DIFFRAC.EVA software with the 2022 database.

### *2.9 Visual wettability*

API RP-42 outlines a qualitative visual wettability test designed for the rapid assessment of a fluid's inclination to wet a solid surface. The test used a sample extracted from the reservoir, introducing 10 mL of the clean reservoir sample into a 50 mL test solution. Following a half-hour contact period, the mixture underwent decantation, and a specific quantity was applied to two glass slides—one with formation water and the other with varsol filtered through silica gel.

The reservoir sample was then deposited onto the glass slides, and the relative dispersion of particles, or their propensity to form clusters in the aqueous and oil phases, was seen. The presence of dispersion showed that the sand was wetted by the medium, while the formation of clusters suggested non-wettability by the medium [15].

### *2.10 Fluid – fluid/rock compatibility*

Compatibility test supplies a qualitative analysis of the interactions between fluids and rock formation, allowing the study of the generation or absence of precipitates, formation of new phases, emulsions, and undesired phenomena. During the test, different proportions of fluids (crude oil - production brine or crude oil - injection brine) were mixed in 100 mL Schott bottles at ratios of 20:80, 50:50, and 80:20. Additionally, solids such as formation sand, inorganic scales, and metal coupons were introduced. Once the compatibility mixtures were prepared, testing were conducted at the reservoir temperature of 68°C. The compatibility between fluid - fluid and rock - fluid was examined at initial time intervals of 0, 0.5, 1, 2, 4, 6, and 24 hours to identify phase changes. As the test is qualitative, the results indicate abnormal phases. A total of 17 experiments were carried out, including compatibility between injection water - synthetic formation brine, crude oil - formation water, crude oil - (synthetic formation brine + injection water) - sand, and crude oil - (synthetic formation brine + injection water + scale inhibitor, corrosion inhibitor) - sand - organic scales. The nomenclature to describe the results is as follows:


Compatible

Incompatible

### *2.11 Emulsion formation*

In evaluating emulsion tendencies, a mixer was employed to combine crude oil, formation/production waters, and sand at 1,800 rpm for 60 s. The occurrence of any form of emulsion after 24 hours at room temperature is considered indicative of unfavorable performance.

## 3 Results and discussion

### *3.1 Depositional environments and lithostratigraphy*

The study area is in the Middle Magdalena Valley Basin in Colombia, which covers an area of 30,000 km² [22]. It is situated in the northern part of Colombia along the middle portion of the valley, traversed by the Magdalena River, between the Central and Eastern Cordilleras of the Colombian Andes [22-24], spanning the departments of Boyacá, Santander, Cundinamarca, and Antioquia [23].

To the north, its boundary is defined by the presence of the Espíritu Santo fault system. In the northeastern direction,

its limit is proved in relation to the Bucaramanga-Santa Marta fault system. To the southeast, its border is marked by the Bituima and La Salina fault systems. To the south, its extent is in proximity to the Girardot fold belt. Finally, on its western boundary, it contacts the Neogene deposits of the Serranía de San Lucas, as well as the basement of the Central Cordillera [22,24].

The uplift of the Central and Eastern Cordilleras gave rise to the opening where the Middle Magdalena Valley Basin was deposited during the Mesozoic [25]. The basin's filling is characterized by calcareous and siliciclastic sediments, resulting from the development of an epicontinental transgression process from the Triassic to the early Cenozoic. The Paleogene sequence is primarily composed of siliciclastic rocks deposited under continental conditions with some marine influence [22,24-26]. The stratigraphic sequence of the Middle Magdalena Valley Basin is shown in Fig. 1, supplying a visual representation of the geological layers.

### *3.2 Engineering data*

In this study, the mechanisms of formation damage in two wells, named A and B, were investigated in a brown oil and gas producing field. The mechanical states of the wells, along with pressure logs and analyses, indicate the presence of gas in the upper production intervals and oil in the lower intervals, showing a pronounced depletion over time since the start of their production life. Fig. 2 provides a schematic representation of the mechanical states, highlighting the depths of the perforated intervals. The wells are characterized by gas production from the upper intervals through the annulus and oil production from the lower intervals through tubing with mechanical pumping, in a dual production scheme. The main difference between the evaluated wells lies in the depth of their completed production zones.

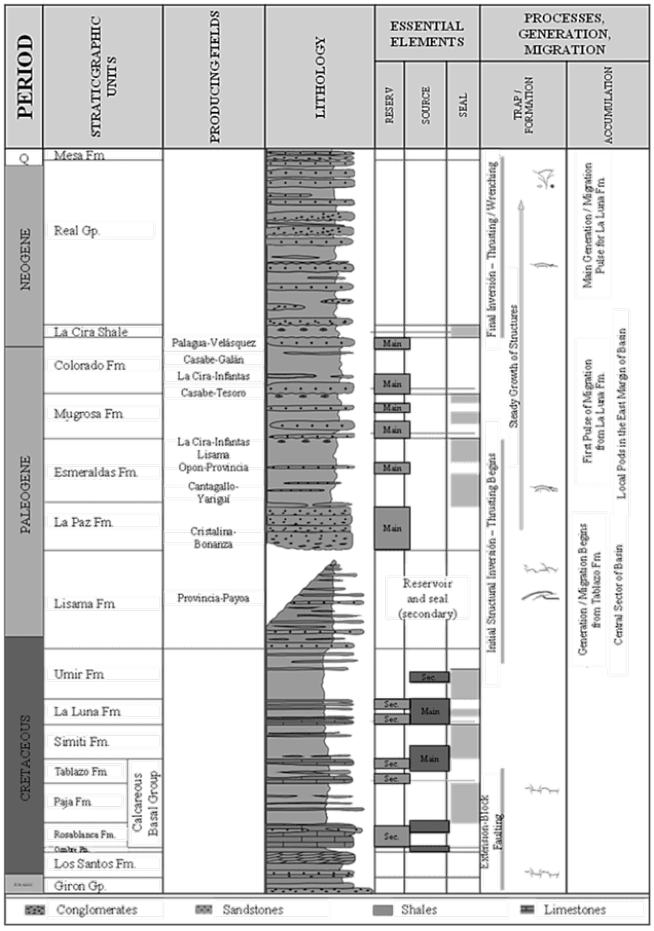

Figure 1. Stratigraphic Column of the Middle Magdalena Valley Basin. Source: Authors.

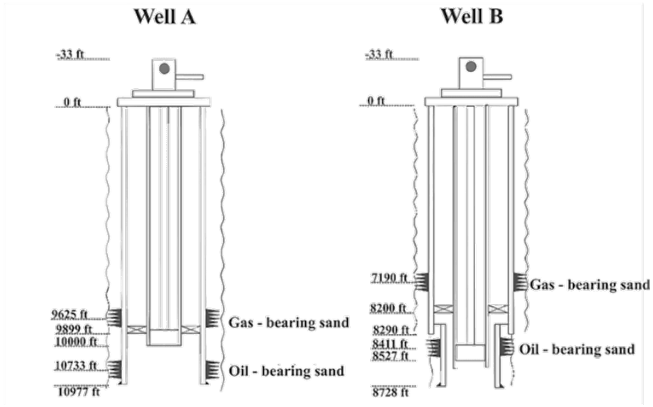

Figure 2. Schematic Representation of the Mechanical States of Wells A and B. Source: Authors.

Table 1.
Relevant production data from wells A and B.

| Well | ALS | API gravity (°) | $Q_o$ (Bbl/ day) | $W_{cut}$ (%) | $Q_g$ (MSCF/ day) | Note |
|---|---|---|---|---|---|---|
| A | BP | 21 | 12 | 60 | N/A | High water cut |
| B | BP | 23 | 5 | 20.5 | 620 | Low water cut |

Source: Authors.

Throughout their productive life, the wells have been intervened for cleaning or stimulation operations. However, they show adverse behaviors in terms of decreased productivity following the completion of interventions [27,28]. Similarly, at the laboratory level, damage to the formation at the pore scale caused by acid stimulation processes during well interventions has been identified.

Table 1 presents initial production data of the wells under evaluation, emphasizing that well A exhibits significantly higher water production, which has had a negative impact on gas extraction. As a proposed hypothesis, it could be set up that the fluids used in workover, control, and/or completion operations in the wells (such as production water and/or crude oil intended for sale) could be the cause of this impact.

### *3.3 Identification of pseudo damage following information analysis*

Following the comprehensive analysis of data pertinent to the study field, encompassing geological interpretation, petrophysical properties, detailed drilling records,

completion parameters, historical intervention records, earlier production patterns, and subsequent mechanical states, the correct identification of detrimental mechanisms that lead to the impairment of formation integrity was achieved.

### *3.4 Inorganic scales*

Throughout the production cycle of the wells, and during conventional operational activities, the occurrence of organic deposits in the production tubing has been documented, with a significant presence of calcium carbonates. Different studies have reported that scale precipitation is one of the most common formation damage mechanisms during the production stage of wells [29]. The formation of carbonate scales is a direct function of factors that affect the thermodynamics, kinetics, and hydrodynamics of the environment, which can include changes in pressure, temperature, pH, concentration of calcium and bicarbonate ions, and ionic strength [12,30,31]. Fig. 3 displays the compositional characterization of ions present in the formation water, revealing a tendency for scaling ions, which may have been accelerated by the natural decline in reservoir pressure.

### *3.5 Organic scales*

Detection of waxes and asphaltenes has been regularly documented, recorded in the historical records of interventions carried out in the wells. Similarly, during the evaluation of the previously conducted crude composition analyses, the asphaltic and paraffinic nature of these samples becomes clear. These elements are prone to precipitate and/or flocculate if destabilization processes occur, because of changes in pressure and temperature throughout the production history of the field, especially in wells where the upper gas sands are cooling the liquid stream within the well due to Joule-Thompson effect [32-34].

### *3.6 Emulsions*

Emulsions can be generated due to incompatibilities between fluids present in the formation and exogenous fluids [5]. These emulsions can lead to permeability reduction by plugging pore throats [35]. The primary evidence lies in the reported BSW values in production records, which reflect heavily emulsified crudes with high water production. Additionally, the use of significant amounts of demulsifier in treatment schemes further supports this observation.

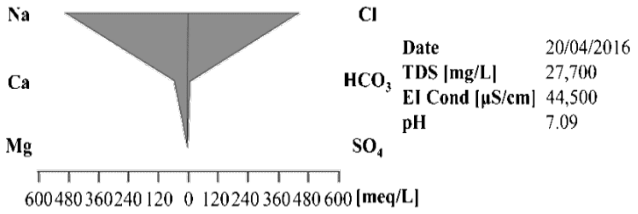


Figure 3. Compositional characterization of formation water ions.
Source: Authors.

Table 2.
Experimental values of °API and %BSW for the crude oils from wells A and B.

| Well | API gravity (°) | BSW (%) |
|---|---|---|
| A | 16.5 | 40 |
| B | 24.9 | 14 |

Source: Authors.

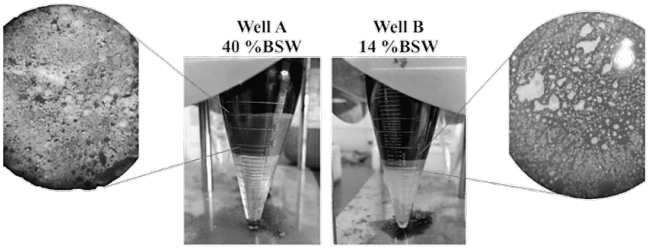


Figure 4. Micrographs of the emulsions, post-centrifuge method, for wells A and B.
Source: Authors.

### *3.7 Basic fluid characterization*

The quantified values of API gravity and the percentage of water and sediment (%BSW) are presented in Table 2. These measurements align with the production data recorded for the wells. Undoubtedly, despite the similarity in the origin of the produced fluids, their nature differs. The crude oil from well A shows higher density, a phenomenon attributed to emulsification, in comparison to the crude oil from well B. Different authors reported that the density of emulsified crudes can increase by up to 28.75% [36,37].

To gather evidence of emulsion formation in each of the crude oils, micrographic images of the emulsified fluids were taken for analysis. The captured micrographs of both emulsions are shown in Fig. 4.

These images reveal a lower percentage of emulsified fluid for crude oil B, further confirming the disparity in emulsifying nature between the two studied crude oils. Both fluids show the formation of multiple emulsions of the crude-oil-water-crude type (O/W/W), which are characterized by a strong tendency towards stability.

### *3.8 Study of reactivity of present clays*

In a preliminary phase, cation exchange capacity (CEC) tests were done on sand samples extracted from the gas-generating and oil-producing formations. These tests were done in two contexts: one with the inclusion of formation water and another with injection water. The results are

Table 3.
Results of CEC for ditch samples from the gas – bearing sand and oil – bearing sand.

| Sample | Cation Exchange Capacity (CEC) [meq/100 g] | |
|---|---|---|
| | Presence of formation water | Presence of injection water* |
| Gas – bearing sand | 12 | 10 |
| Oil – bearing sand | 10 | 8 |

* Note. Injection water refers to the water used to prepare control and stimulation fluids.
Source: Authors.

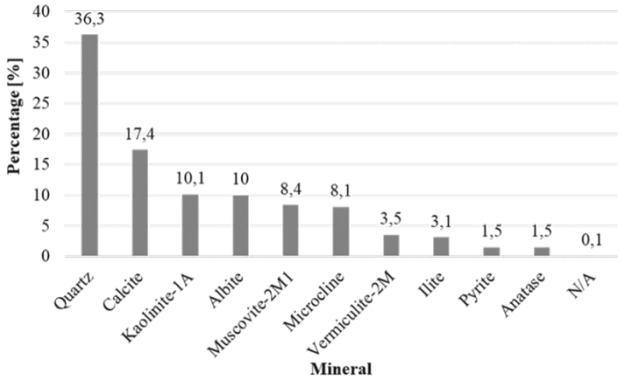


Figure 5. Quantitative characterization of minerals by XRD analysis in gas-producing formation core sample.
Source: Authors.

presented in Table 3, showing a low cation exchange capacity for both soils. Swelling tendency for soils with a cation exchange capacity of less than 20 meq/100 g is low [38]. Additionally, the results reveal a slightly higher degree of reactivity for the gas-producing formation.

Rock samples extracted from the gas-producing formation underwent X-ray diffraction (XRD) analysis, which is presented in Fig. 5. As observed, most of the present minerals show low reactivity or swelling tendency, except for vermiculite-2M and illite; however, their weight percentages were low, 3.50% and 3.10%, respectively.

Furthermore, minerals associated with fines migration are identified, such as quartz, kaolinite, illite, albite, microcline, and muscovite-2M1 [5,39-41]. Nevertheless, due to the presence of polar compounds in the crude oil, these clays demonstrate the ability to form "water-bridging" bonds, facilitating clay hydration [42]. This process may potentially lead to a pseudo-affectation of the formation.

### *3.9 Visual wettability*

For this test, a sample of sand from the oil-producing formation was taken and brought into contact with formation water and injection water systems. All tests demonstrated a water-wet behavior, as reflected in Fig. 6.

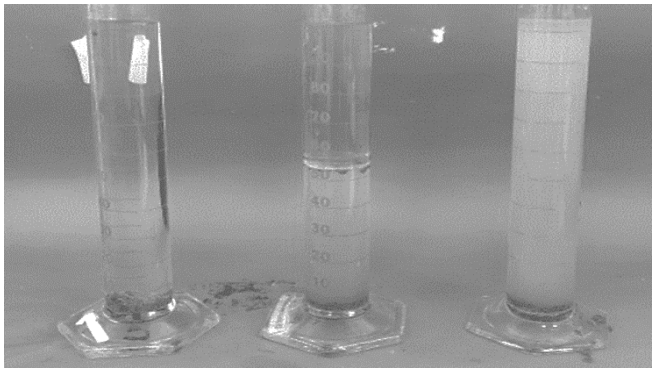

Figure 6. Visual wettability tests, with a test tube containing varsol on the left, a mixture of 50% varsol and 50% distilled water in the middle, and distilled water on the right.
Source: Authors.

Table 4.
Results of compatibility between injection water and synthetic brine.

| Fluids | Mixture ratio | | |
|---|---|---|---|
| | 20:80 | 50:50 | 80:20 |
| Injection water : synthetic brine | ✓ | ✗ | ✗ |

Source: Authors.

### *3.10 Fluid – fluid/rock compatibility*

In this test, the presence of emulsions, precipitates, detergency, and/or other adverse phenomena is evaluated. Table 4 shows the results of compatibility between injection water and synthetic brine (formation brine).

For the 20:80 proportion, the water is slightly turbid, indicating the presence of suspended particulate matter, while the coloration is opaque, denoting impurities. As the concentration of injection water is increased to 50% and 80%, it can be observed that a solubility limit has been reached and the suspended particulate matter precipitates, indicating incompatibility between the fluids.

Table 5 presents the compatibility results for the crude oils from wells A, B, and synthetic formation brine. For well A crude oil, regular compatibility is observed at any of the proportions. In the case of well B crude oil, only regular compatibility is seen between fluids at proportions of 20% crude: 80% synthetic brine and 50% crude: 50% synthetic brine.

For both crude oils at the mentioned concentrations, detergent action and adherence to internal surfaces are clear. Likewise, significant dehydration of the crude oils is observed, due to temperature variations during the test. In the case of well A crude oil, approximately 25% of previously emulsified water was released, while in well B crude oil, the release was approximately 10%.

The previous analysis was subjected to a more detailed examination, in which original crude oil samples and samples after compatibility were subjected to viscosity characterization. The resulting curves are depicted in Fig. 7, clearly illustrating how the dehydration of the crude oils led to a substantial reduction in viscosity.

Particularly noteworthy is the case of well A crude oil, where a significant 49% decrease in original viscosity was seen, highlighting the inherent flow restriction imposed by the natural emulsification of the crude oils. This finding reinforces the concept that hydrocarbon flow is inherently constrained.

Table 5.
Fluid-fluid compatibility tests for wells A and B; base matrix: crude oil with synthetic formation brine.

| Fluids | Mixture ratio | | |
|---|---|---|---|
| | 20:80 | 50:50 | 80:20 |
| Well A crude oil : synthetic brine | ✓ | ✓ | ✓ |
| Well B crude oil : synthetic brine | ✓ | ✓ | ✗ |

Source: Authors.

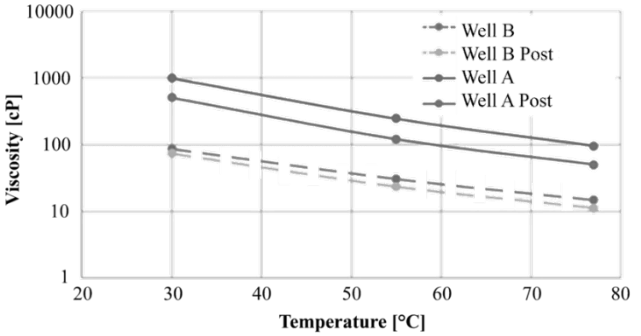


Figure 7. Viscosity curves of the crude oils from wells A and B before and after the fluid-fluid compatibility test.
Source: Authors.

Table 6.
Compatibility test results for fluid-rock for wells A and B.

| Fluids | Mixture ratio | | |
|---|---|---|---|
| | 20:80 | 50:50 | 80:20 |
| Well A crude oil + (injection water + synthetic brine) + sand | ✗ | ✗ | ✗ |
| Well B crude oil + (injection water + synthetic brine) + sand | ✓ | ✗ | ✗ |

Source: Authors.

Table 6 presents the compatibility results for systems that include crude oil, injection water, synthetic formation brine, and formation sand. For the aqueous phase, a proportion of 80% injection water and 20% synthetic brine was used, and the compatibilities were performed with a base of 20%:80%, 50%:50%, and 80%:20% of crude oil and aqueous phase, respectively.

For Well A crude oil, incompatibilities across all specified proportions are existing. It is noteworthy that phenomena of adherence to the glass surface by the crude oil are observed, despite the turbidity, no suspended solids or impregnation of the sand by the crude oil are discerned. However, the formation of a fine tissue near the crude oil-water interface is notably presented in Fig. 8. This phenomenon stems from the incompatibility between the polar constituents within the crude oil and the adhesion of micrometer-sized particles found in the injection water and synthetic formation brine, manifesting as suspended solids.

Figure 8. Close-up view of the tissue formed at the interface.
Source: Authors.

Table 7.
Results of compatibility tests for 50% crude oil + 50% (injection water + corrosion inhibitor, scale inhibitor + synthetic brine) + carbonates + sand.

| Fluids | Mixture ratio |
|---|---|
| | 50:50 |
| Well A crude oil + (injection water + corrosion inhibitor + inorganic scale inhibitor + synthetic brine) + carbonate scale + sand | ✗ |
| Well B crude oil + (injection water + corrosion inhibitor + inorganic scale inhibitor + synthetic brine) + carbonate scale + sand | ✗ |

Source: Authors.

Recent studies by various researchers have characterized the interfacial rag layer formed between water and toluene, containing a fraction of interfacially active asphaltenes (IAA). This layer comprises asphaltenes and fine clays, collectively termed an interfacial membrane [43,44]. It is suggested that the cohesion of these systems arises from inorganic fines and clay material, which facilitate the formation of water bridges and localized hydrations, potentially involving cationic exchanges. Consequently, such interactions lead to flow restrictions within gas and/or crude layers during operations employing aqueous and/or oil-based fluids in wells.

For Well B crude oil, no incompatibilities are evident at 20%:80% concentration. However, at the 50%:50% ratio, there is a discernible emergence of the previously identified fine structure in the bottle tests. Additionally, at the 80%:20% ratio, identification of the aqueous phase in the bottle becomes impracticable.

Finally, Table 7 show compatibility results for bottles containing crude oil, synthetic brine, injection water, inhibitors, inorganic scales, and sand. The test reveals a clear incompatibility, with a visual worsening of the aqueous phase and the adherence of crude oil to the bottle walls.

An illustrative case arises when contrasting the well B crude oil against a blend comprising formation water, synthetic brine, injection water, corrosion inhibitors, scale inhibitors, sand, and carbonates. This comparison is exemplified in Fig. 9, which displays a notable O/W/O (oil-in-water-in-oil) emulsion, prominently stabilized by solid constituents.

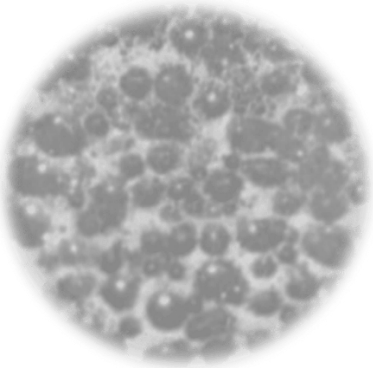

Figure 9. Micrograph of the emulsion formed in the system of crude oil B 50% + 50% (injection water + corrosion inhibitor, scale inhibitor + synthetic brine) + carbonates + sand.
Source: Authors.

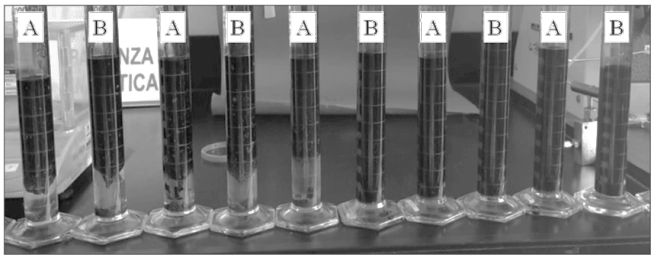

Figure 10. Emulsion bottle tests.
Source: Authors.

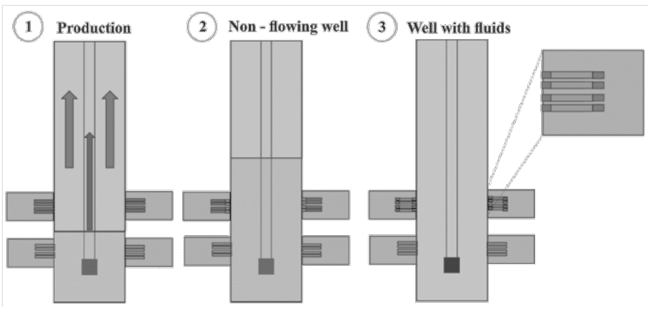

Figure 11. Diagram depicting the stages of interaction during well control.
Source: Authors.

### *3.11 Emulsion test*

Emulsion tests were conducted using analogous systems established for evaluating crude oil's compatibility with formation brine, injection water, and varying proportions of injection water and synthetic brine (80%, 50%, and 20%), each incorporating sand. These systems underwent agitation in a shaker operating at 1800 rpm for around 1 minute. The results obtained from the 24-hour evaluations are depicted in Fig. 10.

The findings from the tests highlight the emulsions' remarkable stability and plugging efficacy, particularly evident under lower temperatures. At ambient room temperature (~25°C), there was no observed breakdown of the existing emulsion. For Well A crude oil, the tests revealed structures reminiscent of icebergs, underscoring the robust solid stabilization at the interface. Conversely, Well B crude oil exhibited significantly lower water content in the emulsion, displayed enhanced water retention capability. Notably, the interface remained imperceptible throughout the test duration, demonstrating continuous emulsion development.

### *3.12 Diagnosis*

Once all the information and laboratory test results were compiled, a diagnosis of the damage to the formation in the wells under study was prepared. For this purpose, a comprehensive assessment of the conditions and events occurring in the well during each intervention or control was initiated. In this analysis, three essential phases were identified that encompass various interactions at the level of the perforations in the gas-producing areas of the formations:

1. During the production phase of the well, only the presence of gas is detected.
2. After the well is shut in, a rise in liquid level (either crude oil and/or formation water) to the gas perforations is seen, leading to the coexistence of gas, oil, and formation water.
3. Injected fluids are introduced, resulting in a final interaction between this fluid, oil, formation water, and gas.

The interplay of these factors is combined with the presence of various clay components, as identified in the studies, some of which are hydratable or migratory. This combination of factors leads to the manifestation of the observed phenomena in the results phase. These stages and their interactions are visually represented in Fig. 11.

The presence of asphaltic compounds in the crude oil, even without precipitation, triggers the impregnation of both

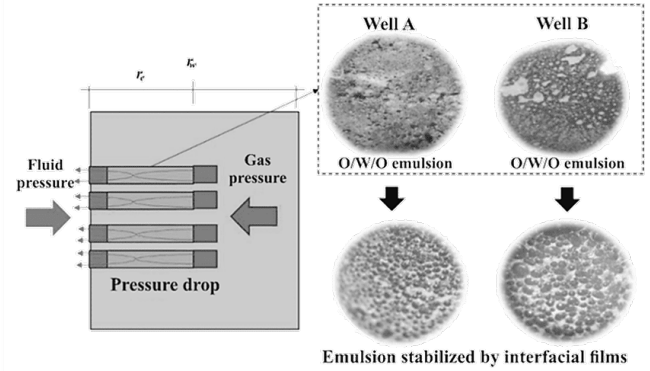

Figure 12. Diagram of the formation damage diagnosis in the wellbore.
Source: Authors.

matrix-bound and suspended minerals by the oil. This impregnation fosters cohesive forces surrounding water droplets, thereby stabilizing the O/W/O emulsions via the mechanism recognized as “interfacial membranes”. Moreover, this phenomenon is bolstered by the collaboration of inorganic fines and clay compounds, which establish water connections and prompt localized hydration reactions.

This collective interplay of factors results in flow restrictions within gas and/or oil layers during fluid-based processes within wells, be it aqueous or oily. Fig. 12 delineates a schematic representation of the associated damage and its impact on producing formations.

## 4. Conclusions

The comprehensive working methodology presented here consists of four steps, beginning with the recognition of operational issues, the collection of samples and geological and engineering information to perform a pre-diagnosis, laboratory tests including basic fluid and rock characterization, fluid-fluid and rock-fluid interaction studies, and finally, relating the pre-diagnosis results to those obtained in the laboratory to determine associated formation damage mechanisms and suggest solutions.

The presented methodology allowed the identification of the presence of organic and inorganic scales, minerals sensitive to swelling and migration through X-ray diffraction, and interfacial phenomena such as the formation of plugging emulsions and interfacial membranes strengthened by the presence of clay-like particles with a strong tendency to alter

their wettability due to interactions with polar components of the crude. Thus, it enables obtaining a representative diagnosis of formation damage mechanisms during Workover or well servicing operations.

In intervening in these wells, it is important to consider the existing physicochemical mechanisms and interactions between the injected and native fluids, as proved, significant incompatibilities arise that lead to various synergistic formation damage mechanisms at the wellbore face. It is from this point that conventional treatments do not yield satisfactory results, and the productivity of gas intervals is severely affected after these field interventions. This damage is further accentuated and strengthened with each intervention.

Finally, conducting formation damage studies in fields of this nature is crucial to decide the behaviors and/or interactions of the elements composing the fluid flow in the petroleum system. This is essential for implementing necessary measures to recover and/or enhance productivity by designing remediation treatments that address pseudo damage.

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# Structural equations modelling applied to the study of Communities Supported Agriculture (CSAs) located in the Southeastern region of Brazil

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**Abstract**
Food production is an increasingly relevant issue in the current framework associated with food and water security and future years projections. In addition, the production of organic food has gained significance in recent years, revealing a growing change in the population's consumption habits. The Communities Supported Agriculture (CSAs) play an important role in enabling productive areas for planting crops in agroecological and biodynamic standards. Given this, this study aimed to investigate the relationship between different CSAs variables located in the Southeastern region of Brazil to validate or not the hypotheses created. Thus, the study was designed as a descriptive research and quantitative approach, using an inductive logic survey. In addition, the methodology was set up with the support of the Structural Equation Modeling technique. The study confirmed the hypothesis (H1) that socioeconomic characteristics positively influence CSAs' performance. The limitations were associated with the method of data collection and the difficulties imposed by the Covid-19 pandemic.

*Keywords*: structural equation modeling; communities supported agriculture; agroecology.

# Modelación de ecuaciones estructurales aplicada al estudio de Agricultura Apoyada por Comunidades (AAC) ubicadas en la región Sudeste de Brasil

**Resumen**
La producción de alimentos es un tema cada vez más relevante en el marco actual asociado a la seguridad alimentaria e hídrica y las proyecciones para años futuros. Además, la producción de alimentos orgánicos ha ganado importancia en los últimos años, revelando un cambio creciente en los hábitos de consumo de la población. La Agricultura Apoyada por las Comunidades (AAC), por sus siglas en inglés) juega un papel importante al habilitar áreas productivas para la siembra de cultivos con estándares agroecológicos y biodinámicos. Teniendo esto en cuenta, este estudio tuvo como objetivo investigar la relación entre diferentes variables de AAC ubicadas en la región Sudeste de Brasil para validar o no las hipótesis planteadas. Así, el estudio fue diseñado como una investigación descriptiva y con enfoque cuantitativo, utilizando una encuesta de lógica inductiva. Además, la metodología se configuró con el apoyo de la técnica de Modelado de Ecuaciones Estructurales. El estudio confirmó la hipótesis (H1) de que las características socioeconómicas influyen positivamente en el desempeño de las AAC. Las limitaciones estuvieron asociadas al método de recolección de datos y a las dificultades impuestas por la pandemia de Covid-19.

*Palabras clave*: modelos de ecuaciones estructurales; agricultura apoyada por las comunidades; agroecología.

## 1 Introduction

The production of healthy food has been one of the issues of concern for the population in the recent framework [1-3]. In this connection, agriculture has advanced in promoting cultivation techniques that have less impact on the environment and that provide higher-quality food [4,5]. Thus, the eating habits of many people could undergo positive changes, adding greater health and well-being to their lives, as well as reducing costs of eating outside the home [3,5].

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On the other hand, sustainable initiatives have sought transformations in agriculture, incorporating new trends in food production, based on agroecological, organic and/or biodynamic systems [6]. Consequently, Communities Supported Agriculture (CSAs) emerged as a new concept that aims to change people's relationship with food [7,5]. CSAs are partnerships established between farmers and a group of local consumers or co-producers [8,5]. In this relationship, responsibilities and risks of food production are shared, as only foods that are viable in that specific period are produced [9]. In addition, farmers' production and work are fully financed by periodic quotas charged to co-producers [4]. Another peculiarity of the CSA movement is the blind delivery of food, that is, the consumer does not choose the items that make up his food basket [10,5].

However, the green revolution and sustainable production patterns have been threatened by practices of irrational exploitation of crops to strengthen the bases of large-scale agricultural production [11]. According to the author [12], the Southeast region showed a growth of 8.4% in grain production comparing the years 2019 and 2020, reaching the level of more than 25 million tons produced by year. In addition, family farming has been jeopardized due to the low farmer's reward and high production costs, as well as the lack of labor to carry out the applicable activities [13].

Therefore, considering the relevance of the movement presented (CSA) and its continuous growth, there is a gap in the aggregation of its value based on the understanding of the variables that compose it and the relationship between them [14,5]. In this connection, the application of the Structural Equation Modeling (SEM) technique represents a way to interpret hypotheses built from the relationship of demographic, socioeconomic, agricultural, ecological origin variables, among others [15]. According to authors [16] and [15], Structural Equation Modeling can be based on regression, factor analysis, clustering or even multidimensional scaling methods, which can be confirmatory or just exploratory.

In this connection, this study aimed to investigate the relationship between different variables in the CSAs located in the Southeastern region of Brazil to validate or not the hypotheses developed. In addition, the study addresses the following research question: What are the relationships between variables of socioeconomic, agricultural and female participation dimensions in the performance of CSAs? Thus, we seek to contribute to the agroecological area, promoting a more technical environment based on knowledge and best production practices. To this end, the study was divided into an introductory section, followed by a contextual section on organic agriculture and CSAs, a section on the importance of food security, a hypothesis and research method section, followed by the methodology, results, discussion and, finally, the conclusion section, acknowledgments and bibliographic references.

## 2 Organic agriculture and Communities Supported Agriculture (CSA)

Organic agriculture, as well as other agroecological production patterns, represents an opportunity to reconstitute the population's healthy eating habits [6,5]. In addition, the sustainable appeal constitutes one of the bases for the evolution of land exploitation modes, to produce food with the least potential environmental impact [9]. In this framework, the philosophy of Communities Supported Agriculture is in line with the principles of low-impact organic agriculture and establishes an important commitment to valuing of farmers' work [17,5].

In this connection, valuing the farmers' work is a decisive aspect of the maintenance of CSAs [8]. Farmers allow the production of natural foods, without using agrichemicals and harvesting manually to reduce losses [14]. In this framework, food security emerges as one of the concerns of communities and organic farmers, who aim to serve with agricultural products a growing number of co-producers or members of CSAs and to minimize food losses and waste [18]. It is estimated that Brazil is the tenth country that wastes food in a total of 54 countries as reported by the United Nations Food and Agriculture Organization [18]. In addition, if waste were avoided, the country would be able to reduce its rate of people going hungry by up to 30% [18].

Food production has recently increased worldwide due to an expanding demand [18]. However, most of the food produced comes from mechanized processes and with the use of agrichemicals, as a large-scale production strategy [13]. The production of organic food has grown more slowly, which reveals a development gap in this area [19]. Hence, it is important that a support from local leaders who mobilize the population to participate in CSAs, as well as other initiatives of a sustainable nature, be implemented. In addition, the transformation of people's eating habits should be continued [20].

Currently, the implementation of technology combined with large-scale agriculture has harmed the continuity of family farming [13]. It is worth remembering some factors such as rural exodus - partly due to cultivation mechanization - as being the main factor responsible for reduced availability of labor in the farms [13]. Hence, the difficulties in maintaining agricultural properties that use family farming techniques increase [7]. On the other hand, in recent years, interest in the consumption of healthy foods has grown, whether motivated by changes in life habits or by concern about emerging environmental problems [3,5].

## 3 The importance of food security

Food security occurs when all individuals have physical, social, and economic access to safe, nutritious and quality food [21,22]. According to author [18], about 2 billion people were food insecure in the world, in 2019. Furthermore, food security is a current and comprehensive issue that involves other issues, such as social inequality [22,23]. In this way, the classification of food security levels represents an initial way to solve this impasse and occurs according to some fundamentals, namely, availability, stability, access, and consumption.

Availability refers to food production and even imports that are carried out, to meet local demands [18,23]. In addition, issues such as storage and food aid are included in this foundation, as a way of guaranteeing a satisfactory amount of food for everyone. At the same time, there is a strong concern about the eradication of hunger in the world, a fact that represents one of the UN's sustainable

development goals. According to data from authors [18], in 2019 almost 690 million people were hungry in the world, however, it is worth mentioning that more than a third of the amount of food produced on a global scale is wasted. In this way, there is a disagreement between the production and consumption of food in the world, which intensifies other issues, such as child malnutrition and growth delays.

Stability refers to the ability to anticipate moments of crisis, so food storage is of great importance to guarantee availability, in times of crisis [18]. In this context, both environmental and economic crises make it difficult to produce and access healthy foods [22,23]. This occurs because the cost of production is increased, either by the losses caused by bad weather or by the increase in the value of inputs, or even by scenarios of dollar appreciation [21].

Access is related to physical or socioeconomic issues. In this sense, there may be problems in production that impact the amount of food produced, making access difficult [18]. In addition, the lack of financial resources to purchase food is an impasse for the issue of access. It is worth mentioning recently the isolation caused by the pandemic of the new Coronavirus, which made it difficult to access and distribute food in different regions of the globe [18,24].

Consumption is the intake of food according to the particularities of everyone, considering their preferences and needs [18]. In this way, it is not only a matter of a balanced distribution of food from a quantitative point of view but also of a nutritional nature that addresses the needs of each citizen, in a personalized way [18]. However, given food scarcity in many regions where food insecurity reaches extreme levels, preference is not a main aspect, as food shortages are a greater concern [22].

## 4 Hypotheses and research method

### *4.1 Hypotheses*

The generation of hypotheses in this study allows a clearer interpretation of the relationships between dependent and independent variable [25]. In addition, if these are confirmed or rejected, the study begins to contribute to decision-making associated with the context of the insertion of such variables [26]. It is worth mentioning the contributions in the construction of social and practical implications in the analysis, to generate knowledge to be used in the foundation of future studies [26,25].

Thus, the first hypothesis presented in this study was associated with the socioeconomic context in which the CSAs are inserted. According to authors [27] and [28], the socioeconomic context of CSAs includes some variables, among them, the time of existence of the CSA (TE), the annual income per farmers' family (AI), the average salary of farmers (ASF), the total available area for cultivation (AC), distance from the farms to the distribution center (DDC), number of members occupying positions in the governance structure (MGS) and number of occupational accidents (OA). Furthermore, according to authors [31], high performance of CSAs can be associated with low rates of work accidents, a long time of existence of the CSA, and a greater number of co-producers who are members of the governance structure. In this connection, the following hypothesis is proposed:

*H1 = Socioeconomic characteristics (reflected by low occupational accidents and a high number of members in the governance structure) positively influence the performance of CSAs.*

The second hypothesis of this study was linked to the agricultural dimension, which includes some variables, namely, farmers' experience time (FET), total number of products produced (ProdP), quantity of food wasted in the marketing process (Qty_FW), annual revenue for investments in technology (AR_tec), number of training courses undertaken by farmers (Tr_courses), amount paid by co-producers for food baskets (AP_basket)[29,30]. According to authors [30], high values for the variables 'farmers' experience time' and 'annual revenue for investments in technology' suggest a high performance of CSAs. In addition, farmers' training contemplates a new scenario for organic agriculture, as specialized labor raises the standard of production based on innovative techniques and, consequently, the productivity and performance of CSAs [31,30]. In this connection, the following hypothesis is proposed:

*H2 = The number of training undertaken by co-producers positively influences the performance of CSAs.*

Finally, the third and final hypothesis of this study was associated with the context of female participation in CSAs. According to authors [32] and [31], this dimension addresses some variables such as the number of female co-producers/members in the CSAs (Cop_fem), the level of education of women participating in the CSAs (Educ_fem) and the number of women managing the CSAs (Wom_manag). In addition, gender equality is a relevant topic to be addressed in the field of CSAs, given the importance that women have shown in sharing different skills, helping to reach new levels of performance for CSAs [31,32]. That said, the following hypothesis is proposed:

*H3 = The number of female co-producers/members influences the performance of CSAs.*

Given this, the proposed structural equation model was built with the help of SmartPLS 3 (Partial Least Squares) software, as shown in Fig. 1.

According to Fig. 1, the model presented contemplates a relationship of four constructs: Socioeconomic Characteristics, Farmer Training, Female Participation, and CSA performance. In addition, the Socioeconomic Characteristics construct is reflexive, that is, the socioeconomic characteristics of the CSAs are dictated by two predictor variables, in this case, the number of occupational accidents (OA) and the number of members occupying positions in the governance structure (MGS).

On the other hand, the other constructs are formative, demonstrating that the predictor variables form the basis for developing the constructs. The CSA performance construct establishes a relationship of dependence on the other constructs, which allows the generation of the previously listed hypotheses. Thus, the Farmer training construct is

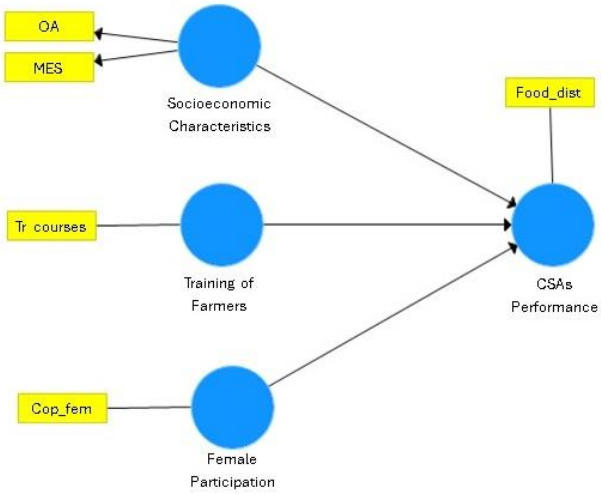


Figure 1. Proposed Structural Equation Model.
Source: Authors, 2023.

formed by the predictor variable number of training carried out by farmers (Tr_courses); the Female Participation construct is composed by the predictor variable number of female co-producers in CSAs (Cop_fem), and the CSA Performance construct is composed of the predictor variable amount of food distributed by CSAs (Food_dist).

### *4.2 Structural Equation Modeling (SEM)*

The use of statistical analysis has been a recurring practice in scientific studies for the verification and interpretation of results [16]. In addition, the improvement of multivariate analysis techniques is an advance in the understanding of more complex situations, promoting the interrelationship between the variables and in some cases the causality effect between them [15]. In this connection, Structural Equation Modeling represents a general multivariate statistical technique that enables theoretical construction from latent constructs [35]. That is, the relationship between theoretical constructions is represented by trajectory or regression coefficients between observed or latent variables [33,16].

Structural Equation Modeling combines regression and factor analysis techniques [34]. In addition, it is a technique that allows the performance of simultaneous estimations and measurements, as well as the identification of direct and indirect effects between explanatory and response variables [15]. The use of trajectory diagrams is worth mentioning for the representativeness of structural equation models, where it is possible to graphically indicate the relationships between observed and measured variables [16].

Thus, on the one hand, regression analysis is a deterministic analysis technique, where the relationships between a dependent variable and one or more independent variables are estimated [36,16]. Factor analysis, on the other hand, contemplates the use of a covariance matrix to estimate the structural factor [35]. In addition, the covariance matrix aims to reduce the types of variables in the model [16]. Thus, factor analysis indicates that covariances between a set of observed variables can be justified by a reduced set of latent constructs [33,16].

## 5 Methodology

The scientific research methodology is a field that aims to evaluate the most suitable methods for each type of scientific research. In this connection, this study was descriptive research, as it was based on the description of information collected in a set of CSAs assessed. In addition, the study displayed a quantitative approach, supported by a survey, as data on scalar variables were collected from the characteristics and opinions of individuals from the CSAs. Finally, the study presented an inductive logic, as it started with punctual information for the generalization of knowledge within the analysis universe. This study can be replicated in other contexts of analysis.

The study followed the structure shown in Fig. 2 regarding the research stages. Thus, a literature review was carried out a priori on the topic of analysis, to assist in the construction of the theoretical framework and the understanding of the context and the relationships considered between variables and constructs addressed. Then, the theoretical conceptual model and the hypotheses to be tested were built. Subsequently, a structured questionnaire was developed for use in the research; it was composed of 36 questions, each one targeting an analysis variable. In other words, this study was based on obtaining primary data using questionnaires. In addition, these variables represent demographic, socioeconomic, agricultural, ecological, natural resources, food security, female participation, certification, and circular economy performance indicators. These are quantitative indicators.

Thus, a total of 25 questionnaires were distributed to CSAs in different municipalities in the Southeast region of Brazil corresponding to the universe of analysis, and 16 were answered correctly. In the next step, data from the 16 CSAs were tabulated using Microsoft Excel 2019, where it was possible to apply the Principal Component Analysis (PCA) technique using the statistical software R-Project 3.2.2. It is worth mentioning that the reduced number of analyses/questionnaires is that the development of CSAs is still in an embryonic phase in the Southeast region compared to other regions of Brazil, such as the Federal District, where there is a greater number of supporters. In general, the data collection stage took place during the period when the COVID-19 pandemic was in a critical period with a low rate of vaccinated people, which made the contact with some CSAs difficult.

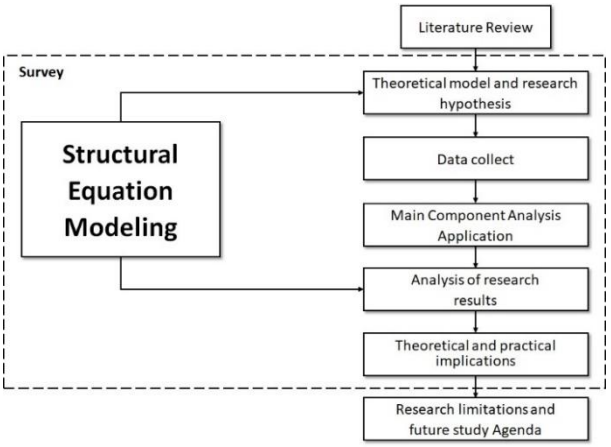


Figure 2. Research steps.
Source: Authors, 2023.

Considering the application of mathematical and statistical techniques, the analysis of the principal components can be stated according to the adapted formulation by authors [37] and [38] in Eq 1. In this case, Yi corresponds to the principal component, the number of variables being less than or equal to the number of principal components [40,41], that is, Yi= 1, 2, ..., p; e refers to the eigenvectors (e = 1, 2, ... p) and X to the original variables (X = 1, 2, ... p).

$$Y_i = e_{i1}X_1 + e_{i2}X_2 + \cdots + e_{ip}X_p \quad (1)$$

In this framework, the PCA was initially applied to the 36 original predictor variables, obtaining a variance of only 54%. The variables considered were: Male_gen (Quantities of men), Female_gen (Quantities of women), AGF (Age group of farmers), Coprod (Number of members/co-producers participating in the CSA), MPF (Number of members of the producer's family), TE (Time of existence of the CSA, in years), AI (Annual income per family, in reais), FAS (Farmer's average salary, in reais), AC (Total area of land available for cultivation, in hectares), DDC (Distance from the property to the distribution center, in km), MGS (Number of members occupying positions in the governance structure), OA (Number of occupational accidents), FET (Farmers' experience time, in years), ProdP (Total number of products produced for CSA, in units), Qtv_FW (Amount of food wasted in the marketing process (transport, handling, sale) in percentage (%)), AR_tec (Percentage of annual revenue spent on technology investment), Tr_courses (Number of training courses carried out, per year, in units), Land_size (Land size), Baskets (Number of food baskets), AP_basket (Monthly amount paid by members to purchase the food baskets, in reais), Ac_prod (Average production cost, in reais), Prod_capacity (CSA production capacity, in kg/hectare/month), F_consump (Fuel consumption (gasoline, diesel), per month, in liters), Pack_cons (Number of packages consumed, in units, month), Vol_Water (Volume of water consumed per month), Distr_P (Number of CSA distribution points, in units), Serv_radius (CSA service radius, in km), Food_dist (Average of food distributed per month (kg or units)), Food_prod (Average food produced per month (kg or units)), Dissem_channels (Number of dissemination channels (Sites, Instagram, Facebook...) used, in units), Part (Number of CSA key partners, in units), Cop_fem (Number of female CSA members/co-producers, in units), Educ_fem (Level of education of women, in years), Wom_manag (Number of women in CSA management, in units), Certif (Number of certifications of CSA producers, in units), RE_Expensas (Amount of financial investments made in renewable energy, in reais).

Therefore, only highly correlated variables in the first 3 principal components, with correlation equal to or greater than 70%, were selected, resulting in a set of 18 variables. Thus, PCA was applied again, obtaining a variance of 81%. The variables with correlation greater than 70% were selected, resulting in 11 variables. PCA was applied to the 11 variables, obtaining a correlation of 76%. From there, the variables were divided into two groups, 6 inputs and 5 outputs. Thus, the correlation between the two groups was obtained separately, and variables with a correlation greater than 60% were excluded, resulting in 7 variables, 4 inputs, and 3 outputs. Subsequently, the correlation between the remaining variables was calculated and those variables with a correlation below 1 were excluded, resulting in 5 variables, 3 inputs, and 2 outputs, with a variance of 94%. The selected variables were OA, MGS, Tr_courses, Cop_fem, and Food_dist.

In this sense, the result analysis step was performed using the Structural Equation Modeling (SEM) technique based on the 5 selected predictor variables. Data quality was addressed based on the elimination of variables with null or missing data. Thus, after verifying the quality of the data, an analysis of the proposed structural model was performed about its convergent and discriminant validity through Confirmatory Factor Analysis (CFA), as an accommodation strategy for the use of the model and its validation. Discriminant validity can be evaluated according to the value presented in the HTMT criterion (Heterotrace-Monotrace), where a value above 0.90 indicates that discriminant validity is not present. Table 1 corresponds to the observed values of the HTMT analysis for the approached constructs, in which all presented values are lower than 0.90, indicating the discriminant validity of all of them.

In addition, the reliability of the indicators was verified according to the criterion of cross-loading, where values greater than 0.708 suggest that each construct explains more than 50% of the variance of the indicator [16]. Given this, Table 2 corresponds to all factor loadings of the proposed structural model used in this study, which presented all values greater than 0.708 in their respective constructs (in bold) and lower in the others, indicating the reliability of the indicators.

Table 1.
Discriminant validity analysis based on the HTMT criterion (Heterotrace-Monotrace).

| Variables | Farmers Training | Socioeconomic Characteristics | CSAs' Performance | Female Participation |
|---|---|---|---|---|
| Farmers Training | - | - | - | - |
| Socioeconomic Characteristics | 0.560 | - | - | - |
| CSAs' Performance | 0.083 | 0.675 | - | - |
| Female Participation | 0.386 | 0.160 | 0.039 | - |

Source: Authors, 2023.

Table 2.
Confirmatory Factor Analysis (CFA).

| Variables | Farmers Experience | Socioeconomic Characteristics |
|---|---|---|
| OA | 0.376 | **0.893** |
| Food_dist | -0.083 | 0.569 |
| Tr_courses | **1.000** | 0.469 |
| Cop_fem | 0.386 | -0.130 |
| MGS | 0.453 | **0.866** |
| **Variables** | **CSAs Performance** | **Female Participation** |
| OA | 0.526 | -0.042 |
| Food_dist | **1.000** | -0.039 |
| Tr_courses | -0.083 | 0.386 |
| Cop_fem | -0.039 | **1.000** |
| MGS | 0.473 | -0.194 |

Source: Authors, 2023.

Table 3.
Cronbach's Alpha, Average Extracted Variance (AVE), Composite Reliability (CR) and Correlations.

| | Cronbach's Alpha | CR |
|---|---|---|
| Farmers Experience | 1.000 | 1.000 |
| Socioeconomic Characteristics | 0.708 | 0.872 |
| CSA performance | 1.000 | 1.000 |
| Female participation | 1.000 | 1.000 |
| | **AVE** | **Farmers Experience** |
| Farmers Experience | 1.000 | 1.000 |
| Socioeconomic Characteristics | 0.773 | 0.469 |
| CSA performance | 1.000 | -0.083 |
| Female participation | 1.000 | 0.386 |
| | **Socioeconomic Characteristics** | **CSAs Performance** |
| Farmers Experience | | |
| Socioeconomic Characteristics | 1.000 | |
| CSA performance | 0.569 | 1.000 |
| Female participation | -0.130 | -0.039 |
| | **Female Participation** | |
| Farmers Experience | | |
| Socioeconomic Characteristics | | |
| CSA performance | | |
| Female participation | 1.000 | |

Source: Authors, 2023.

Table 4.
Collinearity analysis.

| Variables | VIF |
|---|---|
| AcT | 1.429 |
| Alim_dist | 1.000 |
| Ccap | 1.000 |
| Cop_fem | 1.000 |
| MEG | 1.429 |

Source: Authors, 2023.

Discriminant validity was also verified by the Fornell-Larcker criterion, in which the square root of the Average Variance Extracted (AVE) must be greater than the correlations between the constructs of the model, as shown in Table 2. In the case of convergent validity, this was evaluated based on the values presented for the Average Variance Extracted (AVE) which must be greater than 0.50. Given this, the analysis suggested that the model of this study has convergent validity, according to Table 3.

Internal consistency was evaluated, according to the composite reliability criterion (Composite Reliability - CR), in which the values must exceed the minimum limit of 0.70. According to Table 4, the composite reliability scores for all constructs were greater than 0.70, indicating good internal consistency. In addition, a similar analysis can be performed, noting that Cronbach's Alpha values were greater than 0.70 in all constructs, also indicating good internal consistency. However, the composite reliability criterion offers a better estimate of the variance shared by its indicators, as well as an analysis from the perspective of factor loadings of the variables [34].

Finally, the analysis of the variance factor (VIF) was performed to verify the formative indicators. Given this, VIF values above 5 indicate critical collinearity problems, and it is recommended that this value be, if possible, lower and close to 3 [34]. According to Table 4, the VIF values presented for the variables were all lower than 3, indicating the existence of collinearity between indicators.

Thus, the study continued in its analysis with the discussion of results and presentation of theoretical and practical implications, limitations of the research, and proposal of an agenda for future studies.

## 6 Results

The present study was based on an analysis focused on CSAs located in the Southeast region of Brazil. A total of 16 CSAs were analyzed. In this sense, the sample revealed uniform values for the number of farmers of both sexes, in all analyzed CSAs. In addition, the farmers' age in the CSAs ranged between 26 and 60 years. According to the results obtained with the application of the questionnaire, the CSAs indicated proportionality relationships between the number of co-producers/members of the CSAs, the area available for planting, and the radius of service to the communities. In addition, an agreement was recorded between the number of food baskets distributed and the average annual income of farmers.

According to the answers obtained, the CSAs evaluated showed a direct relationship between the amount charged for food baskets to co-producers and the service range of the CSAs. Another variable that impacted the average value of the baskets, as shown in the research, was associated with electricity costs, which also revealed values directly proportional to the variety of food produced, the area available for planting and the demand of co-producers. About the rate of waste of food produced, the CSAs evaluated showed a reduced amount for the variable. Thus, the results indicated an average of 4% of waste generated among the evaluated CSAs. In addition, the greatest waste was associated with communities with a wide variety of food produced. In terms of partnerships established between communities and other institutions, a small number of partnerships were observed, including for dissemination channels. However, some CSAs with a greater number of key partners also presented high numbers for the disclosure channels used. In this sense, the study continued its analysis based on the 5 predictor variables selected from the Principal Component Analysis (PCA) technique. Thus, some relationships were verified, as shown in Fig. 3.

According to Fig. 3, to verify the predictive relationship between the constructs and the study hypotheses test, the structural model was reviewed. The results obtained with the PLS Algorithm indicated an explanation of the performance by the construct "Socioeconomic characteristics" in more than 90% of the variance. On the other hand, the constructs "Farmers' training" and "Female participation" presented explanation variances of -0.633 and 0.323, respectively. In general, the model presented a degree of explanation of 55.7%. This value is reduced, yet, this is justified by the number of constructs and variables addressed, which was also reduced. In addition, the full bootstrapping technique was used with 5.000 samples, with corrected and accelerated bias and a two-tailed test type with a significance level of 0.05, for the evaluation of the general adherence of the model. In this connection, Table 5 corresponds to the results obtained with this analysis. It is worth remembering that bootstrapping allows the evaluation of the relationships between constructs, as well as the validation or rejection of hypotheses.

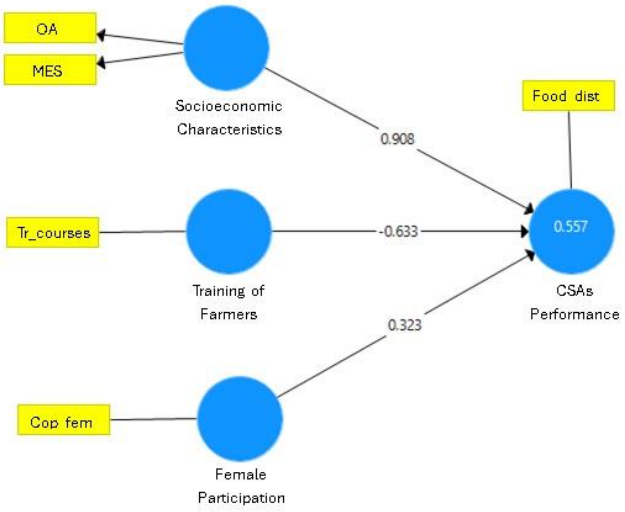


Figure 3. Result of the proposed Structural Equation Model.
Source: Authors, 2023.

Table 5.
Structural model analysis and hypothesis testing.

| Hypothesis | T statistic | p-value | Signal found | Result |
|---|---|---|---|---|
| Socioeconomic Characteristics → CSAs Performance | 2.033 | 0.042** | + | Accepted |
| Farmers' Experience → CSAs Performance | 1.395 | 0.163 | - | Rejected |
| Female Participation → CSAs Performance | 0.755 | 0.45 | + | Rejected |

Note: ** Significant at 0.05.
Source: Authors, 2023.

According to Table 5, the model results accepted hypothesis 1, that socioeconomic characteristics (reflected by a low number of work accidents and a high number of members in the governance structure) positively influence the performance of CSAs. Concerning hypotheses 2 and 3, these were rejected with a significance level higher than 0.05 (p-value>0.05). In other words, there was a low influence of the number of farmers trained as well as the number of female co-producers on the performance of the evaluated CSAs.

## 7 Discussion

According to the study results, it can be inferred that in the Southeast region of Brazil, CSAs are still undergoing a process of adaptation and development, compared to other regions of the country, where the CSA movement is more advanced, such as, for example, in the Federal District. This fact is reinforced by the small volume of questionnaires distributed in this research, and out of a total of 25, only 16 CSAs presented complete answers to all questions. This indicates the lack of preparation and more elaborate planning on the part of CSA leaders, given the reduced time of existence of some communities. In addition, there are requirements to be met, so that communities can act within this movement, which are related to the production area, number of members, and governance structure, among others.

When it comes to the gender balance in the number of farmers for the analyzed sample, this is due to the existence of farmers' couples residing in rural properties, which in many cases end up building their families in the same place where the CSAs are installed. In this sense, this fact reveals the existence of different types of workers with different levels of experience. It is worth mentioning that in many cases the high age of farmers can mean a higher level of experience, which can positively reflect on good food production practices and internal management of CSAs [39].

Furthermore, based on the agreement between the number of co-producers and the area used for planting in the analyzed CSAs, this reveals that CSAs with a greater number of co-producers have greater demands for food production and, consequently, need larger areas for planting. In addition, the concept of CSAs superimposes sustainable production over conventional standards, without the purpose of making a profit from the activities, according to [31]. In this sense, there was agreement between the number of baskets distributed and the average annual income of farmers, which indicates the model's self-sufficiency in paying internal production costs, in agreement with the analysis by Ghosh et al. (2019) and authors [6].

In this context, food security becomes one of the concerns of the movement, more specifically directed to the pillar of availability, since production in sufficient quantity for consumption by co-producers and farmers must be met. However, a differential of the movement consists in the production of organic foods respecting the periods of cultivation. Thus, the baskets are assembled based on food grown in that specific period, and the respective co-producers will be able to choose only the amount of food inserted.

Regarding the relationship between the amount charged for the baskets and the service radius of the analyzed CSAs, the communities located in capital cities or in regions close to the CSAs reported higher fuel expenses and, consequently, a higher average value of the distributed baskets. Another variable that impacted the average value of the baskets, as shown in the research, was associated with electricity costs, which also revealed values directly proportional to the variety of food produced, the area available for planting, and the demand of co-producers, as authors [9] and [27] also point out.

When it comes to the rate of waste of food produced, the reduced values verified confirm one of the main characteristics associated with the contexts of food security and circular economy, which is the reduction of food waste [21]. Given that the food undergoes inspection processes by the farmers themselves to guarantee their quality, and the remains of food unfit for consumption are used in the manufacture of natural fertilizers administered in the planting of food.

To partnerships established between communities and other institutions, the small volume of partnerships, including for the dissemination of communities, reveals the existence of a development gap still to be filled by the Southeast region about improving the communication in these CSAs. Given this, this problem of prospecting members impacts the access

of new co-producers to the movement and, above all, their access to healthy and quality food. In this way, an indirect relationship is identified to one of the foundations of food security, in this case, people's access to food [39]. However, the reason for the lack of access may be related to the difficulty of prospecting, as well as financial issues, due to the high prices of baskets in some CSAs.

It is worth remembering the scenario experienced by CSAs during the pandemia caused by the new Coronavirus, in which, due to isolation protocols, there were difficulties on the part of community leaders in the financial and logistical administration of the flow of baskets [24]. In this case, the concept of stability, as the foundation of food security introduces the importance of planning for possible eventualities, such as economic and health crises, among others. However, what was observed was a lack of planning on the part of both the population and the analyzed CSAs, which generated consequences from the increase in the prices of baskets, caused by the increase in inputs and fuels, logistical problems due to the reduction of delivery points for compliance with health protocols, even reducing the number of co-producers, in some cases.

Thus, based on the results presented, it was verified an agreement with the literature in the field of CSAs by confirming the H1 hypothesis (p-value < 0.05) that socioeconomic characteristics (reflected by a low number of occupational accidents and a high number of members in the governance structure) positively influences the performance of CSAs. According to authors [28], greater integration between CSAs co-producers can be favored by the inclusion of new members in the communities' governance structure, so that they start to participate more actively in internal decision-making to promote greater performance and productivity. Furthermore, for the sample of this study, a direct relationship was found between the size of the CSAs and the number of co-producers included in the governance structure. The size of the CSAs can be verified based on the CSAs time of experience, the demand of co-producers, service range and available area for cultivation, for example [27].

Also, regarding hypothesis H1, according to authors [31], a reduced number of occupational accidents indicates a greater preparation of the CSAs regarding the effectiveness and execution of their processes. In addition, a direct relationship can be verified between the number of work accidents and the size of the CSAs, since a greater number of members/co-producers statistically suggests a greater probability of accident occurrence. In line with authors [31] and [27] conclusions, this study also identified a positive impact of the reduction of occupational accidents on CSAs performance.

In the case of hypothesis H2, there was a divergence between the literature and the result of the structural model reviewed. According to authors [29] and [30], the holding of courses and the participation of farmers in agroecological events can favor the process of implementing new technologies to expand both the food varieties and the volume produced by the CSA. In addition, the training of farmers is directly associated with the quality inspection systems implemented by the CSAs, helping to produce organic foods with high nutritional value [30]. However, the results presented rejected the H2 hypothesis. This indicates that, for the sample in question, few efforts were made in this direction for the training and qualification of farmers. Thus, a low influence of this construct on the performance of the CSAs assessed was verified.

Finally, based on the rejection of the third hypothesis, according to the author [32], female participation in CSAs has shown great relevance, given the presence of women in different sectors of activity in the communities. However, the study presented a divergent result, which may be associated with the low volume of co-producers in the CSAs reviewed, especially female co-producers, the low number of women occupying positions in the governance structure as well as their level of education, in many cases, they had completed only elementary and high school, without taking technical or higher education courses.

## 8. Conclusion

The present study achieved its purpose, establishing theoric relationships between constructs and variables addressed by the structural model developed. In addition, the study brought theoretical relations associated with the Structural Equation Modeling (SEM) method due to its multidisciplinary application, with adherence to different analysis contexts, including in the field of CSAs. In terms of social contributions, the study made it possible to share information on the organic agriculture model presented by the CSAs, helping to publicize such communities, besides promoting and encouraging new partnerships. Another social contribution was present in the understanding of the relationship between the production dynamics and pillars of CSAs and the fundamentals of food security. On the other hand, managerial contributions were associated with increased efficiency in the CSAs internal decision-making by the governance structure in place in each community.

It is worth mentioning that the study also had some limitations, among them the data collection method as well as the existence of missing data in the research, which were responsible for the exclusion of a few variables from the questionnaire, until the questionnaire was closed in 36 original predictor variables. In addition, another limitation was the difficulty in contacting CSAs during the COVID-19 pandemic, making face-to-face interviews impossible.

Finally, the study contemplated the proposition of an agenda for future studies. In this connection, a suggestion is to consider the 36 original predictor variables in the structural model to bring a broader and more robust approach to the relationships between variables and constructs. Another suggestion is to replicate the analysis to other regions of Brazil and carry out comparative studies between them.

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# Analysis of the scientific production on the implementation of knowledge management for supply chain sustainability

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**Abstract**
This research aims to analyze the scientific production on the implementation of knowledge management for sustainability of supply chain. The study is of a descriptive quantitative type, by performing a bibliometric analysis executed in the Scopus database where only the articles found in open access in the areas of engineering, business, administration and accounting sciences were considered. A total of 43 articles were detected. The authors with the major contributions were Tseng, M.L. and Mangla, S.K. The most productive institutions were Brunel University London and Brunel Business School. The country in which the largest number of research papers were published was The United Kingdom. The articles were published in 29 journals. A bibliometric map of co-authorship was carried out, which showed that these were grouped into four clusters and that of co-occurrence of keywords structured into six clusters, which identified six lines of research.

*Keywords*: knowledge management; sustainability; supply chain; bibliometric analysis.

# Análisis de la producción científica sobre la implementación de la gestión del conocimiento para la sostenibilidad de la cadena de suministro

**Resumen**
El objetivo de la investigación es analizar la producción científica sobre la implementación de la gestión del conocimiento para la sostenibilidad de la cadena de suministro. El estudio es de tipo cuantitativo descriptivo, mediante la realización de un análisis bibliométrico ejecutado en la base de datos Scopus donde solo se consideraron los artículos que se encontraron en acceso abierto en las áreas de ingeniería, negocio, administración y ciencias contables. Se detectaron un total de 43 artículos. Los autores que más aportaron fueron Tseng, M.L. y Mangla, S.K. Las instituciones con más contribuciones fueron Brunel University London y Brunel Business School. El país en el que se publicó el mayor número de investigaciones fue el Reino Unido. Los artículos se publicaron en 29 revistas. Se realizó el mapa bibliométrico de coautoría que evidenció que estos se agruparon en cuatro clústeres y el de coocurrencia de palabras clave estructurado en seis clústeres que de su estudio se identificaron seis líneas de investigación.

*Palabras clave:* gestión del conocimiento; sostenibilidad; cadena de suministro; análisis bibliométrico.

## 1 Introduction

In today´s increasingly competitive environment, organizations are exploring variants that help them face the challenges that arise in the supply chain sector [1]. In this scenario, organizations need to be more flexible and be able to adjust their processes to market requirements, where the exchange of information to manage suppliers, production and marketing of products prevails [2].

The supply chain is composed of all the elements involved in the fulfillment of a customer order [3]. Understanding its composition is essential for organizations,

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since it facilitates the implementation of strategies that make it possible to distinguish it from competitors [4], hence the need to study its structure in order to develop and enhance the production and marketing of goods and services [5].

The area of supply chain management emerged to manage the products, services and information generated along the supply chain [6]. Its implementation expanded worldwide to combat the high levels of insecurity in the business sector [7].

The benefit of preserving proper supply chain management is manifested on organization performance [8], its readiness to face the environment, designing products more dynamically and supplying them consistently to the market [9].

The appearance of a supply chain is closely linked to ecological parameters and sustainable development [10,11], because sustainability in the supply chain is a management variant for achieving more sustainable processes and products and contributing to economic, social and environmental development [12,13], so its practice should be encouraged in organizations [14].

Entities are currently exploring the use of strategies that benefit the integration of the supply chain with the aim of producing long-term links with their suppliers and customers, allowing them to remain in the market for a longer period of time [15].

Knowledge management has been considered as a fundamental aspect for supply chain management and as a precedent for sustainability practices in the supply chain [16; 17], because managing knowledge favors the distribution of external knowledge and coordination among the members that make up the chain to increase efficiency [18,19].

Knowledge management can be defined as organizational planning based on an innovative environment and the use of ICTs, with the aim of creating the conditions for the storage, transfer, application and protection of the knowledge generated in an organization to contribute to increasing the sustainability and competitiveness of a supply chain and all the companies that make it up [20].

Based on the above, it is essential to determine the knowledge of each of the parts that make up a supply chain in order to determine their characteristics and functions, so that this knowledge can be preserved and used for the benefit of organizations and to achieve competitive advantages [21].

The link between knowledge management and supply chain sustainability offers an alternative to contribute positively to the development of society and care for the environment [22].

The project "Improvement of supply chain processes", which belongs to the University of Matanzas and is associated with a national program in Cuba, among its objectives, it studied 42 supply chains in different strategic sectors of the country, and identified seven (7) main deficiencies associated with the management of the supply chain due to the lack of adequate knowledge management:

1. Inadequacies in the recording of information from the different links in the chain.
2. Incipient implementation of ERP systems in companies and chains.
3. Insufficient integration of knowledge generated throughout the chain, which leads to a lack of knowledge of customer needs, deficient information from suppliers, and failure to meet delivery and payment dates.
4. Poor knowledge and information transfer of among links in the chain and within the company.
5. Poor recording of information on the end client and their needs in the rest of the chain, which means that the product does not reach the client with the requested requirements.
6. There is no platform for exchanging information in the chain.
7. Insufficient application of ICTs to knowledge management in the supply chain.

The objective of the research is to analyze the scientific production on the implementation of knowledge management for the supply chain sustainability.

## 2 Methodology

A descriptive quantitative type study was carried out by performing a bibliometric analysis with the intention of examining the scientific production linked to the implementation of knowledge management for the supply chain sustainability; it was carried out in the Scopus database in the period 2009-2024. This period was selected in order to visualize how the scientific production on the implementation of knowledge management for supply chain sustainability has behaved in the last 15 years and in the different stages that have occurred in that period such as pre-pandemic, pandemic and post-pandemic.

The search strategy was: TITLE-ABS-KEY ("supply chain" AND "sustainability" AND "knowledge management") AND PUBYEAR > 2009 AND PUBYEAR < 2024 AND (LIMIT-TO (SUBJAREA, "BUSI") OR LIMIT-TO (SUBJAREA, "ENGI") OR LIMIT-TO (SUBJAREA, "DECI")) AND (LIMIT-TO (DOCTYPE, "ar")).

Only research articles found in open access in the areas of engineering, decision sciences, accounting, business and management were considered. The search was executed on December 5, 2023, a sum of 43 publications was reached. The preliminary scan was performed by one of the researchers, who checked the title, abstract and the document as a whole. A set of indicators were analyzed as shown in Fig. 1.

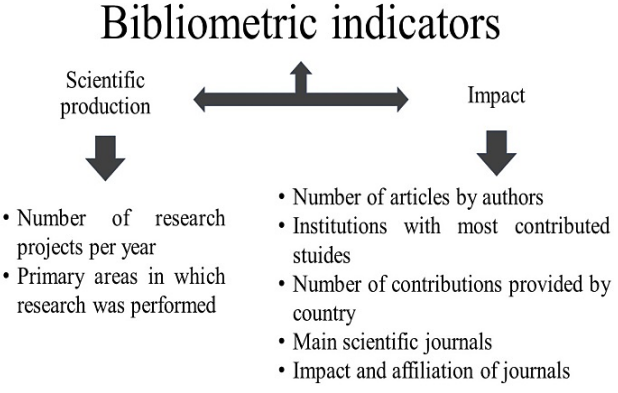


Figure 1. Bibliometric indicators analyzed.
Source: own design.

## 3 Bibliometric indicators studied

Indicators were considered to analyze scientific production in the selected stage:

- Trend indicator to study the number of researchers carried out per year.
- Determination of the primary areas of knowledge in which research was carried out, considering the quantity.

Impact indicators were evaluated at the stage:

- Authors who contributed the most articles in the period.
- Institutions with more studies contributed to the area of knowledge.
- Number of contributions provided by country.
- Main scientific journals: where the total number of citations received, the h-index and the SCImago SJR Rank (SJR indicator) and the quartile were considered. Bibliometric maps were prepared for the analysis of word co-occurrence and for the identification of lines of research.
- For quantitative analysis of indicators, the .CSV format files were downloaded from Scopus database (https://www.scopus.com/), while the components linked to the impact and affiliation of the journals were acquired from SCImago Journal Rank, Sci Journal (https://www.scijournal.org/).

Bibliometric maps were prepared to analyze word co-occurrence and detect lines of research and author co-authorship.

## 4 Results and discussion

Fig. 2 shows the behavior of scientific production by year. It is evident that the number of works carried out from the year 2010 to 2015 was very irregular (in the years 2012 and 2015 no research was carried out) while from 2016 there is a tendency to increase until the year 2021 in which there is only one (1) article; in the years 2022 and 2023 have the highest number of publications with eight (8) and nine (9) respectively, representing 39.53 % of the total (43) where all are articles.

It was recognized that 149 authors have carried out research in the years analyzed, with only two (2) of them having more than one publication (Fig. 3), which represents 1.34 % of the total.

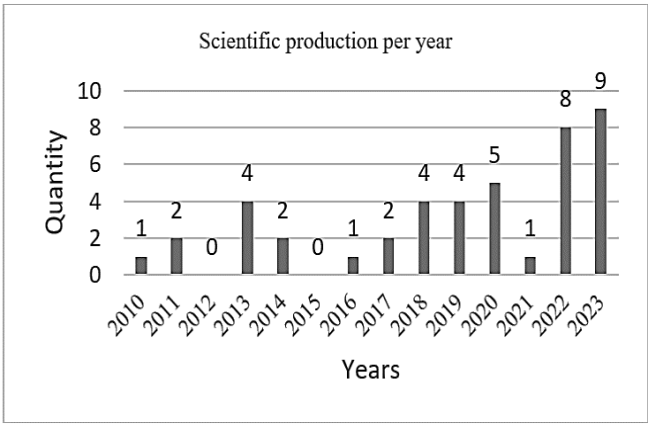


Figure 2. Scientific production per year.
Source: own design.

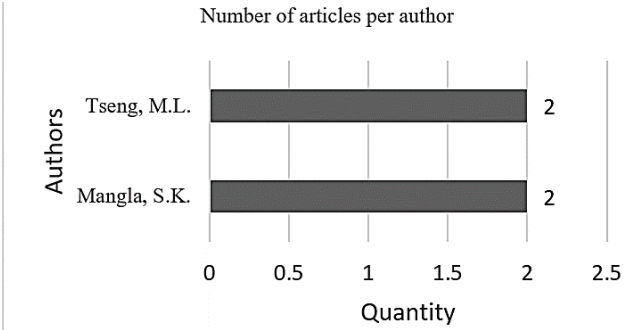


Figure 3. Number of articles per author.
Source: own design.

The bibliometric map was made to check levels of co-authorship among researchers (Fig. 4), where the maximum number of authors per document was 25, and 16 items were obtained, linked in three (3) clusters.

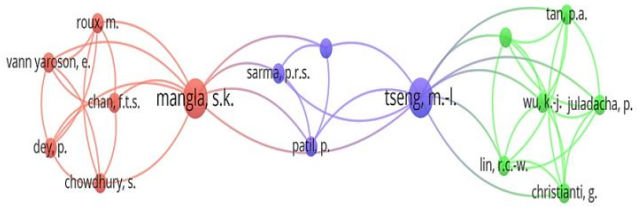


Figure 4. Bibliometric map of author co-authorship.
Source: own design.

Table 1 shows an analysis of the three (3) clusters in order to detect the most related authors (items).

Table 1.
Number of interrelations or collaborations between authors.

| Clusters | Items | Color | Authors |
|---|---|---|---|
| 1 | 6 | Red | Chan, F.T.S.<br>Chowdhury, S.<br>Dey, P.<br>Mangla, S.K.<br>Roux, M.<br>Vann Yaroson, E. |
| 2 | 6 | Green | Christiani, G.<br>Juladacha, P.<br>Lin, R.C.W.<br>Tan, P.A.<br>Todumrongkul, N.<br>Wu, K.J. |
| 3 | 4 | Blue | Patil, P.<br>Sarma, P.R.S.<br>Tseng, M.L.<br>Uniyal, S. |

Source: own design.

The research works were carried out in 128 affiliations; only 4.68 % have more than two (2) affiliations (Fig. 5).

There were carried out studies according to authors 'country of origin in 34 countries. An analysis of countries with more than three (3) publications (Fig. 6) showed that the most relevant was the United Kingdom with 10 articles, followed by the United States, Australia and Spain with seven (7), five (5) and five (5), respectively.

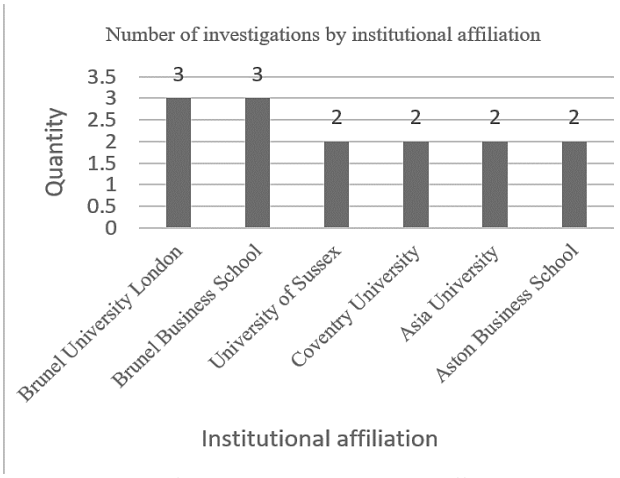


Figure 5. Number of investigations by institutional affiliation.
Source: own design.

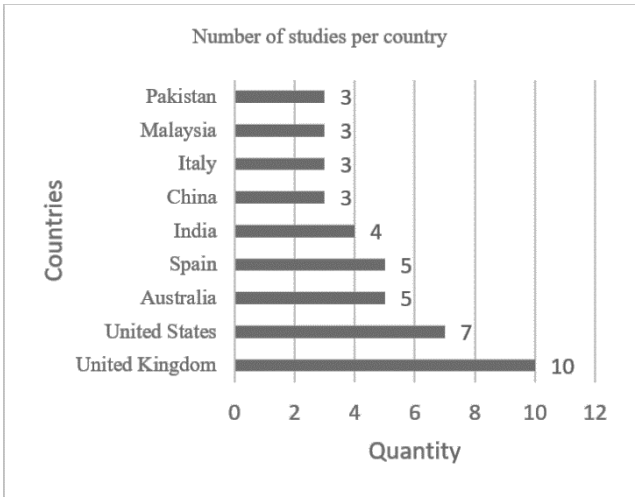


Figure 6. Number of studies per country.
Source: own design.

Research was conducted in 11 thematic areas with a total of 123 research projects (Fig. 7). The area with the highest number is Business, Management and Accounting with 35 representing 28.45 % of the total; it is followed by Engineering, Decision Sciences and Computer Science with 23, 19 and 16 respectively.

The bibliometric network map (Fig. 8) aimed to examine the co-occurrence of keywords from the n=2 level onwards, 62 items were found united in six (6) clusters.

Table 2 shows an analysis of the six (6) clusters in order to find the most frequent keywords (items).

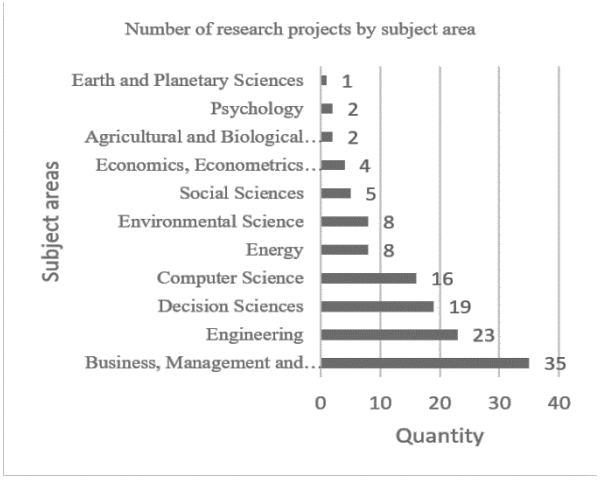


Figure 7. Number of research projects by subject area.
Source: own design.

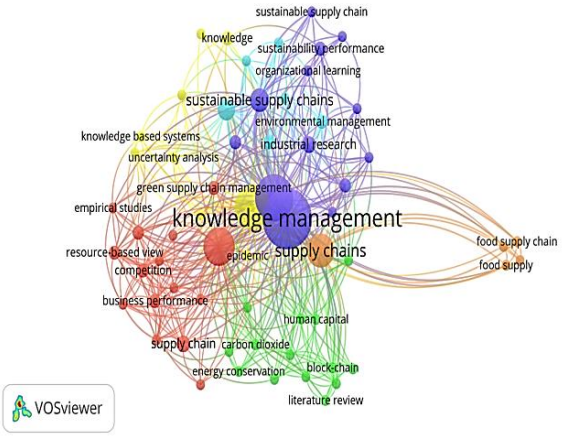


Figure 8. Network map of keyword co-occurrence.
Source: own design.

Table 2.
Cluster analysis of keywords with the highest frequency of occurrence.

| Clusters | Items | Color | Keywords |
|---|---|---|---|
| 1 | 15 | Red | Business performance, competition, competitive advantage, corporate social responsibility, empirical studies, energy utilization, environmental knowledge, green supply chain management, information systems, information technology, resource-based view, supply chain, sustainability, systematic literature review, triple bottom line. |
| 2 | 14 | Green | Block-chain, blockchain, carbon dioxide, cost reduction, energy conservation, human capital, literature review, mapping, planning, supply chain collaboration, supply chain visibility, sustainable production. |
| 3 | 13 | Blue | Buyer-supplier relationships, industrial research, knowledge management, least squares approximations, manufacture, operational performance, organizational learning, structural equation modeling, sustainability knowledge, sustainability performance, sustainable development, |

| | | | |
|---|---|---|---|
| | | | sustainable supply chain, sustainable supply chains. |
| 4 | 9 | Yellow | Conceptual framework, construction industry, epidemic, innovation, knowledge, knowledge-based systems, supply chain management, sustainable supply chain management, uncertainty analysis. |
| 5 | 6 | Celeste | Artificial intelligence, decision making, environmental impact, environmental management, environmental performance, information management. |
| 6 | 5 | orange | Food supply, food supply chain, multiple-case study, supply chains, waste management. |

Source: own design.

There were defined Six (6) lines of research linked to the implementation of knowledge management for supply chain sustainability derived from the cluster analysis (a line of research per cluster was defined on the basis of the keywords of which it consisted):

1. The impact of green supply chain management on business performance.
2. Impact of blockchain technology [24] on supply chain sustainability.
3. Impact f knowledge management on sustainable supply chain performance [25].
4. Sustainable supply chain management in the construction industry [26] in times of uncertainty and epidemics.
5. Application of artificial intelligence [27] in decision making to improve environmental performance and information management in enterprises.
6. Optimizing waste management in food supply chains [28].

It was performed an evaluation of scientific production related to the implementation of knowledge management for supply chain sustainability from 2009 to 2024, and it showed there are studies in different thematic areas, mostly in Business, Management and Accounting.

The centers that contributed the most are Brunel University London and Brunel Business School with three (3) each, while United Kingdom represents the major country´s contributions.

The articles were published in 29 journals, where Journal of Cleaner Production stands out with four (4) researches, International Journal of Production Economics and Production Planning and Control with three (3) each. A list of the 10 journals with the most citations (Table 3) is led by Journal of Strategic Information Systems.

The article with the highest number of citations is: “From green to sustainability: Information Technology and an integrated sustainability framework” with 496.

The journal with the highest h-index is the Journal of Cleaner Production with a value of 268. On the other hand, the journal with the highest SJR is the Journal of Strategic Information Systems with 4.011.

Bibliometric studies have been used in different contexts [29-31], in the area of supply chain management, to identify its challenges [1], in all cases to organize different science indicators and identify lines of research.

Table 3.
Journals with the most citations.

| Journals | Number of cites | h-index | SJR | Quartiles |
|---|---|---|---|---|
| Journal of Strategic Information Systems | 496 | 104 | 4,011 | Q1 |
| International Journal of Production Economics | 325 | 214 | 3,028 | Q1 |
| Journal of Knowledge Management | 185 | 134 | 2,22 | Q1 |
| Business Strategy and the Environment | 148 | 131 | 2,87 | Q1 |
| Production Planning and Control | 105 | 92 | 1,719 | Q1 |
| Technological Forecasting and Social Change | 75 | 155 | 2,644 | Q1 |
| Journal of Cleaner Production | 58 | 268 | 1,981 | Q1 |
| Journal of Manufacturing Technology Management | 40 | 84 | 2,083 | Q1 |
| Journal of Enterprise Information Management | 31 | 75 | 1,242 | Q1 |
| Journal of Innovation and Knowledge | 30 | 39 | 2,649 | Q1 |

Source: own design.

Although a link between the terms knowledge management and supply chain can be seen, it is weak [14], it is considered that there is little research that associates knowledge management with supply chain sustainability.

The country with the most research conducted was the United Kingdom (as shown in Fig. 6), a criterion that agrees with other research [32], which highlights this country as one of the most prominent in scientific production internationally. The affiliated institutions with the most articles were Brunel University London and Brunel Business School (as shown in Fig. 5), both in the United Kingdom, an aspect that is consistent with the most productive country according to the origin declared by the author and that agrees with other studies [33].

One of the restrictions of the research is that it has only been carried out in the Scopus database, however, its choice by the researchers was due to the fact that it is one of the main stream databases with the highest impact at international level (element that enhances its generalizability in other impact databases such as web of science, ScienceDirect, PubMed, Scielo, among others; and to carry out comparative analyses among them). In addition to considering other indicators not used in this research, such as the journals where they were published, as well as their country of origin, Prince’s index, analysis of collaboration between institutions or countries, number of journals discontinued in the database due to lower quality standards.

Among the positive aspects of the research is the analysis of the scientific production on the implementation of knowledge management for supply chain sustainability through the use of different bibliometric indicators and the identification of lines of research that will serve as a basis for future research.

## 5 Conclusions

The number of researches in the period behaved irregularly, with a tendency to increase from the year 2016, with the exception of 2021 in which there was a decrease, the highest value was obtained in the year 2023 with nine (9). The country with the highest number of publications was the United Kingdom with a total of 10.

Only two (2) authors had more than one (1) publication in the period analyzed, while the institutions with the most research were Brunel University London and Brunel Business School, both with a total of three (3). The subject area with the most studies was Business, Management and Accounting with 35.

The most cited journal was Journal of Strategic Information Systems with 496 citations, the one with the highest h-index was Journal of Cleaner Production with a value of 268 and the one with the highest SJR was Journal of Strategic Information Systems with 4.011.

A cluster analysis on author co-authorship was conducted to identify the main authors who have done research on the implementation of knowledge management for supply chain sustainability and the interrelations or collaborations between them.

Based on the analysis of the bibliometric network map of the co-occurrence of keywords, six (6) lines of research were detected (a line of research per cluster was defined on the basis of the keywords of which it consisted).

For future studies, it is recommended to analyze scientific production in other databases that have a high impact such as web of science, ScienceDirect, PubMed, Scielo, as well as to use other indicators such as Prince's index, analysis of collaboration between institutions or countries, number of journals discontinued in the database due to lower quality standards.

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UNIVERSIDAD NACIONAL DE COLOMBIA

# Analysis of intense hydrological periods based on observed and estimated flow series at a reference station on the Paraná River, Argentina

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**Abstract**
The hydrological variability and especially extreme phenomena such as droughts and floods affect natural and human systems worldwide. The Paraná River sub-basin, belonging to the La Plata basin, is of great regional importance, and in recent years extreme events have been observed that have impacted socio-economic aspects of the community. This study compares the series of a relevant hydrological index, calculated from observed flows and unregulated contributions within Argentine territory, at the same reference station. Intense hydrological periods are analyzed in both cases, for droughts and excess water events, for subsequent comparison.

*Keywords*: extreme hydrological phenomena; SDI index; regulated and unregulated flows

# Análisis de períodos hidrológicos intensos a partir de series de caudales observados y estimados en una estación de referencia del río Paraná, Argentina

**Resumen**
La variabilidad hidrológica y en especial los fenómenos extremos como las sequías e inundaciones afecta a los sistemas naturales y humanos en todo el mundo. La subcuenca del río Paraná perteneciente a la cuenca del Plata, es de gran importancia regional y en los últimos años se han observado eventos extremos que han afectado aspectos socieconómicos de la comunidad. En este estudio se comparan las series de un índice hidrológico pertinente, calculadas a partir de caudales observados y de aportes sin regulación dentro del territorio argentino, en una misma estación de referencia. Se analizan los períodos hidrológicos intensos en ambos casos, tanto de sequías como de excesos hídricos, para su posterior comparación.

*Palabras clave*: fenómenos hidrológicos extremos; índice SDI; caudales regulados y no regulados

## 1 Introducción

Hydroclimate variability affects natural and human systems worldwide.

Impacts of such climate-related extremes include alteration of ecosystems, disruption of food production and water supply, damage to infrastructure and settlements, morbidity and mortality, and consequences for mental health and human well-being [1].

Droughts and floods stand out as extreme hydrological phenomena.

Extreme events occurring in the La Plata basin can greatly affect the natural systems of the basin as well as the social and economic sectors. [2].

The Paraná-Plata basin is the second largest hydrological basin in South America and is of great importance for the countries of the region (Argentina, Bolivia, Brazil, Paraguay and Uruguay [3].

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Also, this basin is the most densely populated region in South America and is economically dependent on agriculture and hydroelectric power generation. Within this basin is the sub-basin of the Paraná River, whose main tributary is the Paraguay River, covering an area of approximately 2,700,000 km². In Argentina, the Paraná River valley stretches over a length of 900 km, starting at the confluence of the Paraguay and Alto Paraná rivers in Corrientes.

He absence of precipitation in a specific area over a certain period leads to a hydrological deficit known as "drought." Surface hydrological drought is characterized by reduced flow in river channels, lower water levels in lakes, reservoirs, and other water bodies. This climatic challenge has significant negative impacts on the socioeconomic aspects of a region [4].

Given the recent changes in the frequency, duration and intensity of droughts, a comprehensive understanding of water scarcity is needed at different temporal and spatial scales. This requirement is pressing given the marked increase in demand of water for agriculture, energy production, industry and human consumption [5]

Recently, a multi-year drought has affected the La Plata basin from mid-2019 until at least the first months of 2023. This prolonged and severe drought has severely impacted water availability for various socioeconomic activities and natural ecosystems [6].

Regarding water excesses, they form the opposite phase to deficit phenomena, causing floods in which case their harmful effects affect different sectors and aspects of human activity and their quality of life. In the 20th century, humidity has progressively increased in the Río de la Plata basin, and the probability of major flooding is also increasing [7].

The Paraná River (main channel of the Plata Basin) presents annual floods that, in irregular periods are more intense and with an approximate frequency of two per century, are extraordinary and catastrophic [8].

Nevertheless, it is necessary a joint view of the main hydroclimatic variables and their sectoral impacts at different timescales to provide accurate and integrated information that will facilitate decision-making processes [9].

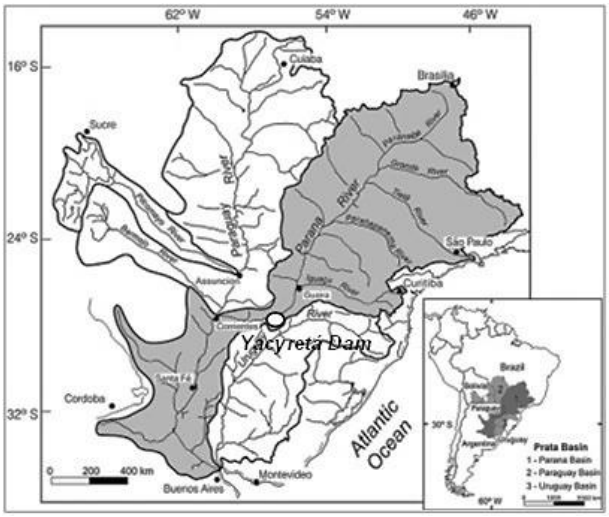


Figure 1. The La Plata Basin is formed by the Paraná–Paraguay and Uruguay Rivers. The Paraná River receives the Paraguay River near Corrientes, Argentina. Source: Stevaux, J. and Meurer, M., 2009 [10]

Table 1.
Selected stations

| River | Name | Country | Period |
|---|---|---|---|
| Paraná | Corrientes (Observed series) | Argentina | 1904-2022 |
| Paraguay | Puerto Bermejo | Argentina | 1956-2022 |
| Iguazú | Baixo Iguaçu | Brazil | 1956-2022 |
| Paraná | Itaipú | Brazil | 1931-2022 |

Source: Own elaboration

In such a way that the tasks carried out in order to evaluate these extreme hydrological events are of great importance in the national territory and in this case in the sub-basin of the Paraná River, belonging to the Plata Basin.

From this and due to the hydrological variations that have been observed in recent years in the Paraná River, it is considered necessary to analyze the dry and wet historical periods, based on a basic quantitative evaluation in fluvial sections of the Paraná, Iguazú River (both still in Brazilian territory) and Paraguay, with the purpose of estimating the series of monthly flows upstream of the Corrientes station (Paraná River in Argentine territory) and its subsequent comparison with the data series observed in the latter (Fig. 1), to analyze the occurrence of historical extreme hydrological events, dry and humid, and the possible influence of regulation, within the national territory, in a reference station of the Paraná River.

## 2 Methodological procedure

### *2.1 Preprocessing*

First, the sum of flows from the two stations in Brazil is carried out: Itaipú on the Paraná River and Baixo Iguaçu on the Iguazú River (upstream of the binational Yacyretá Dam) and from the Puerto Bermejo station on the Paraguay River (previously completed by statistical processing with a nearby series upstream, called Puerto Bermejo) [11]

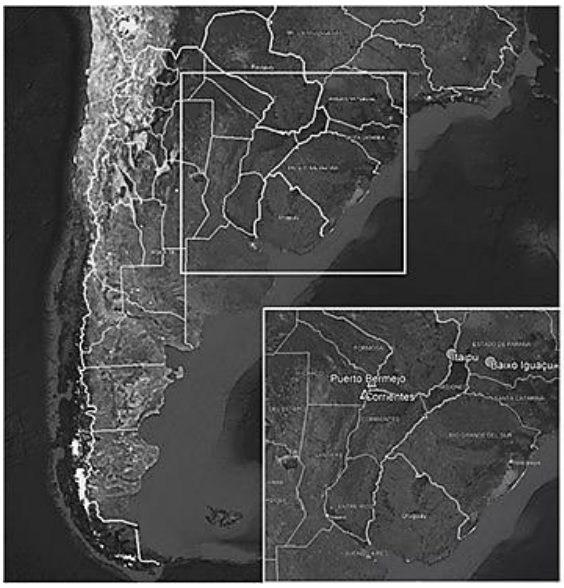


Figure 2. Relative location of the study area and the selected stations. Source: Own elaboration from Google Earth images. Data SIO, NOAA, U.S Navy, NGA, GEBCO. Image Landsat / Copernicus

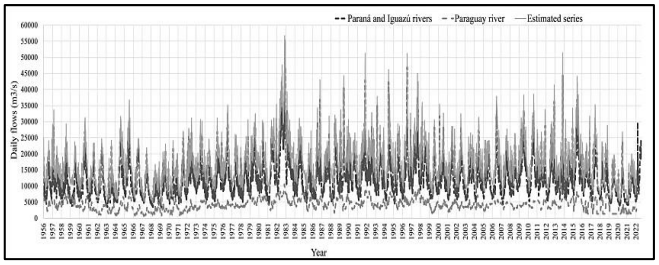


Figure 3. Observed daily data series: sum of the Paraná and Iguazú rivers (Brazil); the Paraguay river and estimated total daily series at the confluence.
Source: Own elaboration

After preprocessing and statistical analysis, the series detailed in Table 1 were obtained. Their relative location is shown in Fig. 2.

The estimated series with contributions (not regulated in Argentine territory) in the stretch upstream of the Corrientes station is compared with the observed values at that site, and through a relevant index, the different hydrological periods are analyzed.

### *2.2 Hydrological drought index*

Streamflow Drought Index (SDI) developed by Nalbantis (2008) was used to analyze hydrological droughts. The SDI index allows the determination and classification of droughts in a basin. However, sufficiently long series of data is required data to estimate the frequency of drought events. Nalbantis (2008) indicated that SDI index is based in the analyze of the accumulated values of flows, volumes or runoff in three, six, nine or twelve months within for each hydrological year, called k1, k2, k3 and k4 respectively. These intervals allow to analyze the evolution of droughts in the annual period considered [12]. The SDI index function eq. (1):

$$V_{i,k} = \sum_{j=1}^{3k} Q_{ij} \quad (1)$$

$$\mathrm{i} = 1,2,\ldots,\mathrm{n};\ \mathrm{j} = 1,2,\ldots,12;\ \mathrm{k} = 1,2,3,4$$

Where $Q_{i,j}$ are streamflow volume values, i is the hydrological year, j month within a hydrological year and $V_{i,k}$ cumulative of streamflow volume for the i year and k reference period. Then the SDI function is eq. (2):

$$SDI_{i,k} = \frac{V_{i,k} - V_k}{s_k} \quad (2)$$

$SDI_{i,k}$ is a hydrological drought index for the i year and k reference period. $V_k$ and $s_k$ are, respectively, the mean and standard deviation of volume data for k interval considered. The definition of the hydrological drought levels according to the SDI index is shown in Table 2.

From this classification, it is defined for this work that opposite periods of equal magnitude are defined as wet with the same level denomination (mild, moderate, severe and extreme).

Table 2.
Definition of states of hydrological drought with the aid of SDI

| Description | Criterion | Probability |
|---|---|---|
| No drought | SDII,k=> 0 | 50 |
| Mild drought | -1 <= SDII,k <0 | 34.1 |
| Moderate drought | -1.5 <= SDII,k <-1 | 9.2 |
| Severe drought | -2 <= SDII,k <-1.5 | 4.4 |
| Extreme drought | SDII,k <-2 | 2.3 |

Source: Nalbatis, 2008 [13]

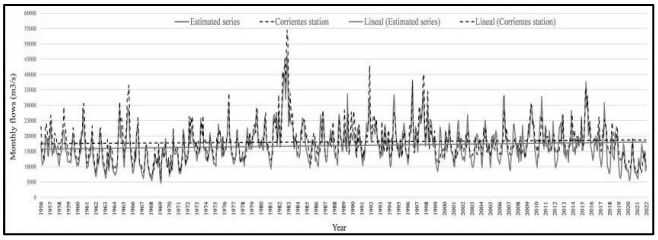


Figure 4. Flow series estimated at the upstream confluence and observed data series at the Corrientes station (1956-2022).
Source: Own elaboration

The present study focuses on the occurrence of intense periods (severe and extreme), that is, starting from the values (-1.5) and 1.5 of the SDI to evaluate this index at the Corrientes station for the observed data series and the estimated series, in order to observe the characteristics and evolution of dry cycles in years with historical records of monthly flows and then make an analogy with opposite values to characterize wet periods.

## 3 Results

Fig. 3 shows the series of the contributing rivers and the total estimated at the confluence of these. It is possible to observe that the contribution of the Paraguay river is notably less than the total contribution of the rivers coming from Brazil

Then, the estimated monthly flow series upstream of the Corrientes station and the data series observed at this station are obtained (Fig. 4).

In general, the estimated series tends to underestimate the important peaks until the mid-90s and this can even be observed in the phase shift of the trend lines. From that time on, the peaks are slightly overestimated in several cases and the minimum values (valleys of the curves) are more intense with respect to the observed series.

It should be noted that the Yacyretá dam (Fig. 1) began to be built in 1983 and was put into operation at the end of 1994. Which would cause modifications in the behavior of the natural flow regime in the analyzed site. This change better shown in Fig. 5 (period 1956-1994) and Fig. 6 (period 1994-2022) where the trend changes from positive to negative. Also, in both cases the trend of the estimated series is slightly lower than the trend of the observed series.

This would indicate that natural flows present lower values than those regulated, marking the greatest probability of presenting dry cycles in the Corrientes station of the Paraná River.

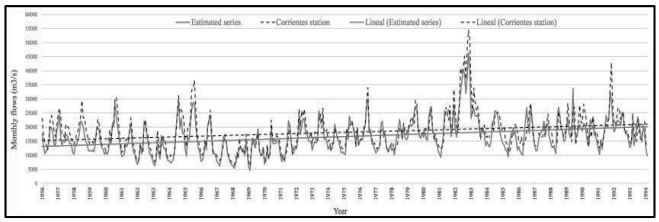


Figure 5. Flow series estimated at the upstream confluence and observed data series at the Corrientes station (1956-1994).
Source: Own elaboration

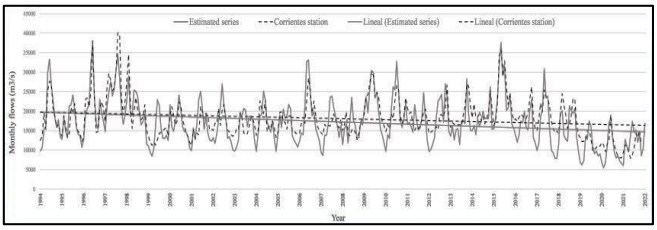


Figure 6. Flow series estimated at the upstream confluence and observed data series at the Corrientes station (1994-2022).
Source: Own elaboration

From this, the SDI indices are calculated with the estimated and observed data series for the analysis of dry and wet hydrological cycles (Fig.7). In addition, their 12-month moving averages are graphed and the lines of SDI 1.5 and (-1.5) are highlighted to facilitate the identification of severe or extreme events in wet and dry hydrological periods, respectively.

In the case of the characterization of the dry and wet periods with the SDI index, it is observed that both series present a similar behavior in their evolution over time, however, the estimated series would present more intense periods of drought, such as the years 1963-1964, 1967-1968 and 2019-2021.

In the case of excess water, the opposite happens. The maximum peaks of the estimated series present lower values than the observed series peaks, such as in the years 1982-1983, 1997-1998 and 2015-2016.

It should be noted that since the beginning of the 1980s the trend remained at normal to humid values until 2019. Then, it began to decrease noticeably.

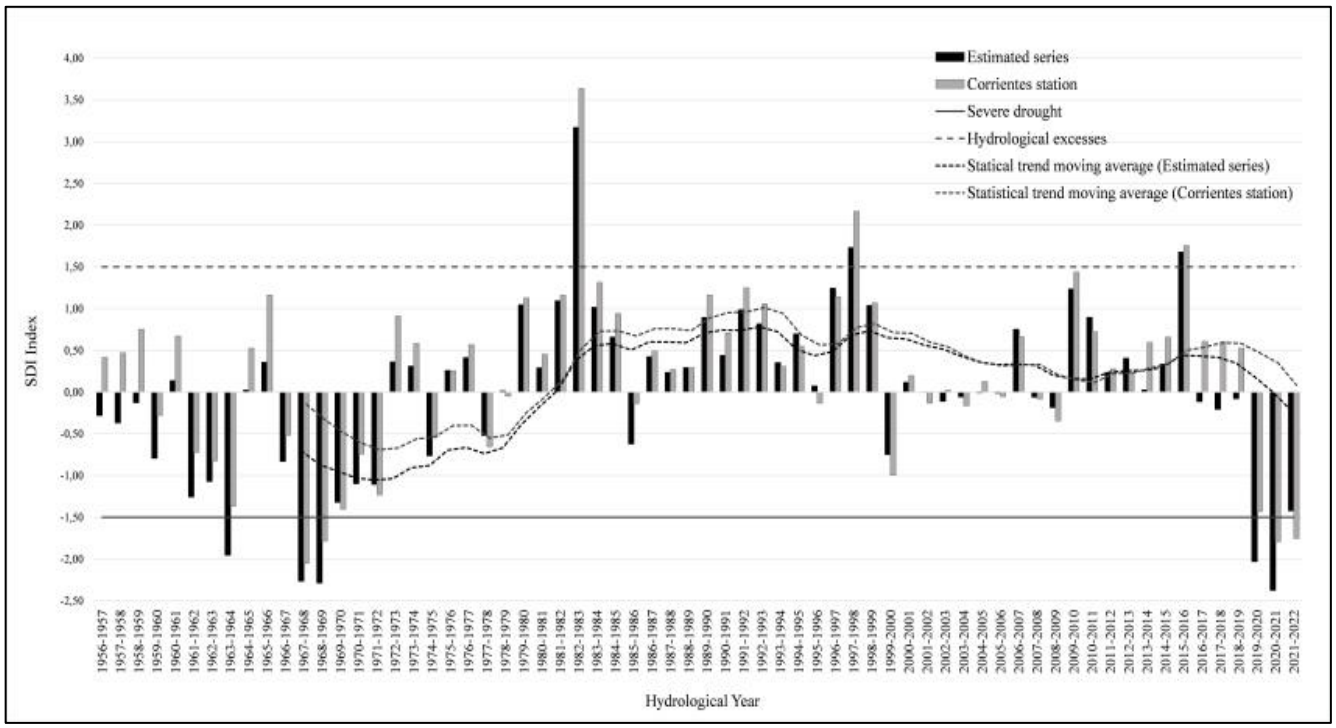


Figure 7. SDI indices of the estimated flow series at the upstream confluence and the observed flow series at the Corrientes station (1956-2022); their respective moving averages (12 months) and the lines of the indices representing excesses and severe droughts: 1.5 and (-1.5), respectively.
Source: Own elaboration

## 1 Conclusiones

It was possible to collect records in sections of the Paraná and Iguazú rivers (Brazil) and the Paraguay River in order to obtain a series of total flows at the confluence, upstream of the Corrientes station, which is adopted as a reference for subsequent comparison with the observed data series. This was done to analyze extreme hydrological events and periods and evaluate the possible influence of flow regulation and management during intense droughts and floods.

It was also observed that, in the absence of regulation, dry periods would likely be more intense, while periods of excesses would be less severe.

Years of extreme hydrological values were identified throughout the analyzed period.

It is worth noting that it is considered necessary to continue and expand this study from an integrated perspective of Water Resources; as well as to update it as the necessary records are obtained, allowing to advance in the understanding of extreme hydrological phenomena in the Paraná River basin, due to its regional importance.

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# Evaluation of drying techniques for postharvest residue utilization in 'Nufar' Basil (*Ocimum basilicum* L.) production

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**Abstract**
In this study, drying techniques including lyophilization, forced convection, marquee with polyshade, and refractive window were evaluated in the post-harvest residue of Nufar variety basil (*Ocimum basilicum* L.) in the department of Tolima, Colombia. The physicochemical and bromatological analysis showed that lyophilization and forced convection better maintained the organoleptic properties of dry basil, while the marquee with polyshade technique did not affect the phenolic content and antioxidant capacity. The refractive window technique showed higher rehydration capacity but lower essential oil content. In the sensory evaluation, the infusions of dried leaves in the marquee with polyshade method were highly accepted. The results suggest that drying by forced convection and marquee with polyshade are effective methods to preserve the quality of dried basil, presenting a viable alternative for the use of post-harvest residue and improving the useful life of the product, benefitting local producers by increased employability and added value.

*Keywords*: *Ocimum basilicum*; agroindustry; drying systems; residues use.

# Evaluación de técnicas de secado para el aprovechamiento del residuo poscosecha en la producción de albahaca 'Nufar' (*Ocimum basilicum* L.)

**Resumen**
En este estudio se evaluaron las técnicas de secado por liofilización, convección forzada, marquesina y ventana refractiva en los residuos postcosecha de albahaca (*Ocimum basilicum* L.) variedad Nufar en el departamento del Tolima, Colombia. El análisis fisicoquímico y bromatológico mostró que la liofilización y la convección forzada mantuvieron mejor las propiedades organolépticas de la albahaca seca, mientras que la técnica de marquesina no afectó el contenido de fenoles y su capacidad antioxidante. La técnica de ventana refractiva mostró mayor capacidad de rehidratación, pero menor contenido de aceite esencial. En la evaluación sensorial, las infusiones de hojas secadas en marquesina fueron altamente aceptadas. Los resultados sugieren que el secado por convección forzada y marquesina son métodos efectivos para preservar la calidad de la albahaca seca, siendo una alternativa viable para el aprovechamiento de residuos postcosecha y mejora de la vida útil del producto, beneficiando a los productores locales al aumentar su empleabilidad y valor agregado.

*Palabras clave*: *Ocimum basilicum*; agroindustria; sistemas de secado; aprovechamiento de residuos.

## 1 Introduction

Basil (*Ocimum basilicum* L.) belongs to the Lamiaceae family and is an herbaceous plant with a height of 20 to 60 cm and purplish-white flowers. It is grown in Mediterranean countries and regions with temperate and warm climates. Basil is an agricultural and agroindustrial alternative for Colombia; it is an aromatic species that is characterized by its condiment and pharmaceutical use, given its diuretic and stimulant properties, as well as its essential oil content, based

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on cineole, methyl chavicol, linalool, estragole, eugenol and thymol, used in the cosmetics, food and pharmaceutical industries [1] .Aromatic species, such as basil, are promising crops in Colombia with great economic potential, which increasingly attract more producers due to their recent and growing commercialization in international markets [2]. In many regions worldwide, dehydrated basil is used as an alternative to impart aroma and highlight the flavor of foods such as pasta-based preparations and salads.

Basil cultivation in the department of Tolima was, by 2017, one of the most promising crops with a growth of 21%, and it was the main aromatic plant exported [3]. However, there are still gaps in the harvest and postharvest stages identified in the municipalities of Espinal, Honda, and Mariquita, such as the amount of residue generated that becomes a phytosanitary reservoir for pests and diseases, which limits the reduction in export material. The non-exportable remainder is estimated at 30 to 50%, which could be used in different agro-industrial processing processes.

This article presents alternatives and treatments using various drying systems, including freeze-drying, forced convection, marquee with polyshade, and refractive window. The sun drying technique is the most used. However, it has many problems, such as prolonged exposure during drying, environmental pollution, climate uncertainty, and labor requirements. There is often a decrease in the quality of dried products because most conventional techniques use high temperatures during the drying process. Processing can introduce undesirable changes in appearance and cause texture, flavor, and color changes. Furthermore, drying is one of the conservation methods that guarantee microbial safety and, in turn, prolong the shelf life of food.

Consequently, the objective of the work was to evaluate different drying techniques for post-harvest basil residue in terms of physicochemical and sensory characteristics. It is sought which of the drying techniques such as freeze-drying, forced convection, refractive window and canopy with polyshading allow to increase the useful life and preserve the quality of dried basil.

## 2 Materials and methods

Plant residues (leaves and stems) of basil (*Ocimum basilicum* L.) of the Nufar variety were collected from the postharvest process on producer farms in the municipality of Espinal, Tolima Department, Colombia, following the guidelines indicated in Resolution 1466 of December 3, 2014, of Autoridad Nacional de Licencias Ambientales (ANLA) [National Environmental Licensing Authority]. The leaves were removed from the stem, and only healthy leaves were selected.

### *2.1 Drying techniques for postharvest basil residues*

The drying of basil leaves was carried out using the following four different techniques that allowed the dehydration of the plant material until a moisture percentage of less than 10% was obtained. 1) Marquee with polyshade: Basil leaves were dehydrated in a marquee-type dryer with a 65% polyshade cover (20.4–52.5°C, 24.5–95% moisture); 2) Refractance window: this technique utilized basil leaves mixed with water in a 1:3 w/w ratio and subjected to sonication in a Hielscher UP 200s sonicator for 1 h at an amplitude of 100% and 0.5 cycles. After this period, the water was removed, and the leaves were macerated until obtaining a paste that was dehydrated in a refractance window pilot equipment at 80°C; 3) Forced air convection drying system: the basil leaves were taken to a Memmert reference UF55 dehydrating oven coupled to a forced convection system that allows the recirculation and homogenization of hot air; the process was carried out at a temperature of 50°C with a ventilation setting of 50% and a hatch opening of 100% that allows the generated water vapor to escape; and 4) Lyophilization: Freeze-drying of the classified leaves was carried out in a Christ Alpha model 1-4 LO Plus laboratory pilot-scale freeze-dryer. The plant material was previously frozen at -22°C ± 2 in a conventional freezer for 3–4 h. Once this first stage was completed, it was taken to the lyophilizer with the condenser freezing setting of -51°C ± 2 for 16 h as the main drying stage and then the final drying stage of 2 h; the vacuum level, i.e., the absolute pressure of the lyophilization process was 0.035 mbar with the manufacturer's adjustment to the condenser temperature.

#### *2.1.1 Bromatological and physicochemical determination of postharvest residues of dried basil*

The bromatological and physicochemical analysis was determined based on the dry matter obtained in the drying processes with a moisture of less than 10%. The variables determined were pH and conductivity previously calibrated with a Bante 900P Multiparameter, water activity (aw) with a Hygropalm probe from the Rotronic brand, moisture % through the gravimetric technique (ISO 6496:2009-NTC 4888:2000), ash content (AOAC 942.05, Ed. 21, 2019), ether extract (AOAC 2003.06-2006 21 th 2019), protein (AOAC 960.52-2008 21 th 2019), and crude fiber (ISO 6865:2000-NTC 5122:2002) of dried and macerated basil leaves.

#### *2.1.2 Dry substrate rehydration capacity*

The rehydration capacity of the samples was determined according to the method described by Telfser and Gómez Galindo [4]. Three leaves were weighed, and each was placed in a different beaker with 100 mL of distilled water at room temperature. After 1 h, the samples were extracted, and the excess water on their surface was removed with blotting paper to measure the weight gained. The leaves were then placed back into the beakers. This procedure was repeated every hour for 24 h. The rehydration capacity (%) was calculated as the ratio between the weight of the rehydrated sample and the weight of the dried sample.

#### *2.1.3 Color Determination*

It was carried out following the methodology proposed by Díaz Castro [5]. Color measurements were determined with a Konica Minolta colorimeter (Model No: CR-400) in a light-controlled room; L*, a*, and b* values were measured for fresh and dry leaves. The color index was calculated as described by Vignoni et al. [6]. according to Eq. 1, where L, a, and b are the parameters and color identification was carried out according to Table 1.

$$IC* = \frac{a * 1000}{L * b} \quad (1)$$

Table 1.
Ranges for color index (CI*)

| Range of CI* | Color |
|---|---|
| -40 to -20 | From blue-violet to deep green |
| -20 to -2 | From deep green to yellowish green |
| -2 to +2 | Greenish yellow |
| +2 to +20 | From pale yellow to deep orange |
| +20 to +40 | From intense orange to deep red |

Source: Own elaboration

### *2.1.4 Determination of total phenol content and antioxidant activity*

#### 2.1.4.1 Preparation of extracts from dried basil leaves

The dried basil leaves were macerated with liquid nitrogen. Extraction was carried out with 80% ethanol in a 1:15 w/v ratio, and the sample was shaken in an orbital shaker brand for 2 h on a bench of ice. The sample was centrifuged at 6000 RPM for 20 min; the supernatant was separated and filtered using a Büchner funnel with a Whatman grade 1 filter.

#### 2.1.4.2 Total phenols

The total phenolic content was quantified by the Folin-Ciocalteu method with modifications reported by Mahmoud et al. [6]. A volume of 100 µl of the extract of dry basil leaves was taken, 2100 µl of distilled water was added, followed by 350 µl of Folin Ciocalteu reagent at 1N concentration. Subsequently, it was shaken in a Heidolph brand vortex for 30 s, and 700 µl of 20% $Na_2CO_3$ was added and placed in the dark for 2 h. The absorbance was measured in a Thermo Scientific brand Helios zeta spectrophotometer at 765nm. The total phenolic content was quantified with a gallic acid calibration curve, and the results were expressed in mg gallic acid/100 g of dry leaves.

#### 2.1.4.3 Antioxidant capacity

The DPPH method was used with some modifications to determine the antioxidant capacity [7]. A volume of 20 µl of ethanolic extract from dried basil leaves was taken, and 300 µl of DPPH was added, allowing it to react for 30 min, and the absorbance was measured at 517 nm in a Thermos Scientific brand Multiskan plate reader. From a calibration curve with Trolox, the trapping capacity of the DPPH radical was calculated in mg Trolox/100 g of dry leaves.

### *2.1.5 Extraction and obtaining of essential oil*

The extraction of essential oils from basil residues was carried out by the hydrodistillation method. microwave-assisted (MWHD). A hydrodistillation equipment was used, with a capacity of 2L, in which 400g of leaves, with 300mL of distilled water, were introduced into the extraction flask. and heated for 30 min, divided into three 10 min cycles; As a source of microwave radiation, an oven was used conventional. The essential oils were collected in a Dean Stark type device; The separation of the essential oil was carried out by decantation, it was immediately stored at 4°C in amber glass bottles, until analysis.

#### 2.1.5.1 Determination of the volatile fraction in solids by HS-SPME/GC-MS

The simultaneous concentration extraction of the compounds in the sample(s) was carried out using a fused silica fiber coated with PDMS/DVB of 65 µm thickness, an equilibrium time of 10 min, an extraction time of 30 min, an extraction temperature of 60°C, a desorption time in the chromatographic port of 10 min, and a desorption temperature in the injection port of 250°C. The certified $C_6$-$C_{25}$ hydrocarbon mixture (AccuStandard, New Haven, CT, USA) was used as reference material.

### *2.1.6 Descriptive Sensory Analysis*

The sensory effect consisted of evaluating and assessing aromatic infusions from the drying treatments of the basil residue, considering attributes such as flavor, aroma, color, and acceptance. The test was effective in a global panel of 90 untrained people who showed some taste or affinity for this type of infusion. The descriptive test included the following appreciations: I don't like it; I neither like it nor dislike it; I like it; and I like it a lot, to establish a description of the parameters evaluated with respect to the effect of drying techniques. The samples were coded, and a commercial sample was used as a control. The level of acceptance of the drying techniques was determined in comparison to a commercial sample concerning the evaluated variables.

### *2.1.7 Data Analysis*

Chemical composition and sensory acceptance data were analyzed by ANOVA—one-way and two-way (samples and participants as the source of variation), respectively—and Fisher's LSD test ($p \leq 0.05$) using the statistical package Statgraphics Centurion XVII.

## 3 Results

The drying conditions that basil residues were subjected to according to different drying methods are shown in Table 2.

### *3.1 Bromatological and physicochemical determination of dried basil*

The analysis of the results of the physicochemical characterization of dried basil under different techniques recorded significant differences at a confidence level of 95% for the moisture and protein variables, forming two homogeneous groups in the LSD test. The variables fat percentage, water activity, conductivity, and ash formed three homogeneous groups in the multiple-range test. Moisture grouped the results of the freeze-drying, convection, and refractive window technique in the first group with the lowest recorded moisture content, followed by the marquee with polyshade technique in the second group, and the commercial control, which recorded the highest moisture content with respect to the other samples. The water activity of the evaluated treatments was found to be between 0.19 and 0.65 for the dried basil samples from the refractive window and convection drying techniques, respectively (Table 3).

Table 2.
Drying conditions of basil residue in different drying methods.

| Drying Method | Drying Conditions | Advantages | Desventajas |
|---|---|---|---|
| Freeze drying | Stage 1: Freezing T°: -22°C ± 2<br>Time: 3-4 h<br>Stage 2: Principal drying<br>T°: -51°C ± 2<br>Time: 16 h<br>Vacuum pressure: 0.035 mbar<br>Stage 3: End drying<br>T°: -51°C ± 2<br>Time: 2 h Vacuum pressure: 0.035 mbar | - Better quality by-product<br>- Best color<br>- Low oxidation<br>- Better palatability<br>- Greater freshness feeling<br>- Good preservation of antioxidant activity | - High costs<br>- Longer dehydration time.<br>- Low essential oil content<br>- Lower loading capacity per drying batch<br>- Low performance |
| Forced Convection Oven | Oven T°: 50°C<br>Hatch: 100%<br>Ventilation: 50%<br>Drying Time: 14 h | - Low cost<br>- Shorter dehydration time<br>- Greater loading capacity per drying batch<br>- Good preservation of antioxidant activity<br>- Little volatilization of essential oil<br>- High performance | - Greater oxidation<br>- Less freshness sensation<br>- Greater color loss |
| Refractive Window | Mix with Water Ratio 1:3 w/w<br>Sonication time: 1 h<br>Amplitude: 100%<br>Cycles: 0.5<br>Window T°: 80°C | - 4th generation technology<br>- Conservation of bioactive compounds<br>- Low direct heat transfer | - High-cost technology |
| Marquee with Polyshade | Polyshade 65% (20.4–52.5°C, 24.5–95% moisture) | - Low production cost<br>- Higher performance<br>- High conservation of antioxidant activity<br>- Greater conservation of essential oil volatilization | - Long drying times<br>- Greater oxidation<br>- Less control of microbial contamination |

Source: Own elaboration

Table 3.
Physicochemical characterization of dried basil subjected to different drying treatments.

| Treatments | M (%) | Aw | pH | C (mS/cm) | Ash (%) | Fat (%) | Protein (%) | Fiber (%) |
|---|---|---|---|---|---|---|---|---|
| Commercial control | 10.17± 0.76 | 0.62±0.012 | 6,21±0.04 | 7.86± 0.03 | 10.3±0.86 | 4.57± 0.21 | 17.17± 0.79 | 11.60±1.32 |
| Forced convection | 7.58± 0.13 | 0.65±0.002 | 5.91±0.02 | 6.82± 0.166 | 15.67±0.40 | 1.51±0.12 | 22.85± 0.51 | 9.55±0.41 |
| Lyophilization | 6.78± 0.13 | 0.58±0.019 | 6.07±0.05 | 7.40± 0.628 | 16.30±0.34 | 2.53±0.09 | 21.13± 0.32 | 11.03±0.26 |
| Refractive window | 7.59± 0.78 | 0.19±0.018 | 5.93±0.25 | 5.12± 0.08 | 14.04±0.95 | 3.16±0.18 | 21.97± 0.76 | 8.56±0.39 |
| Marquee with polyshade | 10.00± 0.69 | 0.56±0.027 | 6.16±0.06 | 4.38± 0.108 | 17.44±0.90 | 3.06±0.58 | 22.07± 0.79 | 11.73±1.17 |

M: Moisture, C: Conductivity
Source: Own elaboration

### *3.1 Rehydration capacity*

The rehydration capacity of the postharvest residue of dehydrated basil presented statistically significant differences in the drying systems evaluated, at a confidence level of 95%, forming three homogeneous groups corresponding to the freeze-drying technique in the first group, forced convection, marquee with polyshade and the commercial control in the second group, and finally, the third group with refractive window (Table 4), which recorded the highest rehydration capacity, reflected in shorter rehydration time to reach osmotic balance, leaving the lesions evident caused in the cell wall and high permeability, allowing the rapid diffusion of water at the cellular level [8].

Table 4.
Rehydration capacity of dried basil subjected to different drying methods

| Treatment (Drying methods) | Rehydration capacity (%) | |
|---|---|---|
| | Mean | SD |
| Lyophilization | 20.23[a] | 0.72 |
| Forced convection | 26.23[b] | 0.64 |
| Refractive window | 45.27[c] | 0.79 |
| Marquee with polyshade | 34.11[d] | 1.16 |
| Commercial sample | 32.93[d] | 0.64 |

[a,b,c,d] Different letters indicate statistically significant differences in LSD Fisher's test at P<0.05
Source: Own elaboration

### *3.2 Total phenol content and antioxidant capacity*

The average value of the total phenolic content and antioxidant capacity of the drying techniques studied is shown in Fig. 1. The evaluated techniques presented significant statistical differences with a P-value of 0.0000 for the variables total phenolic content and antioxidant capacity. According to the results obtained, marquee with polyshade drying was the technique that allowed the highest content of total phenols to be preserved in dried basil with 223.69 mg gallic acid/100 g dry leaves, followed by the forced convection oven techniques with 194.76 mg gallic acid/100 g dry leaves and refractive window with 191.50 mg gallic acid/100 g dry leaves, which did not show significant differences by homogeneous groups.

Drying by lyophilization and the commercial control obtained values of 146.02 and 58.72 mg gallic acid/100 g dry leaves, respectively, showing commercial dried basil as the sample with the lowest total phenols values.

Regarding the antioxidant capacity of dried basil leaves, the forced convection and marquee with polyshade techniques presented the highest values with 330.11 and 320.06 mg Trolox/100 g dry leaves, which did not show significant differences for this group, in contrast to dried basil by lyophilization, refractive window and the commercial control that showed significant differences between them, with contents of 306.23, 170.38, and 110.42 mg Trolox/100 g dry leaves, respectively.

### *3.3 Color index*

Dried basil showed differential behavior in terms of color index for the drying techniques to which fresh basil was subjected (Fig. 2). According to the results of Table 5, the CI* showed statistically significant differences with a P-value of 0.0001 for the drying methods. The commercial control did not show good results, showing a CI* of 7.29±0.43, ranging from pale yellow to intense orange. Likewise, the refractive window and lyophilization techniques presented a CI* of 1.99±0.45 and -3.41±0.53, respectively, registering colors from greenish yellow and deep green to yellowish green, showing that lyophilization preserved the expected coloration for dried basil leaves. In the forced convection and marquee with polyshade techniques, the leaves showed a greenish-yellow color with a CI* of -0.19±0.02 and -1.52±0.61, respectively.

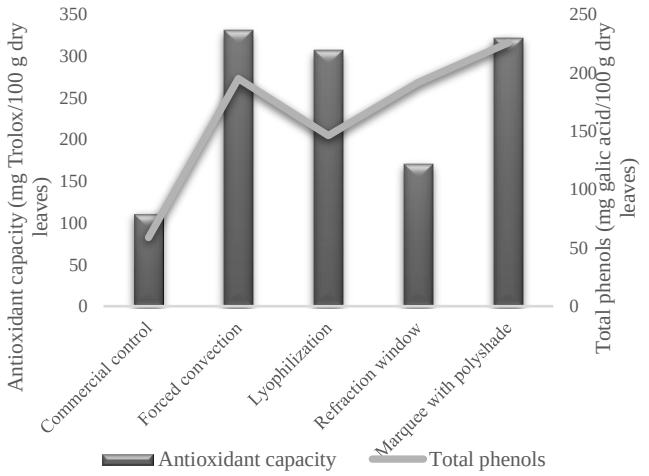



Figure 1. Total phenolic content and antioxidant capacity of dry basil subjected to different drying techniques.
Source: Own elaboration

Table 5.
Color index (CI*) of dry basil samples with different drying methods

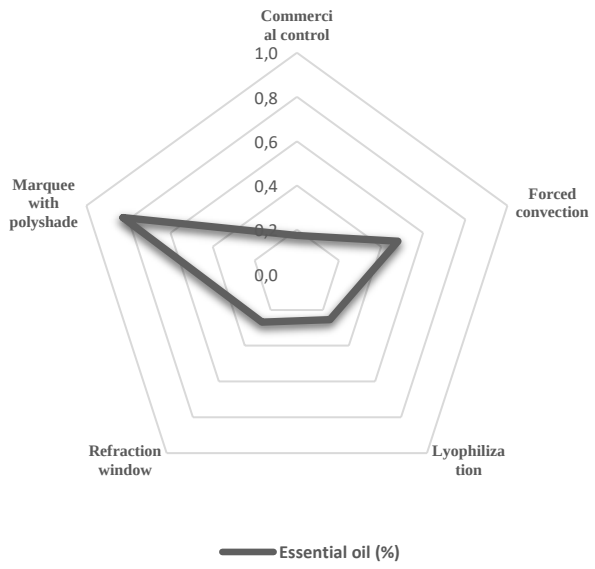
| Treatments (drying methods) | CI* | |
|---|---|---|
| | Mean | SD |
| Commercial control | 7.29[a] | 0.43 |
| Refractive window | 1.99[b] | 0.45 |
| Forced-convection | -0.19[c] | 0.02 |
| Marquee with polyshade | -1.52[c] | 0.61 |
| Lyophilization | -3.41[d] | 0.53 |

[a,b,c,d] Different letters indicate statistically significant differences in LSD Fisher's test at P<0.05
Source: Own elaboration


Figure 2. Color of samples of dried basil leaves subjected to different drying techniques (top, from left to right: commercial control, lyophilization, forced convection oven; down, from left to right: marquee with polyshade, and refractive window).
Source: Own elaboration

### *3.4 Percentage of essential oil*

The essential oil content of the evaluated treatments showed significant differences at a confidence level of 95%, generating four homogeneous groups. The first includes the commercial control which registered the lowest value with 0.175%, followed by a second group comprised of lyophilization and the refractive window techniques, which registered an average of 0.25% and 0.26%, respectively. The third and fourth groups included the forced convection and marquee with polyshade techniques with percentages of 0.48% and 0.41% of essential oil, respectively (Fig. 3).




Source: Own elaboration
Figure 3. Percentage of essential oil from dried basil residue under different drying techniques.

### *3.5 Volatile compound profile*

The volatile composition of the analyzed samples (Table 6) showed the effect of the drying technique, finding different concentrations of the compounds when the postharvest residues were subjected to different dehydration treatments. The volatile compounds most present in the basil samples were trans-oxide, linalool with up to 40.3% in the sample dried by lyophilization, linalool, and estragole with 33.3% and 21.5%, respectively for the sample dried by forced convection. Eugenol was detected in proportions of 5.8% and 2.8% for basil from lyophilization and marquee with polyshade drying techniques. These compounds have been associated with the typical basil aroma and good antioxidant properties [9].

Table 6.
Volatile compound profile of dried basil subjected to different drying techniques.

| Volatile compounds | Relative concentration (%) | | | | |
|---|---|---|---|---|---|
| | Commercial control | Forced convection | Lyophilization | Refractive window | Marquee with polyshade |
| α-pinene | 0.2 | 0.2 | 0.3 | 0.1 | 0.2 |
| benzaldehyde | 0.1 | 0 | 0 | 0 | 0 |
| sabinene | 0.1 | 0.3 | 0.3 | 0.1 | 0.2 |
| β-pinene | 0.4 | 0.6 | 0.7 | 0.2 | 0.4 |
| β-myrcene | 0.2 | 0.2 | 0.3 | 0 | 0.2 |
| limonene | 0.1 | 0.1 | 0.1 | 0 | 0.1 |
| 1,8-cineole | 5.9 | 5.9 | 7.6 | 1.5 | 4.3 |
| trans-β-ocimene | 0.1 | 0.4 | 0.4 | 0.1 | 0.2 |
| γ-terpinene | 0.1 | 0 | 0 | 0 | 0 |
| cis-linalooxide | 1.9 | 0 | 0 | 0 | 0 |
| ethyl 2-(5-methyl-5-vinyltetrahydrofuran-2-yl)propan-2-yl carbonate | 1.7 | 0 | 0 | 0 | 0 |
| fenchone | 0.1 | 0 | 0 | 0 | 0 |
| pinocarvone | 0.1 | 0 | 0 | 0 | 0 |
| sabinene transhydrate | 0 | 0.4 | 0.3 | 0.1 | 0.3 |
| trans-oxide linalool | 0.4 | 0.2 | 40.3 | 0.1 | 0.1 |
| linalool | 17 | 33.3 | 0.1 | 12 | 21.4 |
| hotrienol | 0 | 0 | 0 | 0.1 | 0.1 |
| phenylethanol | 0 | 0 | 0 | 0 | 0 |
| camphor | 0 | 0.1 | 0.1 | 0.1 | 0.1 |
| δ-terpineol | 0.2 | 0.1 | 0.1 | 0.1 | 0.2 |
| cis-linalool oxide | 0.4 | 0 | 0 | 0 | 0 |
| terpinen-4-ol | 0.1 | 0 | 0 | 0 | 0 |
| 2,6-dimethyl-3,7-octadiene-2,6-diol | 0.7 | 0 | 0 | 0.1 | 0.2 |
| estragole | 1.5 | 21.5 | 19 | 4.1 | 15.8 |
| octyl acetate | 0.1 | 0.2 | 0.3 | 0.1 | 0.4 |
| hydroxycineum | 0.1 | 0 | 0 | 0 | 0 |
| 3-exo-Hydroxy-1,8-cineole | 0.2 | 0 | 0 | 0 | 0 |
| methylethylmaleimide | 0 | 0 | 0 | 0 | 0.1 |
| chavicol | 0 | 0 | 0.6 | 0.2 | 0.3 |
| linalyl acetate | 0 | 0.1 | 0 | 0.1 | 0.1 |
| 2,6-dimethyl-1,7-octadien-3,6-diol | 0.3 | 0 | 0 | 0 | 0.1 |
| cis-methyl cinnamate | 7.7 | 0 | 0 | 0 | 0 |
| 3-exo-hydroxy-1,8-cineyl acetate | 0.2 | 0 | 0 | 0 | 0 |
| 2-exo-hydroxy-1,8-cineyl acetate | 0.3 | 0 | 0 | 0 | 0 |
| α-cubebene | 0.3 | 0 | 0 | 0 | 0 |
| bornyl acetate | 0 | 0 | 0 | 0.1 | 0.1 |
| eugenol | 0.1 | 2.7 | 5.8 | 1.7 | 2.8 |
| α-copaene | 0.5 | 0.6 | 0.5 | 0.5 | 0.5 |
| trans-methyl cinnamate | 29.9 | 0 | 0 | 0 | 0 |
| β-bornonene | 0 | 0.3 | 0 | 0.3 | 0.5 |
| β-elemene | 0 | 3.4 | 2.7 | 4.9 | 3.2 |
| methyleugenol | 0 | 0 | 0 | 0.8 | 1.2 |
| β-ylangelo | 0 | 0.4 | 0 | 0.5 | 0.3 |
| trans-β-caryophyllene | 0.6 | 0.9 | 0.7 | 0.9 | 1 |
| β-Cedrene | 0.4 | 0 | 0 | 0 | 0 |
| β-Copaene | 0.4 | 0 | 0 | 0 | 0 |
| trans-α-bergamotene | 0 | 1 | 0.9 | 1.4 | 1.4 |
| α-guaien | 1.5 | 1 | 1 | 1.3 | 1.1 |
| trans-Muurola-3,5-diene | 0.5 | 0 | 0 | 0 | 0 |
| trans-β-farnesene | 0 | 0 | 0 | 0.7 | 0.7 |
| α-humulene | 1.1 | 3.6 | 2.6 | 4.4 | 4.7 |

| | | | | | |
|---|---|---|---|---|---|
| muurola-4, 14(5)-diene | 1 | 1.1 | 0.8 | 2 | 1.3 |
| γ-curcumene | 0 | 0.4 | 0 | 0.7 | 0.4 |
| germacrene D | 2.2 | 7 | 5.1 | 6.7 | 4.2 |
| β-selinene | 0.5 | 0 | 0 | 0 | 0 |
| bicyclogermacrene | 1.2 | 3.4 | 2.2 | 3.9 | 2.1 |
| α-bulnesene | 1.9 | 1.3 | 0.9 | 2 | 1.6 |
| γ-cadinene | 5.4 | 3.8 | 2.6 | 7.9 | 6 |
| calamenene | 0.8 | 0 | 0 | 0 | 0 |
| δ-cadinene | 0 | 0 | 0 | 0.5 | 0.3 |
| cis-calamenene | 0 | 0.4 | 0 | 1.1 | 0.8 |
| 10-epi-cubebol | 0 | 0 | 0 | 1 | 0.3 |
| dihydroactinidiolide | 0 | 0 | 0 | 0 | 0.3 |
| α-cadinene | 0 | 0 | 0 | 0.2 | 0.2 |
| trans-nerolidol | 0.3 | 0.4 | 0.3 | 3.8 | 1.9 |
| maaliol | 0.3 | 0 | 0 | 0 | 0 |
| spatulenol | 0.9 | 0.6 | 0.3 | 3.8 | 3.8 |
| viridiflorol | 0.7 | 0 | 0 | 0 | 0 |
| caryophyllene oxide | 0 | 0 | 0 | 0.3 | 0.3 |
| humulene epoxide II | 0.2 | 0.1 | 0 | 1 | 1.3 |
| 1,10-di-epi-cubenol | 1.4 | 0.5 | 0.3 | 3.5 | 1.7 |
| isospatulenol | 0 | 0 | 0 | 0.4 | 0.4 |
| methyl jasmonate | 0.2 | 0 | 0 | 0 | 0.2 |
| epi-α-cadinol | 5.3 | 2.4 | 2.2 | 20.6 | 8.1 |
| α-cadinol | 0.3 | 0 | 0 | 1 | 0.4 |
| β-eudesmol | 0.3 | 0 | 0 | 1.2 | 0.6 |
| neointermedeol | 0.6 | 0 | 0 | 0 | 0 |
| 6,10,14-trimethyl-2-pentadedione | 0.1 | 0 | 0 | 0 | 0.1 |
| cis-14-nor-muurol-5-en-4-one | 0.2 | 0 | 0 | 0 | 0 |
| mint sulfide | 0 | 0.2 | 0 | 0.3 | 0.2 |

Source: Own elaboration

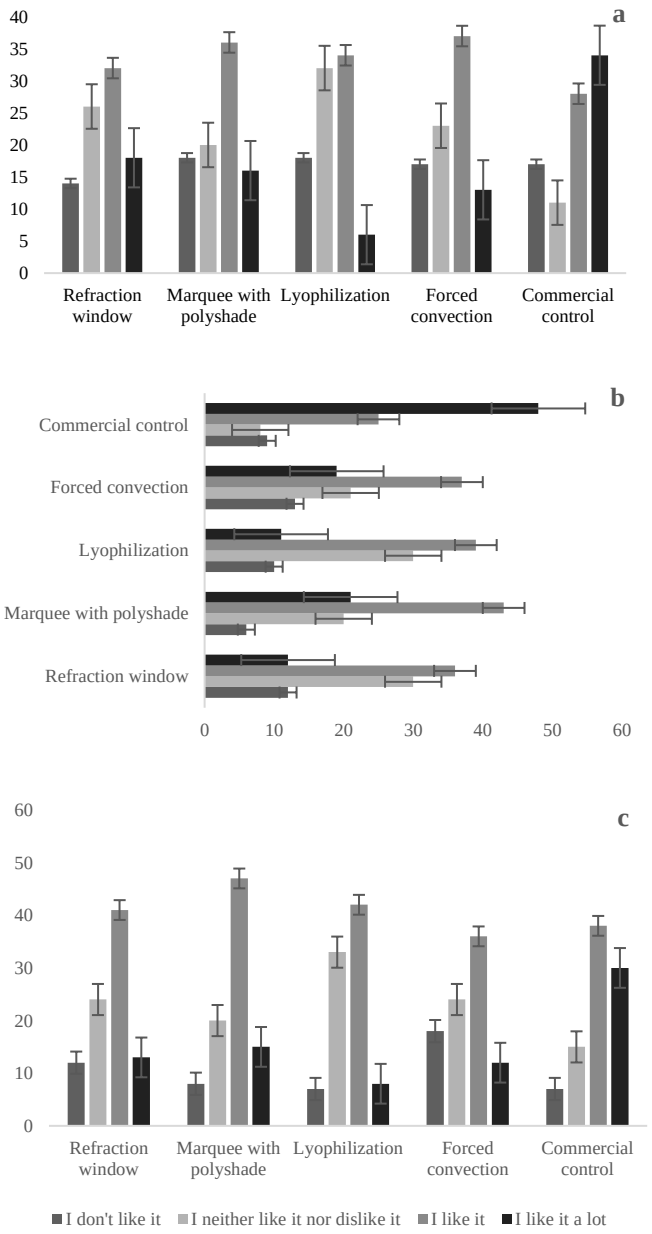



Figure 4. Results of the sensory evaluation of the dry basil leaves subjected to different drying methods concerning a. flavor, b. aroma, and c. color.
Source: Own elaboration

### *3.6 Sensory evaluation*

Fig. 4 shows the sensory evaluation results that 90 untrained evaluators carried out on the preference and taste for the aromatic infusions prepared with the dehydrated material obtained through the different drying methods evaluated. Infusions are usually accepted for taste (a), smell (aroma) (b), and color (c), where there is no significant difference between treatments. However, it is worth highlighting the higher degree of acceptance by the commercial sample in each of the parameters, most likely due to the treatment and mixture with other aromatic species that increase the sweetness in the infused drink.

The results analyzed in each graph for flavor, aroma, and color are very heterogeneous, considering each variable individually. For flavor, the drying methods implemented do not present a significant difference, most panelists like the flavor of the aromatic infusions in contrast to the commercial sample.

A very marked difference is evident in the aroma variable between the commercial sample and the drying methods, with a value higher than 50% of the evaluators expressing that they "really" like this aroma.

There is no significant difference in the drying systems compared to the commercial sample for the color variable of the infusions. It should be noted that the oxidation and browning process of the infusions is very marked as time passes and cooling before being consumed. Color is a variable "liked" or "liked very much" without differences in the drying systems used in the dehydration process.

### *3.6.1 Degree of acceptance*

Table 7 presents the sensory analysis results of the dehydrated basil infusions in the different drying systems. In this table, the degree of acceptance is evident considering the evaluated variables of flavor, aroma, and color and comparing them with the control as a commercial sample. Regarding the degree of acceptance as the sum of "I like it" and "I like it a lot," the commercial sample has the greatest acceptance, with 203 points, followed by the sample dried in a marquee with polyshade, with 178 points. The samples dried with forced convection and refractive window do not show a major difference, with 154 and 152 points, respectively. Regarding the sample dehydrated by lyophilization, it registers a value of 140 points and is presented as the sample with the least acceptance.

Table 7.
Sensory analysis results of dried basil infusions under different drying techniques.

| Drying method | Acceptance degree | Characteristics | | | Acceptance degree points |
|---|---|---|---|---|---|
| | | Flavor | Aroma | Color | |
| Liofilizacion | I don't like it | 18 | 10 | 7 | 140 |
| | I neither like it nor dislike it | 32 | 30 | 33 | |
| | I like it + I like it a lot | 40 | 50 | 50 | |
| Forced convection | I don't like it | 17 | 13 | 18 | 154 |
| | I neither like it nor dislike it | 23 | 21 | 24 | |
| | I like it + I like it a lot | 50 | 56 | 48 | |
| Commercial Sample | I don't like it | 17 | 9 | 7 | 203 |
| | I neither like it nor dislike it | 11 | 8 | 15 | |
| | I like it + I like it a lot | 62 | 73 | 68 | |
| Refractive Window | I don't like it | 14 | 12 | 12 | 152 |
| | I neither like it nor dislike it | 26 | 30 | 24 | |
| | I like it + I like it a lot | 50 | 48 | 54 | |
| Polyshade Marquee | I don't like it | 18 | 6 | 8 | 178 |
| | I neither like it nor dislike it | 20 | 20 | 20 | |
| | I like it + I like it a lot | 52 | 64 | 62 | |

Source: Own elaboration

## 4 Discussion

In the dehydration processes, the aim is to maintain the physicochemical qualities of the sample, bringing it to a safe level of moisture and water activity. Values below 0.6 have been established as a safe range of water activity to guarantee biochemical stability in foods, limiting the development of enzymatic and non-enzymatic reactions that affect nutritional quality, color, and flavor [4].

Reactions such as Maillard's are related to the maximum and minimum water availability values since it plays a double role as a solvent and reagent in the kinetics of the reaction, which, when increased, promotes browning [10]. The water activity of the basil residue subjected to the forced convection technique and the commercial control exceeded this value. However, the moisture contents found are within the limit established in the standard for dried basil CXS 345-2021 of the Codex Alimentarius [11], which requires a maximum of 12% moisture for chopped or crushed dried basil samples.

The refractive window technique generated the greatest effect on the physicochemical quality, reflected in lower percentages of protein, fiber, and minerals expressed in percentage of ash, which, together with a lower percentage of essential oil, revealed the damage caused to the cell wall of the basil residue due to the previous sonication and grinding treatment, since, as the structure of the tissue is altered, the permeability of the cells increases, facilitating the transit of compounds, including essential oils [12]. This behavior agrees with the quantification of volatile compounds, which recorded lower concentrations in most of the compounds in the dried basil residue subjected to the window technique.

The marquee with polyshade technique reported the highest percentage of essential oil, proving to be a less aggressive technique, which, thanks to the adaptation, maintains the drying system at temperatures below 45 °C, suggested as the ideal dehydration temperature without generating loss of volatile compounds [13,14].

The drying system affects the rehydration capacity, considering that the dehydration process damages the plant material since it loses hydrophilic properties for water retention it is important to highlight that the rehydration percentage does not reach the real moisture value of basil under natural conditions before dehydration [15,16].

The different drying techniques to which fresh basil was subjected showed that phenols and antioxidants were significantly preserved at the end of drying, with a high correlation with these compounds. Temperature has a direct impact on these secondary metabolites. Phenols and antioxidants are characterized by being thermosensitive [17], which is related to the conservation of their contents in drying by forced convection and marquee with polyshade.

The temperatures reached in these two methods did not exceed 55ºC, unlike drying in a refractive window and lyophilization. A study carried out by Sharma et al. (2018) [18], reported that the contents of phenols and antioxidants decreased in relation to the drying method, with microwaves maintaining the highest concentration of the compounds.

On the other hand, the color index of dried basil leaves showed a significant difference. Lyophilization allowed preserving a CI* close to deep green, unlike the other treatments that showed colors between greenish-yellow and yellowish-green. This behavior is due to the high chlorophyll contents responsible for the green coloration of the leaves, which degrade, generating compounds such as pheophytin that may be related to enzymatic browning reactions and promote a change in leaf coloration [19].

Therefore, it is essential to guarantee color in food, as this is a significant factor for the consumer when selecting a product for consumption.

The loss of aromatic compounds during dehydration is related to the temperature, drying speed, and vapor pressure of the molecules [20]. The marquee drying technique adapted with polyshading allowed the use of solar radiation, regulating the temperature of the system and achieving a maximum of 43°C inside the marquee. Thus, lower losses of volatile compounds were generated. Behavior supported by the essential oil contents that were up to four and two times

higher in basil residues dried by marquee and convection compared to the commercial control.

## 5 Conclusions

The choice of dehydration method significantly affects the physicochemical qualities of foods. Techniques such as lyophilization (freeze-drying) or forced convection allowed the better preservation of phenols and antioxidants. The refractive window drying technique affected the nutritional composition, phenols, antioxidants, volatile compound profile, and sensory characteristics of dried basil, being the most destructive of the techniques studied, generating damage to the cell wall due to the need for a previous adaptation treatment. Marquee with polyshade drying managed to preserve the composition of the basil and its essential oil content, having the potential for processing postharvest residues due to its low cost by using solar energy as a source of dehydration and physical, chemical, and sensory conservation of the raw material, obtaining dried basil with characteristics superior to those recorded by the commercial sample. The evaluation of drying techniques used for postharvest residue in basil (*Ocimum basilicum* sp. var. Nufar) production provides valuable information to improve the efficiency, quality, and sustainability of the production chain of this crop.

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# Individual factors influencing workers' unsafe behaviors

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**Abstract**
Mining is one of the industries with the highest risk accidentability; being unsafe behaviors one of the main causes of accidents. In this study, the factors that influence the decisions that lead to unsafe behavior of mining workers were evaluated. With a correlational study, the level of workers' unsafe state was measured and work stress and work demand were analyzed as individual factors by applying validated questionnaires, with a sample of 107 collaborators, and the influence between the unsafe state, the individual factors and their dimensions (work stress and work demand) was determined. It was obtained as a result that the insecure state of the workers is of medium level with 70.09% and that there is a positive and significant correlation with work stress and work demand, which allowed corroborating the general hypothesis, the insecure state is positively and significantly correlated with the individual factors.

*Keywords*: individual factors; insecure state; insecure behavior; work stress; work demand

# Factores individuales que influyen en los comportamientos inseguros de los trabajadores

**Resumen**
La minería es una de las industrias con mayor riesgo de accidentabilidad; siendo los comportamientos inseguros una de las principales causas de los accidentes. En este estudio se evaluaron los factores que influyen en las decisiones que llevan al comportamiento inseguro de los trabajadores mineros. Con un estudio de tipo correlacional se midió el nivel del estado inseguro de los trabajadores y se analizó el estrés laboral y la demanda de trabajo como factores individuales aplicando cuestionarios validados, con una muestra de 107 colaboradores, y se determinó la influencia entre el estado inseguro, los factores individuales y sus dimensiones (estrés laboral y demanda de trabajo). Se obtuvo como resultado que el estado inseguro de los trabajadores es de nivel medio con un 70.09% y que hay una correlación positiva y significativa con el estrés laboral y la demanda de trabajo lo que permitió corroborar la hipótesis general, el estado inseguro se correlaciona positiva y significativamente con los factores individuales.

*Palabras clave*: factores individuales; estado inseguro; comportamiento inseguro; estrés laboral; demanda de trabajo.

## 1 Introducción

El sector minero es la industria con mayor riesgo a nivel mundial, con tasas 10 veces mayor de índices de accidentes, afectando de este modo la vida y salud de los trabajadores, la seguridad de las propiedades y al desarrollo social, siendo los comportamientos inseguros la principal razón de los accidentes [1].

La Organización Internacional del Trabajo y el Pacto Mundial de las Naciones Unidas (2021) [2] reportaron que aproximadamente 2,78 millones de trabajadores a nivel mundial fallecen anualmente debido a los accidentes y enfermedades laborales y que otros 374 millones sufren accidentes no mortales, además en América Latina y Caribe son más altas las tasas de mortalidad, según informado por las estadísticas sobre seguridad y salud en el trabajo de la Organización Internacional del Trabajo (2021) [3] Costa Rica y México reportaron las tasas de letalidad más altas de 9,7 y 7,5 por 100,000 trabajadores respectivamente, así mismo el Ministerio de Trabajo y Promoción del Empleo (2023) [4] ha

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reportado un total de 38,219 accidentes de trabajo, 232 enfermedades ocupacionales y 409 accidentes mortales.

En este sentido Li Yang et al. [5] y Xinping et al. [6] investigaron que los accidentes de trabajo eran causados primordialmente por los actos inseguros de los trabajadores, y que eran influenciados por diferentes factores y que estos están clasificados en cuatro categorías que son los individuales, ambientales, de gestión organizativa y de dispositivo.

Los accidentes laborales según la Organización Internacional del Trabajo y el Pacto Mundial de las Naciones Unidas (2021) [2] tienen un peso económico de 4% de PBI mundial cada año debido a las malas prácticas de seguridad, siendo el sector minero uno de los más influyentes. De este modo, Lixia Niu et al. [7] dieron a conocer que los principales accidentes que hubo en minería en China entre 1980 y 2000 el 97,67% eran por factores humanos y que en el año 2000 y 2016 representaban más del 90% de los casos, señalando que es necesario estudiar los factores que causan los comportamientos inseguros de los trabajadores en el sector minero.

Además, el Instituto Ecuatoriano de Seguridad Social [8] la industria minera en Ecuador reportó un total de 249 accidentes en 2021, un 40% más que el año anterior siendo los principales factores que incidieron a los accidentes los mineros y canteros (47,4%) y los trabajadores técnicos y profesionales (28,5%)

El Ministerio de Trabajo y Promoción del Empleo [4] reportaron 1,924 accidentes de trabajo, 29 enfermedades ocupacionales y 21 accidentes mortales. Según Asare et al. [9] estos sucesos pueden originarse porque el entorno minero es un trabajo sometido a presiones, largas jornadas laborales, la gran carga de trabajo, los malos hábitos de sueño, vivir lejos de la familia, todo lo cual puede influir en la salud mental y física de los trabajadores.

Diversas metodologías se han aplicado para abordar este problema. En este sentido Lei Chen et al. [10] aplicaron en su estudio un método cuantitativo desarrollando una encuesta en base a las investigaciones existentes, y el método cualitativo para la realización de entrevistas con expertos en el campo para identificar los elementos de medición para evaluar la satisfacción laboral y el estado de inseguridad de los mineros, la carga de trabajo que se dividió en dos dimensiones: tiempo y demanda de trabajo. Llegando a la conclusión que la carga de trabajo en sus dos dimensiones tienen un impacto positivo significativo en el estado inseguro de los trabajadores pero estos se pueden reducir con la satisfacción laboral, de esta manera verificando que el trabajo prologando para cumplir los requisitos laborales daña la salud física y mental de los trabajadores afectando la capacidad de control y conduciendo de esta forma a los comportamientos inseguros generando así accidentes laborales, por lo que es necesario satisfacer las necesidades de los trabajadores.

De igual manera Muthelo et al. [11] quienes utilizaron en su investigación una metodología cuantitativa, descriptiva y transversal en una mina de cielo abierto. Teniendo como objetivo evaluar los siete factores como las prácticas de salud laboral relacionadas con la normativa, medidas para reducir el riesgo de lesiones/accidentes, papel de la cultura y recursos de seguridad, impacto del medio ambiente y la producción, actitud y comportamiento, papel de la dirección de la mina y el uso y calidad de los equipos para medir las prácticas de norma de salud y seguridad en el trabajo. Llegando a la conclusión que la presión de producción puede afectar y comprometer la seguridad de los mineros y que la disponibilidad de la política, normas y procedimientos tienen un mayor impacto en el cumplimiento de las normas de seguridad y salud.

Lixia Niu et al. [12] quienes desarrollaron una investigación aplicando un método descriptivo, buscando evaluar la mentalidad del líder, agotamiento emocional, conciencia de seguridad, comportamiento de seguridad. Llegando a la conclusión que la mentalidad del líder del interés financiero afecta el comportamiento seguro porque internalizan activa o pasivamente los conceptos erróneos e influyen en el agotamiento emocional y conciencia. Además, Fruhen et al. [13] señalaron que cuando el líder puede cubrir las espaldas de sus trabajadores, estos son menos propensos a participar en actividades de seguridad, afectando que el comportamiento seguro y el compromiso de seguridad de sus trabajadores sean bajas.

Por otro lado, Tiehua Chen et al. [14] desarrollaron un estudio descriptivo y correlacional, utilizando una encuesta, para evaluar los valores laborales conformada por tres dimensiones: confort y seguridad, estatus e independencia, y competencia y crecimiento; Potenciación psicológica conformada por cuatro dimensiones: significación del trabajo, autonomía, autoeficacia e influencia del trabajo; Clima de seguridad conformada por seis dimensiones: incentivo de seguridad, preparación ante el riesgo, formación en seguridad, sistemas y normas, comunicación en seguridad y concientización en seguridad; y el Comportamiento de Seguridad conformada por dos dimensiones: cumplimiento de las normas de seguridad y participación en la seguridad. Llegando a la conclusión que las tres dimensiones de los valores laborales se relacionan positivamente con el comportamiento seguro, la potenciación psicológica y el clima de seguridad, así mismo la capacitación psicológica se relacionó positivamente con el clima de seguridad y el comportamiento seguro; el clima de seguridad se relacionó positivamente con el comportamiento seguro.

Otra investigación realizada por Qin et al. [15] quienes realizaron un estudio correlacional ofreciendo 45 CNY como compensación en la participación de la encuesta. Las tres variables de estudios estuvieron conformadas por el capital psicológico constando de cuatro subescalas: autoeficacia, esperanza, optimismo y resiliencia; el compromiso laboral incluyendo tres subescalas: compromiso fisiológico, cognitivo y emocional; y la seguridad del comportamiento ciudadano constando de seis subescalas: ayuda, voz, administración, denuncia, virtud cívica e iniciación de cambios relacionados con la seguridad. Llegando a la conclusión que el capital psicológico no solo influye directamente en el comportamiento de ciudadanía segura, sino que también indirectamente a través del compromiso laboral. Sin embargo, los resultados de Saleem et al. [16] en su estudio de diseño de investigación transversal encontraron que no hay mediación entre en el compromiso laboral entre la resiliencia y el comportamiento de seguridad y que solo puede verse influenciada por el compromiso laboral como mediador entre la eficacia y el cumplimiento de las normas de seguridad.

Por último, Yuanlong Li et al. [17] realizaron un estudio descriptivo y correlacional utilizando una encuesta para recopilar información demográfica y utilizaron el cuestionario de Actitudes de Seguridad (SAQ) constando cuatro dimensiones de actitud hacia la seguridad: Clima de seguridad en equipo, compromiso de la dirección con la seguridad, fatalismo y estrés laboral; y el cuestionario de comportamientos de seguridad (SBQ) constando de dos dimensiones: Cumplimiento de las normas de seguridad y la participación en la seguridad. Llegando a la conclusión que la actitud de seguridad se correlaciona positivamente con el comportamiento seguro, señalando que cambiar actitudes negativas de seguridad es de vital importancia para promover un buen desempeño en el comportamiento de seguridad. También mencionan que el cumplimiento de las normas de seguridad y la participación en materia de seguridad también se correlaciona con la actitud de seguridad siendo posible que la participación sea un comportamiento activo porque permite que los trabajadores adopten medidas activas para garantizar la seguridad, y que el cumplimiento de seguridad está más relacionado con la observancia de las normas de seguridad porque garantiza el control y la aplicación estricta de las normas.

Con base a las investigaciones analizadas, se puede concluir que los accidentes causados por el comportamiento o estado del trabajador es un problema significativo ya que estos son afectados por diferentes factores, ocasionando daño a su propia salud y al de los demás. También se han visto diferentes conceptos y metodologías para medir y abordar este problema. Los estudios revisados dan a conocer la importancia de identificar estos factores que afectan al comportamiento o estado del trabajador para tomar las medidas preventivas necesarias para que de esa manera se pueda reducir los impactos negativos en el entorno laboral.

Estos estudios proporcionan una base sólida para investigaciones futuras y acciones destinadas a abordar este desafío en diferentes sectores no solo en minería y preservar la salud del estado psicológico y fisiológico del trabajador.

Este estudio tiene como objetivo principal evaluar los factores individuales que influyen el comportamiento inseguro de los trabajadores, teniendo como finalidad determinar el nivel del estado inseguro de los trabajadores, analizar los factores individuales que influyen el comportamiento inseguro y determinar la influencia de los factores individuales en el estado inseguro de los trabajadores. Planteando las siguientes hipótesis: Los factores individuales tienen un correlación positiva y significativa en el estado inseguro (H1), El estrés laboral tiene una correlación positiva y significativa en el estado inseguro (H2), y la demanda de trabajo tiene una correlación positiva y significativa con el estado inseguro (H3).

## 2 Metodología

Estudio es no experimental cuantitativo de alcance correlacional, teniendo como propósito de solo observar o medir las variables tal como se dan en su contexto original [18].

El muestreo es no probabilístico por conveniencia porque no se pudo acceder a ciertas áreas de la empresa minera debido a las actividades de alto riesgo.

Como población se tuvo a 150 trabajadores, de los cuales 107 fueron encuestados, excluyendo a quienes por voluntad propia decidieron no participar de la investigación.

La técnica de estudio es el cuestionario que sirve para recolectar datos con respecto a una o más variables a medir siendo congruente con el planteamiento del problema o hipótesis, y la correlación de Spearman que proporciona una medida numérica que permite describir la relación entre dos variables cuantitativas [18].

Para medir el estado inseguro de los trabajadores se tomó como referencia la escala creada por Lei Chen et al. (2022) [10] que evalua los aspectos fisiológicos, psicológicos, conciencia en seguridad y comportamiento incorrecto habitual de los trabajadores. Los factores individuales se midieron a partir de dos dimensiones: estrés laboral y demanda de trabajo; los ítems para la medición del estrés laboral se utilizó la encuesta del indicador de estrés laboral (OSI) tomando como referencia el estudio realizado por Wu et al. (2018) [22] seleccionando dos dimensiones: trabajo propio y conflicto familia-trabajo; los ítems para la medición de la demanda de trabajo se tomó como referencia la escala de carga de trabajo de Lei Chen et al. (2022) [10] seleccionando la dimensión demanda de trabajo de la cual los ítems fueron extraídos de los estudios Thomas y Ganster (1995) y Daniels y Harris (2005) citados en Lei Chen et al. (2022).

## 3 Resultados

### *3.1 Análisis de validez*

Se utilizó el IBM SPSS Statistics 29.0.2.0 para probar la consistencia del coeficiente α de Cronbach del cuestionario como se muestra en la Tabla 1 sobre validez:

La confiabilidad de la escala es alta por lo que se puede continuar con el análisis.

### *3.2 Análisis descriptivo*

#### *3.2.1 Estado inseguro*

En la Tabla 2 se muestra el promedio de cada ítem con su respectiva dimensión (estado fisiológico, estado psicológico, consciencia en seguridad y comportamiento incorrecto habitual) de los participantes:

Table 1.
Tabla de validez.

| Variable | Número de elementos | α de Cronbach |
|---|---|---|
| Estado inseguro | 8 | 0.787 |
| Estrés laboral | 7 | 0.892 |
| Demanda de trabajo | 6 | 0.828 |

Fuente: elaboración propia.

Tabla 2.
Promedio de las dimensiones del estado inseguro.

| Variable | Estado inseguro | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Grupo | E. F. | | E. P. | | C.S. | | C.I.H. | |
| Ítem | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 |
| Muestra | 3.21 | 2.81 | 4.66 | 1.50 | 3.91 | 3.31 | 4.04 | 3.21 |

Fuente: Elaboración propia.

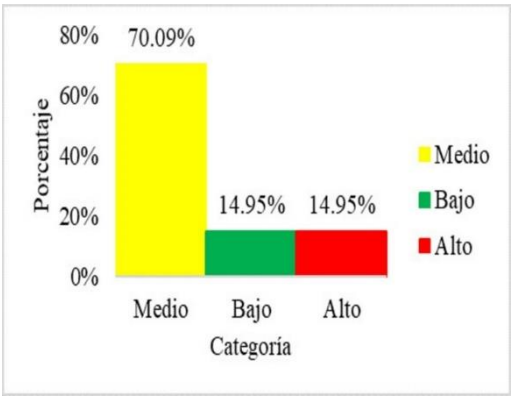


Figura 1. Nivel del estado inseguro de los trabajadores
Fuente: Elaboración propia

Para determinar el nivel del comportamiento inseguro se toma en cuenta la suma obtenida en las dimensiones por cada encuestado agrupando en 3 categorías, tal como se muestra en la Fig. 1. Nivel del estado inseguro de los trabajadores

La puntuación de Bajo nivel de estado inseguro mostrada en la Fig. 1 señala que es de 8 hasta 19, Intermedio nivel de estado inseguro es de 20 hasta 31 y de Alto nivel de estado inseguro es de 32 hasta 40.

Según los resultados, como se observa en la Fig. 1, se obtiene que el porcentaje mayor de estado inseguro de los trabajadores es de 70.09% con un nivel medio, esto quiere decir que el estado psicológico, consciencia en seguridad y el comportamiento incorrecto habitual afecta en las decisiones del comportamiento destacando los ítems 1, 5, 6 y 8, pues el estado fisiológico está siendo afectado por las condiciones del ambiente de trabajo, el conocimiento en materia de la seguridad no los considera significativos al momento de resolver los problemas, esto refleja que no son trabajadores proactivos y no toman medidas preventivas necesarias y se ven influenciados por el entorno o situaciones inmediatas. Además, que el hábito del manejo de los dispositivos o equipos de protección personal dependerá de las participaciones en charlas o capacitaciones del uso correcto de ello.

### *3.2.2 Factores individuales*

Como primera dimensión se tiene el estrés laboral, el promedio de cada ítem se representa en la Tabla 3:

Para determinar el nivel del estrés laboral se toma en cuenta la suma obtenida en los ítems por cada encuestado agrupando en 3 categorías, como se contempla en la Fig. 2 sobre nivel de estrés:

La puntuación de Bajo nivel de estrés laboral, según la Fig. 2, es de 7 hasta 17, Intermedio nivel de estrés laboral es de 18 hasta 28 y de Alto nivel de comportamiento seguro es de 29 hasta 35.

Según los resultados como se observa en la Fig. 2, se obtiene que el porcentaje mayor de estrés laboral es de 38.32% con un nivel medio, debido que los trabajadores regularmente se preocupan por la seguridad en sí mismo debido a las actividades que realizan, suelen hacer horas extras, sienten una pesada carga financiera para su familia, desean pasar más tiempo con su familia pese a que la empresa minera cumple con el régimen de trabajo peruano.

Tabla 3.
Promedio del estrés laboral.

| Variable | Estrés laboral | | | | | | |
|---|---|---|---|---|---|---|---|
| Ítem | P9 | P10 | P11 | P12 | P13 | P14 | P15 |
| Muestra | 2.27 | 2.61 | 2.79 | 4.13 | 2.77 | 2.80 | 4.15 |

Fuente: Elaboración propia.

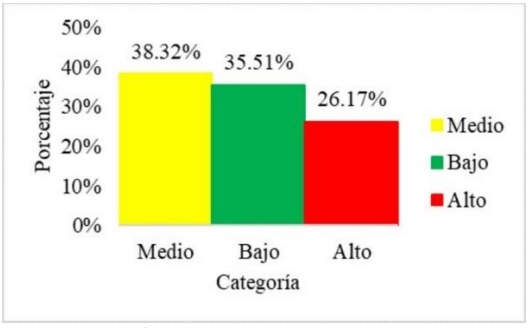


Figura 2. Nivel del estrés laboral
Fuente: Elaboración propia

Tabla 4.
Promedio de demanda de trabajo.

| Variable | Estrés laboral | | | | | |
|---|---|---|---|---|---|---|
| Ítem | P16 | P17 | P18 | P19 | P20 | P21 |
| Muestra | 3.23 | 4.25 | 3.38 | 2.80 | 2.91 | 3.57 |

Fuente: Elaboración propia.

Como segunda dimensión se tiene la demanda laboral, el promedio de cada ítem se representa en la Tabla 4.

En la Fig. 3 sobre nivel de demanda laboral, la puntuación de Bajo nivel de demanda de trabajo es de 6 hasta 14, Intermedio nivel de demanda de trabajo es de 15 hasta 23 y de Alto nivel de demanda de trabajo es de 24 hasta 30.

Según los resultados, como se observa en la Fig. 3, se obtiene que el porcentaje mayor de demanda de trabajo es de 71.96% con un nivel medio, debido que los trabajadores tienen muchas tareas en su trabajo actual, pues la presión laboral puede influir en las decisiones del comportamiento del trabajador ya que por querer terminar las tareas a tiempo pueden cometer actos inseguros y generar accidentes.

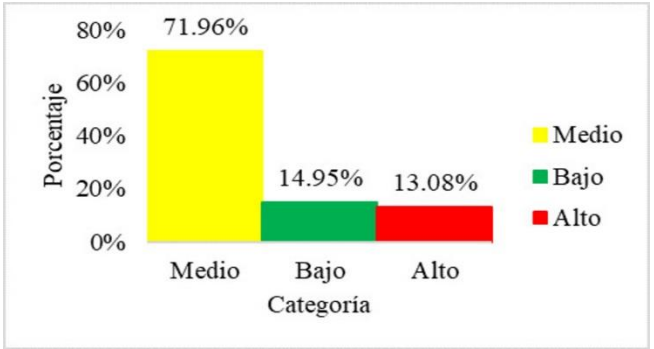


Figura 3. Nivel de demanda laboral
Fuente: Elaboración propia

Tabla 5.
Prueba de normalidad.

| Prueba de normalidad | | | |
|---|---|---|---|
| | Kolmogórov-Smirnov | | |
| | Estadístico | gl | Sig. |
| Estado inseguro | .169 | 107 | <.001 |
| Estrés laboral | .242 | 107 | <.001 |
| Demanda de trabajo | .219 | 107 | <.001 |
| Factores individuales | .140 | 107 | <.001 |

a. Corrección de significación de Lilliefors
Fuente: Elaboración propia.

### *3.3 Prueba de normalidad*

Para conocer el tipo de correlación entre las variables y dimensiones se utilizó la prueba de normalidad de Kolmogoroy-Smirnov, según lo evidenciado en la Tabla 5 sobre prueba de normalidad.

Según la prueba de normalidad Kolmogórov-Smirnov (Tabla 5), la distribución el estado inseguro es no paramétrico porque la significancia es menor a 0.01, por lo que se utilizara el Rho de Spearman.

### *3.4 Análisis de correlación*

Se uso el IBM SPSS Statistics 29.0.2.0 para probar la correlación entre los factores individuales, estrés laboral y demanda de trabajo con el estado inseguro. Los resultados del análisis se muestran en la siguiente Tabla 6:

El coeficiente de correlación entre el estado inseguro y el estrés laboral, según Tabla 6, es de $0.574$ ($p = 0.001 < 0.01$) lo que indica que hay una correlación positiva media y significativa confirmando la hipótesis 2. El coeficiente de correlación entre el estado inseguro y la demanda de trabajo es de $0.682 (p = 0.001 < 0.01)$ lo que indica que hay una correlación positiva media y significativa confirmando la hipótesis 3. El coeficiente de correlación entre el estado inseguro y los factores individuales es de $0.687$ ($p = 0.001 < 0.01$) indicando que hay una correlación positiva media y significativa confirmando la hipotesis1.

Tabla 6.
Análisis de correlación no paramétrica.

| Correlaciones | | | | | |
|---|---|---|---|---|---|
| | | | Estrés laboral | Demanda de trabajo | Factores individuales |
| Rho de Spearman | Estado inseguro | Coeficiente de correlación | 0.574** | 0.682** | 0.687** |
| | | Sig. (bilateral) | <.001 | <.001 | <.001 |

**. La correlación es significativa en el nivel 0,01 (bilateral)
Fuente: Elaboración propia.

## 4 Discusión

El objetivo general de este estudio es evaluar los factores individuales que influyen en el comportamiento inseguro de los trabajadores, en este sentido, es importante identificar la relación entre el estrés y la demanda laboral con el estado del trabajador para prevenir los accidentes mortales y no mortales a causa de ello.

En la evaluación del estado inseguro del trabajador se encontró que estas son afectadas por el estado fisiológico, consciencia en seguridad y el comportamiento incorrecto habitual. Teniendo relación con los estudios Zahari et al. [19] y Xue Li et al. [20] quienes concluyeron que la condición del ambiente si afecta las decisiones del comportamiento de los trabajadores.

En los factores individuales el estrés laboral y la demanda de trabajo tienen un impacto significativo en el comportamiento de los trabajadores. Confirmando estudios como los de Ruipeng Tong et al. [21] y Muthelo et al. [11] quienes concluyeron que la presión laboral y producción están relacionados con los actos inseguros debido a la excesiva demanda de trabajo, así mismo los resultados de Lei Chen et al. [10] demostraron que la demanda de trabajo si se correlaciona positivamente y significativamente con el estado inseguro de los trabajadores.

## 5 Conclusiones

Se confirmaron las hipótesis 1, 2 y 3, es decir, si existe una correlación positiva y significativa entre el estado inseguro y los factores individuales, el estado inseguro y el estrés laboral, el estado inseguro y la demanda de trabajo.

El mayor porcentaje de trabajadores con un nivel medio del estado inseguro es de 70.09%, esto quiere decir que sus decisiones en el comportamiento son afectadas por el estado fisiológico, la consciencia en seguridad y el comportamiento incorrecto habitual.

Del análisis de los factores individuales, se encontró que el nivel de estrés laboral de los trabajadores es medio con un porcentaje de 38.32%, así mismo el nivel de demanda de trabajo con un porcentaje de 70.09%.

El coeficiente de correlación entre el estado inseguro y el estrés laboral es de 0.574 indicando una correlación positiva media y significativa, la correlación entre el estado inseguro y la demanda de trabajo es de 0.682 indicando una correlación positiva media y significativa.

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# Impact of artificial intelligence on financial decision making: opportunities and challenges for business leaders

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**Abstract**
Artificial intelligence (AI) is transforming finance and business with advanced analytics, process automation and accurate predictions. While it improves efficiency and decision making, it requires human oversight to maintain ethics. AI implementation is costly, demands training, provides significant improvements in risk management and financial decision making, improves operations, customer service, optimizes portfolios and identifies investment opportunities.
However, challenges arise such as ethical and privacy concerns, the need to properly interpret results, ensure cybersecurity and comply with regulations. AI automates financial tasks, reduces costs and errors, personalizes services by analyzing customer behavior. However, reliance on data raises privacy and security concerns, biases in data can affect fairness, and complexity of algorithms can hinder transparency and understanding of automated decisions.

*Keywords*: artificial intelligence; financial decision making; impact; opportunities; challenges, enterprises.

# Impacto de la inteligencia artificial en la toma de decisiones financieras: oportunidades y desafíos para los líderes empresariales

**Resumen**
La inteligencia artificial (IA) está transformando las finanzas y los negocios con análisis avanzados, automatización de procesos y predicciones precisas. Aunque mejora la eficiencia y la toma de decisiones, requiere supervisión humana para mantener la ética. La implementación de IA es costosa, demanda capacitación, proporciona mejoras significativas en la gestión de riesgos y en la toma de decisiones financieras, mejora la operación, el servicio al cliente, optimiza carteras e identifica oportunidades de inversión.
Sin embargo, surgen desafíos como preocupaciones éticas y de privacidad, la necesidad de interpretar adecuadamente los resultados, asegurar la ciberseguridad y cumplir las regulaciones. La IA automatiza tareas financieras, reduce costos y errores, personaliza servicios al analizar el comportamiento del cliente. No obstante, la dependencia de datos plantea problemas de privacidad y seguridad, los sesgos en los datos pueden afectar la equidad, y complejidad de los algoritmos puede dificultar la transparencia y comprensión de las decisiones automatizadas.

*Palabras clave*: inteligencia artificial; toma de decisiones financieras; impacto; oportunidades, desafíos.

## 1 Introducción

La inteligencia artificial (IA) ha alterado radicalmente la toma de decisiones financieras en el mundo empresarial, gracias a su capacidad para procesar grandes volúmenes de datos de manera rápida y precisa. En este artículo, se analiza el impacto de la IA en las decisiones financieras, explorando sus beneficios en la optimización de procesos, predicción de

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resultados y personalización de servicios. Se destaca la importancia de recopilar datos precisos y seleccionar herramientas adecuadas para su análisis. Además, se abordan los desafíos asociados, como el sesgo algorítmico y la ética de los datos, y se ofrece orientación sobre cómo abordarlos. Esta investigación proporciona una visión completa de cómo la IA está transformando las decisiones financieras empresariales, preparando a los líderes para aprovechar su potencial en un entorno empresarial dinámico.

## 2 Marco teórico

La inteligencia artificial (IA) ha emergido como un componente fundamental en el ámbito financiero, destacándose por su habilidad para analizar grandes conjuntos de datos de manera rápida y precisa. En particular, en la toma de decisiones financieras [1], la IA está siendo cada vez más utilizada para automatizar procesos [2-4] detectar patrones y tendencias, y proporcionar valiosas perspectivas a los líderes empresariales. Dentro de la IA, se distinguen dos tipos principales: la predictiva y la generativa, esta última capaz de generar rápidamente contenido nuevo y de calidad [5].

Las empresas están explorando nuevas tecnologías de inteligencia artificial para mejorar sus flujos de trabajo, asignar tareas y distribuir el trabajo de manera más eficiente, con el objetivo de aumentar la productividad. No obstante, el ritmo de adopción de estas tecnologías varía significativamente entre diferentes sectores y tamaños de empresas.

El uso de la inteligencia artificial (IA) en la toma de decisiones implica que las organizaciones emplean esta tecnología y algoritmos de machine learning para analizar datos, detectar patrones y hacer recomendaciones que apoyen la toma de decisiones [6]. Según "The Master Algorithm: How the Quest for the Ultimate Learning Machine Will Remake Our World," la IA ha revolucionado el análisis de datos financieros, permitiendo decisiones más rápidas y precisas [7-9].

La inteligencia artificial (IA) ha transformado el sector financiero al automatizar tareas como análisis de datos, gestión de inversiones y detección de fraudes [10-12]. Agiliza las operaciones financieras, mejora la gestión de riesgos y la interacción con los clientes [13,14], y proporciona una comprensión más profunda de los mercados financieros [15]. Además, reduce errores humanos, disminuye costos y aumenta la productividad [16-18].

La inteligencia artificial (IA) mejora la precisión y rapidez en la toma de decisiones financieras al analizar grandes volúmenes de datos en tiempo real. Sus algoritmos detectan patrones complejos y tendencias ocultas, lo que facilita decisiones más informadas y efectivas. Según "Machine Learning for Asset Managers," el aprendizaje automático ha permitido desarrollar modelos avanzados para predecir tendencias del mercado, precios de activos y riesgos financieros [19-22].

Al analizar grandes volúmenes de datos [23] la inteligencia artificial (IA) mejora la toma de decisiones financieras al identificar oportunidades y prever tendencias, además de personalizar la experiencia del cliente. No obstante, el uso de datos financieros plantea preocupaciones sobre privacidad y seguridad, y la implementación de IA enfrenta desafíos éticos relacionados con la transparencia y la equidad, como se discute en The Ethics of Big Data: Current and Foreseeable Issues in Biomedical Contexts [24,25].

La implementación exitosa de la IA requiere una inversión significativa en tecnología y capacitación del personal. Aunque la IA mejora la toma de decisiones financieras mediante análisis avanzados y optimización de procesos, también presenta desafíos como la privacidad de datos y el sesgo algorítmico. Es esencial que las empresas enfrenten estos desafíos proactivamente para maximizar el potencial de la IA en la gestión de riesgos financieros y el cumplimiento normativo. [26,27].

La IA mejora la toma de decisiones empresariales al utilizar datos, lo que aumenta la eficiencia operativa y los resultados financieros. También identifica oportunidades de inversión que podrían pasar desapercibidas para los humanos, generando rendimientos significativos. La IA seguirá transformando la industria financiera, creando nuevas oportunidades para la innovación y el crecimiento económico. Las organizaciones que no integren IA en sus estrategias de marketing corren el riesgo de volverse obsoletas [28-30].

La inteligencia artificial (IA) ha transformado la gestión financiera, permitiendo la personalización de productos y mejorando la relación con los clientes [31]. Facilita la detección de fraudes y errores, automatiza tareas, y ofrece análisis predictivos para la toma de decisiones y cumplimiento normativo, siendo esencial para la gestión de riesgos y optimización de recursos [32,33].

La inteligencia artificial (IA) ha mejorado la eficiencia y precisión en la toma de decisiones financieras [34] y ha impactado la gobernanza corporativa al permitir decisiones más efectivas en condiciones de incertidumbre [35]. La colaboración entre humanos y IA es crucial para el futuro del trabajo [36].

## 3 Métodos

Para el presente artículo se utilizan diversas metodologías para llevar a cabo la investigación de manera rigurosa y obtener resultados significativos, tales como análisis de datos financieros y comparativos, entrevistas y encuestas, como los siguientes:

### *3.1 Datos financieros*

Se toman los estados financieros de los tres últimos años como son el estado de situación financiera y el estado de resultados de las empresas colombianas que en la actualidad están utilizando la inteligencia artificial para la toma de decisiones:

#### *3.1.1 Empresas Públicas de Medellín EPM*

Es un conglomerado empresarial que proporciona servicios públicos domiciliarios como energía eléctrica, gas, agua y saneamiento. Con sede en Medellín, Colombia, y presencia en seis países (Colombia, Bermudas, México, Guatemala, El Salvador, Panamá y Chile), opera en ocho áreas de negocio: generación, transmisión y distribución de energía, suministro de gas, gestión del agua, tratamiento de aguas residuales, gestión de residuos sólidos y comercialización de soluciones innovadoras. En la Tabla 1 se presenta el estado de situación financiera y en la Tabla 2 el estado de resultados de EPM de los años 2023,2022 y 2021 [37].

Tabla 1.
Estado de Situación financiera años 2023, 2022 y 2021

| Estado de Situación Financiera EPM | 2023 | 2022 | 2021 |
|---|---|---|---|
| Activos Corrientes | 15.082.304 | 14.950.653 | 14.576.033 |
| Activos no Corrientes | 62.015.678 | 60.571.586 | 53.064.155 |
| Saldos db cuentas regul. diferidas | 137.883 | 56.135 | 136.282 |
| Total Activos | 77.235.865 | 75.578.374 | 67.776.470 |
| Pasivo Corriente | 14.052.304 | 12.063.158 | 9.720.287 |
| Pasivo no Corriente | 31.825.862 | 32.511.496 | 29.265.114 |
| Total Pasivos | 45.878.166 | 44.574.654 | 38.985.401 |
| Patrimonio | 31.357.899 | 31.003.720 | 28.791.069 |
| Total Pasivo y Patrimonio | 77.235.865 | 75.578.374 | 67.776.470 |

Fuente: Los autores

Tabla 2.
Estado de Resultados EPM años 2023, 2022 y 2021

| Estado de Resultados EPM | 2023 | 2022 | 2021 |
|---|---|---|---|
| Total Ingresos | 35.529.207 | 31.350.429 | 24.803.047 |
| Total Costos y Gastos | 30.881.009 | 27.668.994 | 22.220.400 |
| Ganancia operativa | 4.648.198 | 3.681.435 | 2.582.647 |
| Resultado Financiero | 1.046.667 | 992.841 | 592.674 |
| Ganancias antes de Impuesto | 3.601.531 | 2.688.594 | 1.989.973 |
| Impuestos | 1.569.142 | 363.235 | 470.049 |
| Ganancia en operaciones discontinuas | 97.412 | 19.982 | 4.668 |
| Ganancias Netas | 1.934.977 | 2.345.341 | 1.524.592 |

Fuente: Los autores

### *3.1.2 Protección: pensiones, cesantías, ahorro e inversión*

Es una entidad financiera privada que gestiona fondos y planes de pensiones del régimen de ahorro individual con solidaridad y fondos de cesantías. Como Sociedad de Servicios Financieros y Administradora de Fondos de Pensiones y Cesantías, administra los fondos de sus afiliados, quienes disponen de una cuenta individual respaldada por garantías estatales. Además, utiliza el Sistema de Administración de Riesgo Operativo (SARO) para prevenir posibles pérdidas por eventos adversos. En la Tabla 3 se presenta el estado de situación financiera y en la Tabla 4 el estado de resultados de Protección de los años 2023,2022 y 2021 [38].

Tabla 3.
Estado de Situación Financiera Protección 2023, 2022 y 2021

| Estado de Situación Financiera Protección | 2023 | 2022 | 2021 |
|---|---|---|---|
| Efectivo y Act Financieros de Inversión | 2.224.663 | 1.857.025 | 2.907.361 |
| Cuentas por Cobrar | 139.261 | 83.882 | 70.325 |
| Activo por Impuesto Neto | 340.993 | 398.808 | 424.119 |
| Activos Tangibles Intangibles Otros | 241.297 | 240.505 | 244.605 |
| Total Activos | 2.946.214 | 2.580.220 | 3.646.410 |
| Instrumentos Financieros Derivados | - | 240 | 16 |
| Pasivo por Impuesto Neto | 39.807 | 32.006 | 61.642 |
| Beneficios a empleados | 46.488 | 43.067 | 45.890 |
| Cuentas por pagar y otros pasivos | 45.250 | 75.589 | 56.567 |
| Provisiones | 511.302 | 426.618 | 1.236.583 |
| Pasivo por derecho de uso | 8.881 | 7.356 | 8.299 |
| Total Pasivos | 651.728 | 584.876 | 1.408.997 |
| Patrimonio atribuible a propietarios de la controladora y no Controlantes | 2.294.486 | 1.995.143 | 2.237.413 |
| Total Pasivo y Patrimonio | 2.294.486 | 1.995.143 | 2.237.413 |
| Total Pasivo y Patrimonio | 2.946.214 | 2.580.019 | 3.646.410 |

Fuente: Los autores

Tabla 4.
Estado de Resultados Protección años 2023, 2022 y 2021

| Estado de Resultados Protección | 2023 | 2022 | 2021 |
|---|---|---|---|
| Total Ingresos | 35.529.207 | 31.350.429 | 24.803.047 |
| Total Costos y Gastos | 30.881.009 | 27.668.994 | 22.220.400 |
| Ganancia operativa | 4.648.198 | 3.681.435 | 2.582.647 |
| Resultado Financiero | 1.046.667 | 992.841 | 592.674 |
| Ganancias antes de Impuesto | 3.601.531 | 2.688.594 | 1.989.973 |
| Impuestos | 1.569.142 | 363.235 | 470.049 |
| Ganancia en operaciones discontinuas | 97.412 | 19.982 | 4.668 |
| Ganancias Netas | 1.934.977 | 2.345.341 | 1.524.592 |

Fuente: Los autores

### *3.1.3 Financiera Comultrasan*

Fundada en 1962 en Santander, Colombia, esta cooperativa ha crecido para convertirse en una de las más grandes del país. En 2000, se dividió en una cooperativa multiactiva y una cooperativa financiera. La cooperativa financiera, de derecho privado y sin ánimo de lucro, busca ser un referente nacional en servicio y tecnología, adaptándose a un mercado globalizado y especializándose en servicios de ahorro y crédito. Actualmente, es líder en su sector y un modelo de servicio a nivel nacional, en la Tabla 5 se presenta el estado de Situación Financiera y en la Tabla 6 el Estado de Resultados de Comultrasan de los años 2023, 2022 y 2021.

Tabla 5.
Estado de Situación Financiera Comultrasan, años 2023, 2022 y 2021

| Estado de Situación Financiera Comultrasan | 2023 | 2022 | 2021 |
|---|---|---|---|
| Total Activos | 1.741.854.069 | 1.641.531.011 | 1.534.574.795 |
| Total Pasivos | 1.211.976.322 | 1.116.213.294 | 1.042.172.461 |
| Patrimonio | 529.877.746 | 525.317.717 | 492.402.334 |
| Total Pasivo y Patrimonio | 1.741.854.068 | 1.641.531.011 | 1.534.574.795 |

Fuente: Los autores

Tabla 6.
Estado de Resultados Comultrasan, años 2023, 2022 y 2021

| Estado de Resultados Comultrasan | 2023 | 2022 | 2021 |
|---|---|---|---|
| Total Ingresos | 269.545.093 | 207.633.344 | 181.039.461 |
| Total Costos y Gastos | 329.056.394 | 241.785.987 | 192.108.550 |
| Otros Ingresos | 88.944.890 | 74.452.402 | 59.520.545 |
| Otros Gastos | 8.849.429 | 3.251.173 | 2.347.404 |
| Ganancias antes de Impuesto | 20.584.160 | 37.048.586 | 46.104.052 |
| Impuestos | 33.754 | 63.953 | 42.191 |
| Resultado - participación no controladora | 19.852 | 46.127 | 48.786 |
| Ganancias Netas | 20.570.258 | 37.030.760 | 46.110.647 |
| Utilidad por revaluación de propiedades, planta y equipo | 45.101.562 | 45.101.562 | 35.569.650 |

Fuente: Los autores

### *3.2 Entrevistas y encuestas*

Se encuestó a 177 profesionales de finanzas y tecnología, así como a personas involucradas en la toma de decisiones, para obtener información cualitativa sobre el impacto de la IA en las decisiones financieras. Esta investigación, que combinó diversos métodos y materiales, proporcionó una comprensión profunda del impacto de la inteligencia artificial en la toma de decisiones financieras y ofreció valiosa información para profesionales, académicos y responsables de decisiones.

### *3.3 Revisión de Literatura*

Para investigar el impacto de la inteligencia artificial en la toma de decisiones financieras, se realizó una revisión de literatura académica y técnica en bases de datos como JSTOR, Scopus, Google Scholar y PubMed. Se identificaron estudios previos, marcos teóricos y metodologías relevantes, y se recopilaron datos financieros para llevar a cabo un análisis comparativo utilizando técnicas estadísticas

## 4 Resultados

De acuerdo con un estudio realizado por IBM, casi la mitad de las organizaciones están considerando la adopción de la inteligencia artificial (IA). Entre estas empresas destacan EPM, Protección, Financiera Comultrasan, Fabricato y Finanzauto. No obstante, algunos expertos señalan que existen obstáculos como la falta de conocimiento, la escasez de plataformas adecuadas y herramientas, así como la falta de experiencia en la implementación de la IA en Colombia [39].

### *4.1 Análisis de datos financieros*

#### *4.1.1 Empresas Públicas de Medellín EPM*

Se presenta en comparativo de las principales cifras del estado de Situación financiera de EPM en la Tabla 7 y del estado de Resultados en la Tabla 8 de los años 2023, 2022 y 2021.

Tabla 7.
Empresas Públicas de Medellín EPM: Estado de Situación Financiera

| Estado de Situación Financiera EPM | 2023-2022 | 2022-2021 |
|---|---|---|
| Activos Corrientes | 0,88% | 2,57% |
| Activos no Corrientes | 2,38% | 14,15% |
| Saldos db cuentas regul diferidas | 145,63% | -58,81% |
| Total Activos | 2,19% | 11,51% |
| Pasivo Corriente | 16,49% | 24,10% |
| Pasivo no Corriente | -2,11% | 11,09% |
| Total Pasivos | 2,92% | 14,34% |
| Patrimonio | 1,14% | 7,69% |
| Total Pasivo y Patrimonio | 2,19% | 11,51% |

Fuente: Los autores

Tabla 8.
Empresas Públicas de Medellín EPM: Estado de Resultados

| Estado de Resultados EPM | 2023-2022 | 2022-2021 |
|---|---|---|
| Total Ingresos | 13,33% | 26,40% |
| Total Costos y Gastos | 11,61% | 24,52% |
| Ganancia operativa | 26,26% | 42,55% |
| Resultado Financiero | 5,42% | 67,52% |
| Ganancias antes de Impuesto | 33,96% | 35,11% |
| Impuestos | 331,99% | -22,72% |
| Ganancia en operaciones discontinuas | 387,50% | 328,06% |
| Ganancias Netas | -17,50% | 53,83% |

Fuente: Los autores

El uso de la inteligencia artificial (IA) en EPM entre 2021 y 2023 ha impulsado un notable crecimiento financiero, con aumentos del 11.51% en activos, 7.69% en patrimonio, 26.4% en ingresos y 53.83% en el resultado neto del periodo, además de una mejora en la rentabilidad del patrimonio del 1.14% al 11.37%. La implementación de asistentes digitales como EMA y AURA, especializados en ciencia de datos, ha optimizado procesos y mejorado la experiencia del usuario, gestionando más de tres millones de interacciones y utilizando drones para mantenimiento predictivo, lo que ha mejorado la eficiencia operativa y la toma de decisiones [40]

Tabla 9.
Protección: Pensiones, Cesantías, Ahorro e Inversión. Estado de Situación Financiera

| Estado de Situación Financiera Protección | 2023-2022 | 2022-2021 |
|---|---|---|
| Efectivo y Act Financieros de inversión | 19,80% | -36,13% |
| Cuentas por Cobrar | 66,02% | 19,28% |
| Activo por Impuesto Neto | -14,50% | -5,97% |
| Activos Tangibles Intangibles Otros | 0,33% | -1,68% |
| Total Activos | 14,18% | -29,24% |
| Instrumentos Financieros Derivados | -100,00% | 1400,00% |
| Pasivo por Impuesto Neto | 24,37% | -48,08% |
| Beneficios a empleados | 7,94% | -6,15% |
| Cuentas por pagar y otros pasivos | -40,14% | 33,63% |
| Provisiones | 19,85% | -65,50% |
| Pasivo por derecho de uso | 20,73% | -11,36% |
| Total Pasivos | 11,43% | -58,49% |
| Patrimonio atribuible a propietarios de la controladora y no controlantes | 15,00% | -10,83% |
| Total Patrimonio | 15,00% | -10,83% |
| Total Pasivo y Patrimonio | 14,19% | -29,24% |

Fuente: Los autores

Tabla 10.
Protección: Pensiones, Cesantías, Ahorro e Inversión. Estado de Resultados

| Estado de Resultados Protección | 2023-2022 | 2022-2021 |
|---|---|---|
| Total Ingresos | 13,33% | 26,40% |
| Total Costos y Gastos | 11,61% | 24,52% |
| Ganancia operativa | 26,26% | 42,55% |
| Resultado Financiero | 5,42% | 67,52% |
| Ganancias antes de Impuesto | 33,96% | 35,11% |
| Impuestos | 331,99% | -22,72% |
| Ganancia en operaciones discontinuas | 387,50% | 328,06% |
| Ganancias Netas | -17,50% | 53,83% |

Fuente: Los autores

#### *4.1.2 Protección: pensiones, cesantías, ahorro e inversión*

Se presenta en comparativo de las principales cifras del estado de Situación financiera de Protección en la Tabla 9 y del estado de Resultados en la Tabla 10 de los años 2023, 2022 y 2021.

Como de observa en la Tabla 12. Estados financieros, los activos aumentaron un 14.18% y los ingresos un 13.33%, los resultados antes de impuestos aumentaron un 33.96%, mientras que la rentabilidad del patrimonio paso de 12.35% a 13.79%, desde que se usa la inteligencia artificial IA.

PRONTO es un chatbot que ha gestionado más de 1.5 millones de conversaciones con clientes, generando ahorros de más de cien millones de pesos. La implementación de IBM Watson Personality Insights ha optimizado el proceso de selección de personal mediante análisis rápidos de personalidad. Según Accenture, se estima que las empresas que utilicen IA aumentarán sus beneficios en un 38% para 2035. Anteriormente, los procesos manuales y repetitivos de la empresa requerían presencialidad y tiempo; sin embargo, hace 4 años, la empresa adoptó la IA para automatizar la verificación de documentos en el retiro de cesantías, mejorando la eficiencia y agilidad en la atención [41,42].

Esto posibilitó satisfacer el 53% de las solicitudes de manera automatizada mediante la mejora de los procesos. La implementación del servicio Azure OpenAI de Microsoft facilitó el procesamiento de 22 solicitudes, resultando en un aumento del 50% en la productividad, lo cual es sumamente significativo. Además, se mejoró la rapidez, la experiencia del cliente y la eficiencia operativa [43].

Tabla 11.
Estado de Situación Financiera Comultrasan 2023, 2022 y 2021

| Estado de Situación Financiera Comultrasan | 2023-2022 | 2022-2021 |
|---|---|---|
| Total Activos | 6,11% | 6,97% |
| Total Pasivos | 8,58% | 7,10% |
| Patrimonio | 0,87% | 6,68% |
| Total Pasivo y Patrimonio | 6,11% | 6,97% |

Fuente: Los autores

Tabla 12.
Estado de Resultados Financiera Comultrasan 2023, 2022 y 2021

| Estado de Resultados Comultrasan | 2023-2022 | 2022-2021 |
|---|---|---|
| Total Ingresos | 29,82% | 14,69% |
| Total Costos y Gastos | 36,09% | 25,86% |
| Otros Ingresos | 19,47% | 25,09% |
| Otros Gastos | 172,19% | 38,50% |
| Ganancias antes de Impuesto | -44,44% | -19,64% |
| Impuestos | -47,22% | 51,58% |
| Resultado - participación no controladora | -56,96% | -5,45% |
| Ganancias Netas | -44,45% | -19,69% |
| Utilidad por revaluación de propiedades, planta y equipo | 0,00% | 26,80% |

Fuente: Los autores

#### *4.1.3 Financiera Comultrasan*

Se presenta en comparativo de las principales cifras del estado de Situación financiera de Comultrasan en la Tabla 11 y del estado de Resultados en la Tabla 12 de los años 2023, 2022 y 2021.

En los últimos tres años, la institución financiera ha aumentado sus activos un 13.51% mediante la automatización de procesos y el desarrollo de productos digitales. Destacan FIBOT, que gestiona consultas y documentos, y SmartRoad, que permite la verificación biométrica. Estos avances, centralizados en un Data Center con Certificación Tier III, incluyen modelos analíticos para recomendaciones y un sistema en desarrollo para la aprobación automatizada de créditos [44].

Forbes identifica 51 empresas líderes en inteligencia artificial en Colombia, destacando en servicios financieros, software, lenguaje natural y salud, como Lemonade y Observe.AI, que usan IA para mejorar eficiencia y competitividad [45,46]. Compañías como IMEXHS y Rappi aplican IA para diagnósticos, orientación médica y detección de fraudes. Gartner prevé que el 70% de las decisiones empresariales se basarán en IA en 2024 [47]. Accenture estima un aumento del 40% en la productividad laboral para 2035 con capacitación en IA. En Colombia, la inversión en IA es del 50%, frente al 61% en México, 46% en Chile y 66% en España. Forbes 2024 reporta que el 73% de las instituciones financieras colombianas ya usan IA y big data para mejorar procesos y la interacción con clientes [48,49].

### *4.2 Entrevistas y encuestas*

Se realizaron encuestas a profesionales de finanzas y tecnología y personas involucrados en la toma de decisiones que proporcionaron información cualitativa sobre sus experiencias, percepciones y opiniones sobre el impacto de la IA en la toma de decisiones financieras, los resultados obtenidos fueron los siguientes:

Las respuestas a la pregunta 1. ¿En su empresa o en su profesión usa la inteligencia artificial IA en la toma de decisiones?, se muestran en la Fig. 1:

El 26% de los encuestados utiliza la inteligencia artificial (IA) de manera permanente, mientras que el 46.8% la emplea ocasionalmente. El 27.3% de los encuestados no hace uso de esta tecnología en absoluto, esto refleja un uso variado de la IA entre los participantes del estudio.

Las respuestas a la pregunta 2, "¿El desempeño de la organización o de su profesión ha mejorado desde que se usa la inteligencia artificial para tomar decisiones?", se presentan en la Fig. 2.

La inteligencia artificial (IA) ha mejorado el desempeño organizacional y profesional en diversas áreas: procesos administrativos (39.5%), decisiones financieras (18.4%), atención al cliente (28.9%), gestión de riesgos y fraudes (10.5%), y decisiones gerenciales (2.6%).

Las opiniones sobre la pregunta 3, ¿Algunos indicadores han mejorado en su empresa o creen que pueden mejorarse en su profesión desde que se utiliza la IA?, se muestran en la Fig. 3.

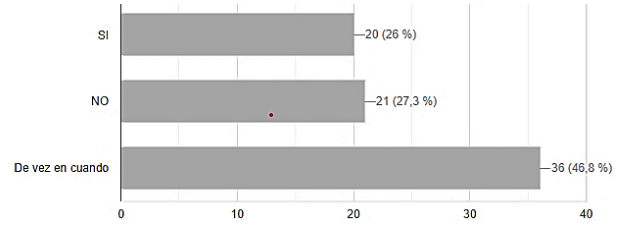


Figura 1. Resultados de encuesta a la pregunta 1.
Fuente: los autores

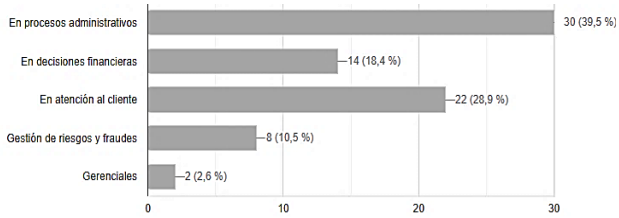


Figura 2. Resultados de la encuesta a la pregunta 2.
Fuente: los autores

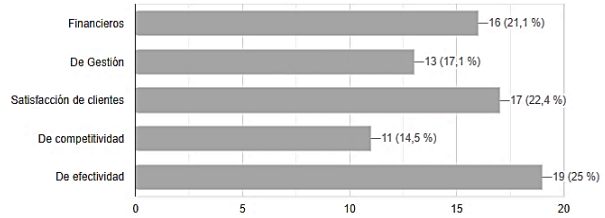


Figura 3. Resultados de la encuesta a la pregunta 3.
Fuente: Los autores

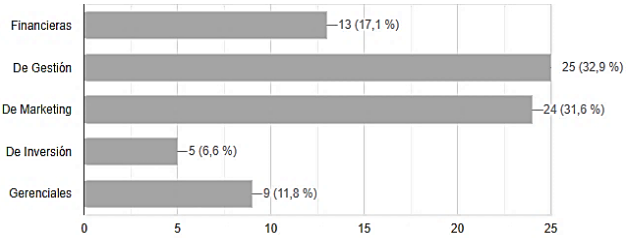


Figura 4. Resultados de encuesta a la pregunta 4.
Fuente: Los autores

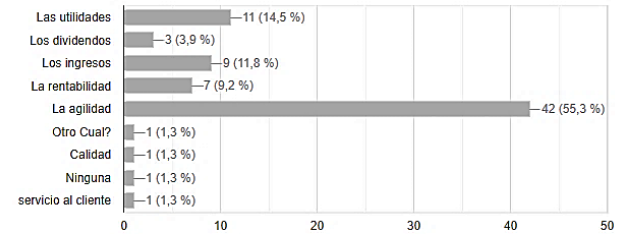


Figura 5. Resultados de encuesta a la pregunta 5.
Fuente: Los autores

El uso de la inteligencia artificial (IA) ha mejorado varios indicadores en las empresas, con mejoras del 21.1% en indicadores financieros, 17.1% en gestión, 22.4% en satisfacción del cliente, 25% en efectividad y 14.5% en competitividad. Se espera que la IA continúe mejorando estos indicadores en las profesiones.

Las respuestas a la pregunta 4, ¿La toma de decisiones en su empresa o en su profesión ha mejorado desde que se utiliza la IA en la toma de decisiones?, se observan en la Fig. 4.

La adopción de inteligencia artificial (IA) ha mejorado significativamente la toma de decisiones en los negocios. En el ámbito empresarial, la IA ha aumentado un 31.6% en decisiones de gestión y marketing, un 17.1% en decisiones financieras, un 11.8% en decisiones gerenciales y un 6.6% en decisiones de inversión.

Las respuestas a la pregunta 5, ¿Han mejorado los beneficios en su empresa o profesión desde la implementación de la IA?, se muestran gráficamente en la Fig. 5.

La implementación de inteligencia artificial (IA) ha mejorado significativamente los beneficios generales en empresas y profesiones. Se destacan mejoras en agilidad (55.3%), aumento de ingresos (11.8%), incremento de utilidades (14.5%), mayor rentabilidad (9.2%), incremento en dividendos (3.9%) y mejora en calidad y servicio al cliente (1.3%).

Las reacciones a la pregunta 6, "¿Se han observado otras mejoras en su organización o profesión desde la implementación de la IA?", se presentan visualmente en la Fig. 6.

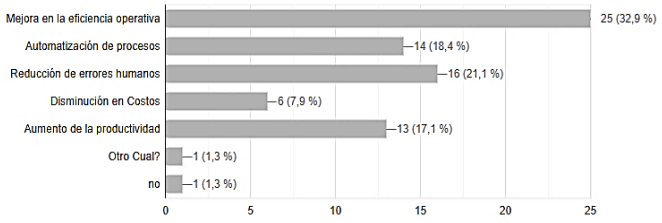


Figura 6. Resultados de encuesta a la pregunta 6.
Fuente: los autores

Se han observado otras mejoras significativas en la organización o en la profesión desde que se utiliza la inteligencia artificial (IA). Entre estas mejoras, se destacan avances en la eficiencia operativa (32.9%), aumento de la productividad (17.1%), automatización de procesos (18.4%), reducción de errores humanos (21.1%), y disminución de costos (7.9%).

Las respuestas a la pregunta 7, ¿Se ha agilizado la toma de decisiones en su organización o profesión desde la implementación de la IA?, se ilustran gráficamente en la Fig. 7

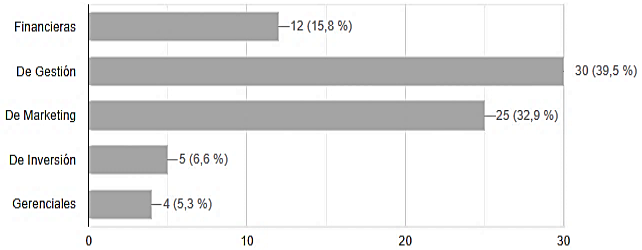


Figura 7. Resultados de encuesta a la pregunta 7.
Fuente: Los autores

Se ha presentado una mejora significativa en la agilidad de la toma de decisiones en la organización o en la profesión desde la implementación de la inteligencia artificial (IA).

Esta mejora se ha observado principalmente en la gestión (39.5%), las decisiones financieras (15.8%), el marketing (32.9%), las decisiones de inversión (6.6%) y las decisiones gerenciales (5.3%).

Las reacciones a la pregunta 8, ¿Las decisiones en su organización o profesión son más precisas y rápidas desde que se utiliza la IA?, se muestran en la Fig. 8.

La precisión y rapidez en la toma de decisiones en la organización o en la profesión han mejorado desde la adopción de la inteligencia artificial (IA). Se ha registrado un aumento significativo en la automatización y mejora de procesos (30.3%), en la calidad del servicio al cliente (28.9%), en la eficiencia operativa (22.4%), en la gestión de inversiones (10.5%) y en la prestación de servicios (7.9%).

Las respuestas a la pregunta 9, ¿Se ha utilizado la IA para predecir tendencias en su organización o profesión?, se muestran representadas en la Fig. 9.

Los principales usos de la inteligencia artificial para predecir tendencias en la organización o en la profesión incluyen la tendencia del mercado (42.1%), los servicios más demandados (19.7%), la mejora de la información de ingresos (17.1%), la identificación de factores estacionales (13.2%) y la predicción de demandas futuras (7.9%).

Las opiniones sobre la pregunta 10, ¿Ha permitido la IA identificar oportunidades de inversión y analizar tendencias del mercado en su organización o profesión?, se ilustran en la Fig. 10.

La inteligencia artificial (IA) ha simplificado la identificación de oportunidades de inversión, el análisis de tendencias del mercado y la toma de decisiones estratégicas. Los principales beneficios incluyen la identificación de nuevos servicios (36.8%), la entrada en nuevos mercados (14.5%), y la realización de simulaciones de mercado

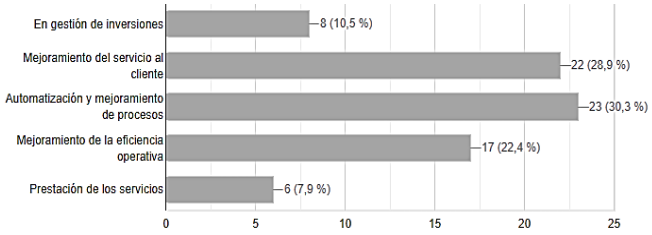


Figura 8. Resultados de encuesta a la pregunta 8.
Fuente: Los autores

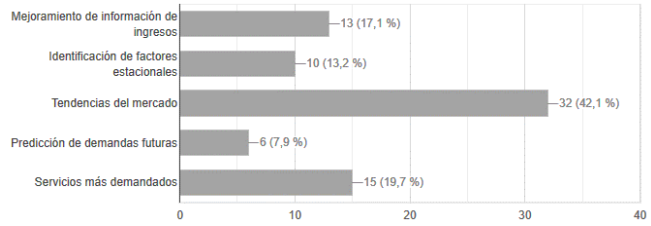


Figura 9. Resultados de encuesta a la pregunta 9.
Fuente: Los Autores.

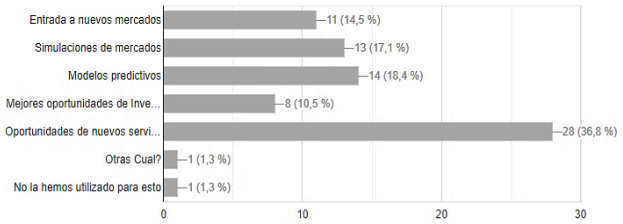


Figura 10. Resultados de encuesta a la pregunta 10.
Fuente: Los autores

(17.1%). Además, se han empleado modelos predictivos para detectar mejores oportunidades de inversión (10.5%).

### *4.3 Revisión de Literatura*

En los últimos años, la inteligencia artificial (IA) ha transformado el sector financiero, proporcionando nuevas herramientas que revolucionan la toma de decisiones. Esta revisión examina la literatura reciente (2020-2024) para identificar cómo la IA está impactando las decisiones financieras, destacando tanto las oportunidades que ofrece como los desafíos que enfrentan los líderes empresariales.

**Oportunidades de la IA en la Toma de Decisiones Financieras.** La automatización de procesos financieros es una de las principales ventajas de la IA, permitiendo la reducción de costos y errores al automatizar tareas como la reconciliación de cuentas y la generación de informes [50]. Los algoritmos de aprendizaje automático han mejorado el análisis predictivo, optimizando la gestión de riesgos y la previsión de tendencias [51,52]. Además, la IA facilita la personalización de servicios al analizar el comportamiento del cliente para ofrecer recomendaciones y ofertas personalizadas [53].

**Desafíos de la IA en la Toma de Decisiones Financieras.** La dependencia de grandes volúmenes de datos en inteligencia artificial plantea desafíos en términos de privacidad y seguridad, lo que requiere un marco regulatorio sólido [54]. Además, los sesgos en los datos pueden comprometer la equidad en las decisiones financieras, demandando una atención continua para evitar resultados injustos [55]. La complejidad de los algoritmos también complica la transparencia y compren0ión de las decisiones automatizadas y obliga a los líderes a garantizar la interpretabilidad y responsabilidad de los modelos de IA [56].

La inteligencia artificial mejora la toma de decisiones financieras con automatización, análisis predictivo y personalización, pero los líderes empresariales deben enfrentar desafíos de privacidad, sesgo y transparencia para maximizar sus beneficios y gestionar riesgos.

El impacto de la inteligencia artificial (IA) en la toma de decisiones financieras en la industria petrolera es cada vez más evidente, especialmente en la optimización de proyectos energéticos. [57] señalan la utilidad del análisis DOFA, que podría ser mejorado con IA para identificar oportunidades y riesgos con mayor precisión. [58] discuten la viabilidad de tecnologías solares en procesos petroleros, donde la IA puede optimizar la toma de decisiones en escenarios complejos. Además, [59] destacan la mitigación de la precipitación de

asfaltenos mediante nanotecnología, donde la IA podría prever y resolver problemas operacionales. Finalmente, **[60]** analizan la mitigación de emisiones en campos petroleros, donde la IA podría mejorar las decisiones financieras y ambientales en proyectos complejos. Estas referencias subrayan el creciente rol de la IA en la mejora de la toma de decisiones financieras en la industria petrolera.

## 5 Discusión

La inteligencia artificial (IA) se ha vuelto esencial en el ámbito financiero debido a su capacidad para analizar grandes volúmenes de datos de manera rápida y precisa. Se utiliza para automatizar procesos, detectar patrones y tendencias, y proporcionar valiosas perspectivas para la toma de decisiones. Entre sus aplicaciones destacan la IA predictiva, que anticipa eventos futuros, y la IA generativa, que crea contenido nuevo de alta calidad. Estas tecnologías han revolucionado el procesamiento y análisis de datos financieros, mejorando la agilidad y precisión en la toma de decisiones.

La adopción de la IA ha transformado diversas áreas del sector financiero, desde la automatización del análisis de datos y la gestión de inversiones hasta la detección de fraudes. Esta tecnología no solo agiliza las operaciones financieras y optimiza la gestión de riesgos, sino que también mejora la interacción con los clientes al ofrecer una comprensión más profunda de los mercados financieros. Además, la IA contribuye a una mayor eficiencia operativa al reducir errores humanos, lo que resulta en una disminución de costos y un aumento de la productividad.

La inteligencia artificial (IA) mejora la toma de decisiones financieras al analizar datos en tiempo real, detectando patrones ocultos para decisiones más rápidas y precisas. Aunque enfrenta desafíos como privacidad y sesgo algorítmico, empresas como EPM, Protección y Financiera Comultrasan han logrado mejoras significativas en desempeño financiero, eficiencia operativa y gestión de riesgos mediante su implementación.

A pesar de sus beneficios, la implementación de IA en el sector financiero en Colombia enfrenta desafíos como la falta de conocimiento, la escasez de plataformas adecuadas y la inexperiencia en su uso. Sin embargo, se espera que la adopción de IA siga creciendo, transformando la industria financiera y generando nuevas oportunidades para la innovación y el crecimiento económico. En resumen, la IA se presenta como una herramienta clave para la toma de decisiones financieras, con oportunidades y desafíos que las empresas deben gestionar para aprovechar su máximo potencial.

## 6 Conclusiones

La inteligencia artificial (IA) está revolucionando la función financiera mediante análisis avanzados, automatización y pronósticos predictivos, mejorando la eficiencia y la toma de decisiones. Aunque su implementación requiere supervisión humana para mantener ética y precisión, la inversión en tecnología y capacitación es esencial para su éxito, ofreciendo mejoras en la gestión de riesgos y la toma de decisiones. La IA seguirá siendo fundamental en un entorno empresarial en evolución.

La inteligencia artificial (IA) está revolucionando el ámbito empresarial al identificar oportunidades de inversión, analizar tendencias del mercado y descubrir nuevas oportunidades de negocio. Mejora la eficiencia operativa, aumenta la precisión y facilita una mejor toma de decisiones. Estos beneficios destacan la importancia de la IA para el futuro de las organizaciones y profesionales a nivel global.

La inteligencia artificial (IA) está transformando sectores en Colombia, incluyendo servicios financieros, software, lenguaje natural y salud. Empresas líderes como Lemonade, Upstart y Observe.AI han avanzado en atención al cliente y optimización de operaciones, mejorando eficiencia y competitividad. Aplicaciones específicas, como IMEXHS en diagnósticos, el Sisbén para identificar beneficiarios de programas sociales, y Bancolombia para detectar fraudes, ejemplifican el impacto positivo de la IA en diversas áreas [60].

Los estudios indican que el crecimiento de la IA es considerable, con estimaciones que el 70% de las decisiones empresariales estarán basadas en esta tecnología para 2024. Esto resalta la importancia de adaptarse y aprovechar las oportunidades que ofrece la IA para mantenerse relevante en un mercado competitivo. Según consultoras como Accenture, el potencial de la IA para aumentar la productividad laboral es significativo, pero esto requiere la capacitación adecuada del talento humano [61]

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- Optimization of the enzymatic clarification process of glucose syrups derived from agro-industrial residues
- FinTech and its relationship to SMEs financing: a systematic literature review and future research agenda
- Preventive maintance plan for SKF Latin Trade SAS equipment
- Selection of optimal areas for the installation of Wind Farms in the north-eastern part of Cuba
- Distributed generation powered by smart grids
- Optimization of the refined used lubricating oil/diesel mixture to incorporate it into drilling fluids
- CEMPRI, a primary cementing software for vertical onshore wells as a tool for petroleum engineering education
- Predicting Internet addiction in college students using a 1D-CNN model: analysis of influencing factors
- Development of biodegradable plastic films from cassava starch
- Conceptual design of tailings dam and stability assessment
- Identification of short term Fast-Slow patterns using the Nasdaq-100 future through a technical analysis application
- Documentary analysis on productivity in enterprises
- Reliability prediction for automotive electronics
- Integrative approach for formation damage diagnosis in a Colombian brownfield: a comprehensive methodology
- Structural equations modelling applied to the study of Communities Supported Agriculture (CSAs) located in the Southeastern region of Brazil
- Analysis of the scientific production on the implementation of knowledge management for supply chain sustainability
- Analysis of intense hydrological periods based on observed and estimated flow series at a reference station on the Paraná River, Argentina
- Evaluación de técnicas de secado para el aprovechamiento del residuo poscosecha en la producción de albahaca 'Nufar' (*Ocimum basilicum* L.)
- Individual factors influencing workers' unsafe behaviors
- Impact of artificial intelligence on financial decision making: Opportunities and challenges for business leaders

- Optimización del proceso de clarificación enzimática de jarabes glucosados a partir de residuos agroindustriales
- Fintech y su relación con el financiamiento de Pymes: una revisión sistemática de literatura y una agenda de investigación futura
- Plan de mantenimiento preventivo para los equipos de la empresa SKF Latin Trade SAS
- Selección de zonas óptimas para la instalación de Parques Eólicos en el norte Oriental de Cuba
- Generación distribuida potenciada con las redes inteligente
- Optimización de la mezcla aceite lubricante usado refinado/diésel para incorporarlo en fluidos de perforación
- CEMPRI, un software de cementación primaria para pozos verticales terrestres como herramienta para la educación en ingeniería petrolera
- Predicción de la adicción a Internet en estudiantes universitarios mediante un modelo 1D-CNN: análisis de los factores influyentes
- Desarrollo de películas plásticas biodegradables a partir de almidón de yuca
- Diseño conceptual de la presa de colas y evaluación de estabilidad
- Identificación de patrones Fast-Slow de corto plazo empleando el futuro del Nasdaq-100 a través de una aplicación de análisis técnico
- Análisis documental sobre la productividad en las empresas
- Predicción de confiabilidad para electrónica automotriz
- Enfoque integrador para el diagnóstico de daño de formación en un campo maduro colombiano: una metodología integral
- Modelación de ecuaciones estructurales aplicada al estudio de Agricultura Apoyada por Comunidades (AAC) ubicadas en la región Sudeste de Brasil
- Análisis de la producción científica sobre la implementación de la gestión del conocimiento para la sostenibilidad de la cadena de suministro
- Análisis de períodos hidrológicos intensos a partir de series de caudales observados y estimados en una estación de referencia del río Paraná, Argentina
- Evaluation of drying techniques for postharvest residue utilization in 'Nufar' Basil (*Ocimum basilicum* L.) production
- Factores individuales que influyen en los comportamientos inseguros de los trabajadores
- Impacto de la inteligencia artificial en la toma de decisiones financieras: Oportunidades y desafíos para los líderes empresariales