Factors associated with the adoption of technologies for avocado production systems

Factores asociados a la adopción tecnológica en sistemas de producción de aguacate

Jeimmy Cáceres-Zambrano[1*], Joaquín Guillermo Ramírez-Gil[2], and Dursun Barrios[1]

ABSTRACT

The growth of avocado crops has led to an increase in technological needs and research to satisfy the demands of the value chain. There is a wide range of technologies applicable for this fruit crop, and there are challenges for transferring and adopting these processes. The objective of this work was to explore the determining factors in the adoption of technologies for avocado production systems and the perception of producers about these factors. For this, we carried out a socioeconomic characterization of avocado producers in Colombia including the recognition of the perception regarding technological adoption variables and an exploratory factorial analysis to evaluate the adoption factors based on the perception and technological level (TL). We found that some socioeconomic variables are related to the TL of the production systems. Meanwhile, perceptions regarding the adoption variables varied depending on the TL of the producers. Low TL presented a greater number of determinant variables in adoption decision-making. In contrast, for the medium and high levels of TL, adoption of technology was based on economic analysis. This research provides evidence for the effect of socioeconomic factors on the adoption of technologies in avocado production systems and shows how the perception of producers regarding these adoptions involves determinants associated with TL.

Key words: technological changes, multivariate analysis, *Persea americana,* technological level.

RESUMEN

El crecimiento de los cultivos de aguacate ha provocado un aumento de las necesidades tecnológicas y de investigación para satisfacer las demandas de la cadena de valor. Existe una amplia gama de tecnologías aplicables a este frutal, y existen desafíos para transferir y adoptar estos procesos. El objetivo de este trabajo fue explorar los factores determinantes en la adopción de tecnologías para los sistemas de producción de aguacate y la percepción de los productores sobre estos factores. Para esto, realizamos una caracterización socioeconómica de los productores de aguacate en Colombia incluyendo el reconocimiento de la percepción sobre las variables de adopción tecnológica y un análisis factorial exploratorio para evaluar los factores de adopción en función de la percepción y el nivel tecnológico (NT). Encontramos que algunas variables socioeconómicas están relacionadas con el NT de los sistemas de producción. Mientras tanto, las percepciones sobre las variables de adopción variaron dependiendo del NT de los productores. El NT bajo presentó mayor número de variables determinantes en la toma de decisiones de adopción. En contraste, para los niveles medio y alto de NT, la adopción de tecnología se basó en el análisis económico. Esta investigación proporciona evidencia del efecto de los factores socioeconómicos en la adopción de tecnologías en los sistemas de producción de aguacate y muestra cómo la percepción de los productores respecto a estas adopciones involucra determinantes asociados al NT.

Palabras clave: cambios tecnológicos, análisis multivariado, *Persea americana*, nivel tecnológico.

Introduction

Worldwide avocado (*Persea americana* Mill.) cultivation increased to 86% between 2012 and 2021. The continents with the largest increase of harvest were America (66%) and Africa (16%) (FAO, 2023). In Africa, the country with the largest harvest in 2021 was Ethiopia, with 27,946 ha. However, Zimbabwe showed greater growth, increasing from 230 to 1,059 ha between 2012 and 2021. In the case of America, the country with the largest avocado crop in 2021 was Mexico, with 226,534 ha, and the country with the highest increase for this period was Colombia (27,705-94,110 ha) (FAO, 2023).

By 2022, Colombia ranked second place in planted areas and sixth in volume of avocado exports with 98,595 t,

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[1] Grupo de investigación Biogénesis, Departamento de Desarrollo Rural y Agroalimentario, Facultad de Ciencias Agrarias, Universidad Nacional de Colombia, Bogotá (Colombia).
[2] Grupo de Investigación Biogénesis, Laboratorio de Agrocomputación y Análisis Epidemiológico, Center of Excellence in Scientific Computing – CoE-SciCo, Departamento de Agronomía, Facultad de Ciencias Agrarias, Universidad Nacional de Colombia, Bogotá (Colombia).
* Corresponding author: jacaceresz@unal.edu.co

3.3% of the total volume imported in the world (ITC, 2023). Colombia has garnered global significance in the cultivation of avocado, symbolizing a remarkable growth trajectory and an increasingly influential role on the world stage (Cáceres-Zambrano Ramírez-Gil *et al.*, 2022). The country's ascent in avocado production is underscored by its favourable climatic conditions, diverse ecosystems, and strategic geographic positioning (Ramírez-Gil *et al.*, 2019). Colombia's prominence is not merely quantitative but extends to the quality of its avocado varieties that meet international standards. This newfound importance is shaping the nation into a relevant player in the global avocado market (Ramírez-Gil *et al.*, 2019). The socio-economic implications are profound, as the avocado industry becomes a key driver of economic growth and a source of international recognition for Colombia.

As this crop has grown in importance, its production has increased considerably (Cáceres-Zambrano Jiménez-Hernández *et al.*, 2022). However, while new forms of technology may have arisen, this does not mean that they are widely used. In this respect, issues relating to technology transfer, fruit quality, and crop productivity are significant (Ramírez-Gil *et al.*, 2019). Even though research on the cultivation of this fruit tree has led to a wide range of products, there remain challenges in the production system in terms of real and viable solutions to the problems of producers, with a positive benefit-cost ratio (Cáceres-Zambrano Jiménez-Hernández *et al.*, 2022). Additionally, technology transfer must be strengthened and made more strategic, given that regional links between producers facilitate transfer processes through leaders of territorial opinion (Varshney *et al.*, 2022).

The adoption of a new form of technology consists of accepting an innovation and integrating it into the productive context of the adopter (Straub, 2009). This process has been modelled and addressed by various authors. For example, Rogers (1962) proposes an innovation adoption curve, in which adopters are classified according to the time of adoption, focusing on the transfer of innovation. Other authors propose modelling the adoption of technologies according to the behaviour of the adopters (Ajzen, 1985). The Technology Acceptance Model (TAM), which incorporates the factors of perceived ease of use (Davis, 1986) in the utilization of technology (Venkatesh & Bala, 2008). Subsequently, Venkatesh *et al.* (2003) proposes the Unified Theory of Acceptance and Use of Technology (UTAUT) that utilizes various models as a basis and considers four direct factors in its adoption: performance expectation, effort expectation, social influence and facilitating conditions.

The technological classification of producers depends on the practices to be adopted, and transfer processes are constantly changing according to innovation and the characteristics of the social system (Ayisi *et al.*, 2022). In this regard, Curry *et al.* (2021) state that the sociocultural environment should be considered when developing new technology. When the proposed technologies go against the values and traditions of the community, adoption becomes less likely. At the regional level, the technology and knowledge associated with a given crop should be a cross-cutting tool in everyday and educational processes, involving producers and the family nucleus in crop management and thereby promoting local innovation (Gutiérrez García *et al.*, 2020).

The factors involved in the process of adoption of a technology in agriculture include social and demographic determinants, access to technology (Oyetunde-Usman *et al.*, 2021), risks and uncertainties of application, and user perception of benefits (The World Bank, 2007). Šūmane *et al.* (2018) state that a technology is adopted by a producer if it has been previously used and approved by its neighbours. Morris *et al.* (2017) find that technology can support business models in different ways and the active or passive adoption by producers depends on access to information.

Despite the existence of several technologies for the avocado production system, a gap is evident in its adoption (Cáceres-Zambrano Ramírez-Gil *et al.*, 2022). The adoption of technology in avocado production systems encounters multifaceted challenges rooted in a complex web of factors (Cáceres-Zambrano Ramírez-Gil *et al.*, 2022). These obstacles, largely undefined and interconnected, span social, economic, cultural, and market dimensions. The lack of well-established causative relationships hampers effective problem-solving (Cáceres-Zambrano Ramírez-Gil *et al.*, 2022). Understanding these issues is important for devising strategies that enhance the evaluation and subsequent adoption of relevant technologies by producers. By comprehensively unraveling the intricate tapestry of influences, stakeholders can formulate more effective approaches. This, in turn, promises to ameliorate economic, financial, and productivity indicators, fostering sustainability in avocado production systems. The confluence of diverse factors necessitates a nuanced understanding for the development of targeted and impact ful interventions.

Elucidating the factors involved in the adoption of technologies enables efforts to be directed towards the generation and transfer of knowledge, thereby improving the technological level and efficiency of production systems. Given the lack of knowledge relating to the determinants of technological adoption in the avocado agribusinesses in the neotropical country of Colombia, the objective of this research was to explore the determinant factors in the adoption of technologies in avocado production systems and the perception of producers regarding these factors. Based on preceding elements, our research hypothesis posits that the adoption of technology in avocado cultivation within tropical conditions, particularly in the context of Colombia, is multifaceted, context-specific, and contingent upon various social, cultural, economic, and productive considerations inherent to each agricultural system.

Materials and methods

Information collection

Information used in our study was collected from 125 avocado producers located in five departments of Colombia representing the most area planted and greatest volume of production. The departments and their respective municipalities were: Cundinamarca (municipalities of Silvania and Anolaima), Caldas (Belalcazar, Aguadas, Anserma, Manzanares, Manizales, Marquetalia, La Merced, Pácora, Pensilvania, Riosucio, Risaralda, Salamina, San José, Victoria and Villamaría), Antioquia (Sonsón, Abejorral and San Vicente Ferrer), Risaralda (Guática and Quinchía) and Tolima (Ibagué). For this purpose, a semi-structured survey was used to collect information on socioeconomic factors, frequency of use of technologies, and perception of adoption factors. The survey was carried out in person on each producer, during events organised by institutions, unions, associations, or trading houses.

The selection and quantification of producers deviated from conventional sampling techniques due to the absence of consolidated estimates and data within the sector. Ensuring the randomness of everyone posed technical challenges and incurred substantial costs. Consequently, an alternative approach was adopted, wherein individuals were randomly chosen from a finite population linked to the participation of producers in the events. This method was chosen acknowledging the practical constraints and logistical intricacies associated with achieving true randomness in individual selection within the given context. In this sense, the reliability of each instrument was evaluated with the alpha (α) criterion of Cronbach (Cronbach, 1951).

Characteristics of the adopters and the production system

As previously mentioned, the ability to adopt new technology is affected by the characteristics of the production system and of the adopters. Therefore, we characterized the producers and their production systems according to the following: gender, age, academic training, distance to the municipal capital, type of land tenure, source of income, use of credit, availability of internet and computer equipment in the production center, production area, number of trees planted, crop age, workforce, social security payment to workers, technical assistance, certifications, use of technical records, marketing channel, and producer participation in organisations. Subsequently, connections between variables were explored through multiple correspondence analysis (MCA). The objective of this was to infer whether, in the avocado agribusiness in Colombia, the technological level (TL) is linked to the characteristics of the adopters and the production system.

Technological adoption level

To compare the socioeconomic and adoption information collected with the TL, we used the system of Cáceres-Zambrano Ramírez-Gil *et al.* (2022), where by we characterized the TL based on the frequency of use of 82 technologies in the following links of the avocado agribusiness value chain: (i) propagation of plant material and nursery (16), (ii) production (43) and (iii) postharvest (23). The frequency of use was evaluated according to the Likert scale (1932), with five options for each response: 5 = always, 4 = almost always, 3 = sometimes, 2 = almost never, and 1 = never. We previously evaluated the technologies considered in each group, and we used the results of the factorial loads as a weight for the calculation of the TL. We used the TL results generated in the study to find relationships between it and the characteristics of the adopters, the production system, and the perception of adoption factors.

Perception of adoption factors

We consulted producers regarding the perceived importance of a group of preselected technology adoption factors following the UTAUT theory proposed by Venkatesh *et al.* (2003) (Tab. 1). We used a Likert scale (1932) based on the perception of importance, with five response options: 5 = very important, 4 = important, 3 = moderately important, 2 = of low importance and 1 = not important. We grouped the results according to the TL, to elucidate the relationship between it and the adoption factors.

TABLE 1. Technological adoption factors in avocado production systems under neotropical conditions, Colombia.

Factor	Variable	Source
Performance expectation	Increase in cultivation output	(Xie & Huang, 2021)
	Contribution to fruit quality	(Barrios *et al.*, 2020)
	Contribution to avocado export process	(Xie & Huang, 2021)
	Reduction of production costs	(Ruzzante & Bilton, 2021)
	Improvement in employee productivity	(Tami-Barrera, 2021)
Effort expectation	Market availability of technology	(Doss, 2003)
	Experiences of technology use	(Barrios *et al.*, 2020)
Social influence	Adoption by other producers	(Ruzzante & Bilton, 2021)
	Gaining recognition in the region	(Barrios *et al.*, 2020)
	Value of the farm	(Xie & Huang, 2021)
	Environmental impact of technology	(Liu *et al.*, 2018)
	Buyer requirements	(Foster & Rosenzweig, 2010)
	Acceptance by business partners or family	(Ruzzante & Bilton, 2021)
Facilitating conditions	Ease of use of technology	(Taherdoost, 2018)
	Access to credit	(Ruzzante & Bilton, 2021)
	Technical assistance	(Tami-Barrera, 2021)
	Internet availability on the farm	(Tami-Barrera, 2021)
	Technology price	(Ruzzante & Bilton, 2021)
	Support by technology provider	(Tami-Barrera, 2021)

Data analysis

We used the free software R Project v4 (R Core Team, 2022) to perform the statistical analyses. The characterization data were explored with MCA. Adoption factor data were analysed using principal component analysis (PCA) with the aim of carrying out an initial exploration of the data and reducing the number of dimensions, facilitating the observation of relationships between variables. Perception data on adoption factors were used with 125 producers and 19 variables (Tab. 1). A PCA was used prior to the factorial analysis, to verify that the groupings between variables matched what is in the literature and what was proposed in this study (Tab. 1). For this analysis, the libraries *factoMineR* (Lê *et al.*, 2008) and *factoextra* (Kassambara & Mundt, 2020) were used.

Having found that the groups of factors evaluated did not show a grouping like what was proposed, we decided to use an exploratory factor analysis (EFA). We used the EFA to find the distribution according to the perception of importance on the part of the surveyed producers (Lloret-Segura *et al.*, 2014). For this, we used 17 of the 19 variables, since for the other two, the perception of importance was unanimous among the producers. The analysis was carried out for the group of producers in general and by TL (high, medium, and low), with the objective of inferring whether the grouping and loads of the variables changed depending on the TL of the producers. To carry out the EFA, we considered four assumptions. Firstly, for the number of factors to extract, we selected the number with the greatest number of supporting methods (Lloret-Segura *et al.*, 2014). Secondly, for type of rotation to be used, we chose a varimax orthogonal type, considering the absence of relationships between the items evaluated. Thirdly, for the estimation method, we used the weighted least squares (WLS), as this is a robust method used in the analysis of data that does not meet the assumption of multivariate normality, as is the case for the data analysed in the present work (Lloret-Segura *et al.*, 2014). Finally, for the matrix used for estimation, we selected a polychoric type, due to the five-option scale used in the questionnaire based on the Likert scale. For the EFA, the fit of the proposed model was evaluated using the Comparative Fit Index, the Tucker-Lewis index (TLI>0.90), the relative measure for model comparison, and the Bayesian information criterion (BIC) (West *et al.*, 2012; Cavanaugh & Neath, 2019). The library used for the factorial analysis was nFactors (Raiche & Magis, 2020).

Subsequently, and considering that there were producers from each of the three TLs, we used a model for each level to verify whether the fit of the model could be improved for each TL. We also used cross-sectional libraries for the psych analysis (Revelle, 2021), psycho analysis (Makowski, 2018) and plotly analysis (Sievert, 2020) for descriptive analysis and generation of visualization tools.

Results

Characteristics of the adopters and of the production systems

Among the surveyed avocado producers, men (88.8%) predominated over women (11.2%) with non-binaries unrepresented. Ages were between 30 and 60 years (67.2%). For the gender or age, a distribution related to the TL was not found. Predominant education levels were primary (52.8%), followed by secondary (24%), technical or technological education (8.8%), professional (8.8%) and postgraduate (5.6%). Producers with primary and secondary academic training included the three levels of TL (high, medium, and low); the medium and high TL included producers with technical or higher education not found in the low TL. The characteristics of the adopters were grouped according to the TL (Fig. 1).

The departments of Caldas (48.0%) and Antioquia (36.8%) led the distribution of the surveyed producers followed by Cundinamarca (8.8%), Risaralda (4.8%) and Tolima (1.6 %). Producers in the departments with the largest number of people surveyed were mainly in the medium and high TL. The majority of the production systems studied were located less than 10 km from the municipal capitals (62.4%) and 95.2% of the producers surveyed and they carried out the activities on their own properties. The main economic activity was agriculture (84.8%), while 6.4% received income from sources other than production.

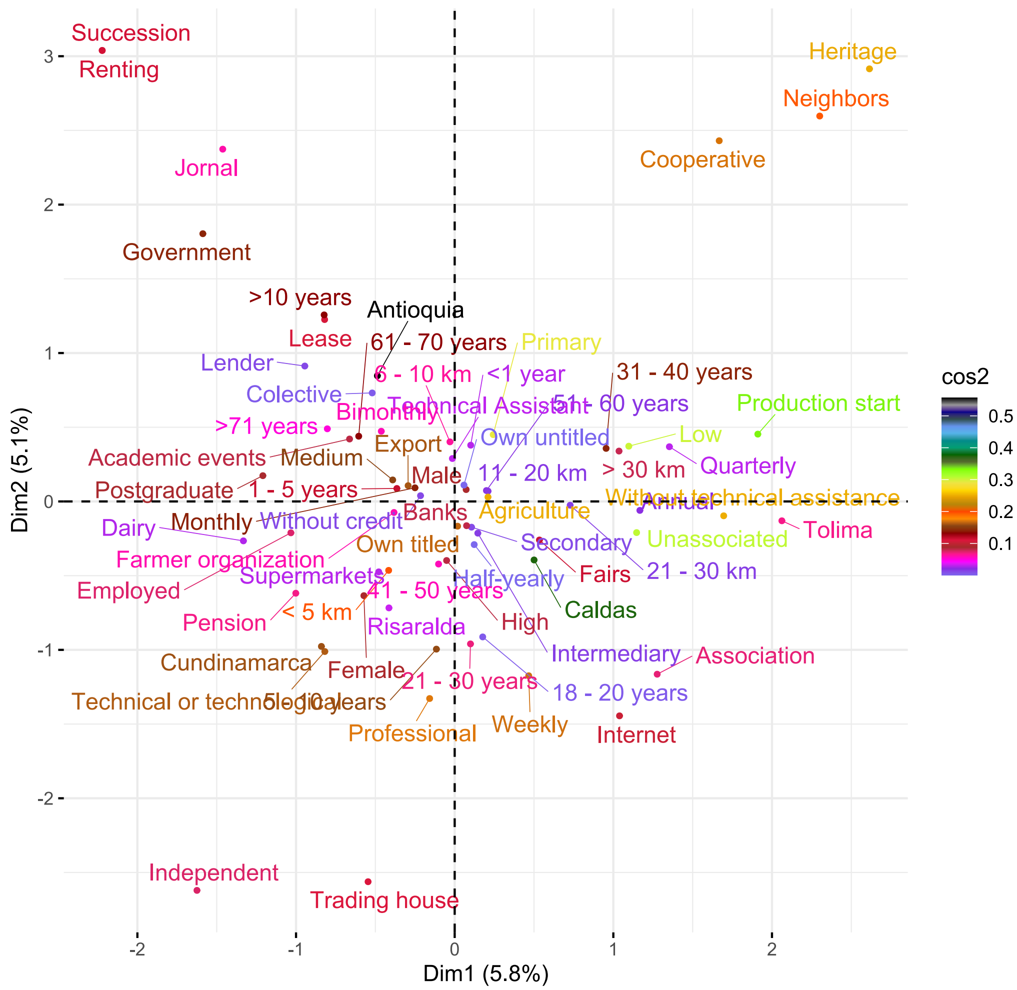

FIGURE 1. Characteristics of the producers and avocado production systems according to the technological level using the multiple correspondence analysis.

Some 77.6% of the interviewers stated that they had used credit to finance their productive activity, and banks were the main source of leverage. Regarding connectivity and use of computer equipment, 65.6% (connectivity) and 68% (computer equipment) of the interviewers did not have internet and computer equipment at the production site. The highest percentage of these characteristics (*i.e.*, credit, possession of computer equipment and access to the Internet) occurred in the high TL.

The area of the production systems and the number of trees were the parameters with high variation in each TL. We observed that with a decrease of the TL the upper limit of the range also decreased (greater number of plants and planted areas). However, we noted a small area of the production systems in the upper TL. Regarding the age characteristics of the cultivation, we found no distribution related to technological level and age characteristics.

The production systems used family labour in 50.4% of the cases. Producers with high TL had a greater use of hired labour, while the medium and low TL producers used a greater proportion of family labour. Of the productive units that used family labour, 46% did pay for this work. We found a low proportion of social security payments. Access to technical assistance by the surveyed producers was high (92%) and was mostly on a contractual basis with a frequency of visits of once per month.

The distribution of GAP global certification had no relationship with the TL. However, the medium and high TL producers were more frequently registered exporting properties. We found that 83.2% of the surveyed producers kept some kind of record of their activities; this was a characteristic that was not related to the technological levels. Meanwhile, the predominant marketing channel was export (62.4%), followed by intermediaries (20.8%). There was a high percentage of producers linked to a trade union or local association (82.4%).

Perception by avocado producers of technological adoption factors

The survey showed average reliability based on α criterion of Cronbach (α = 0.60; $P<0.05$; average r = 0.08), with items usually un-associated with each other. In general, the surveyed avocado producers perceived the adoption factors evaluated as being very important. Of the variables, increase in crop yield and ease of use of the technology stand out, since they are considered very important by 100% of the producers (Fig. 2). The variable considered of least importance was adoption by other producers. Facilitating conditions and social influence factors were rated as less important than those of performance expectation and effort expectation.

By grouping the producers by TL and verifying the frequency in the perception of importance of the selected variables, we found some overlap in the importance rating among producers with different TLs (Fig. 3). The medium and high TL producers share variables with each other and, to a lesser extent, with the low TL producers. However, the producers located in the low TL valued a greater number of variables as "very important" compared with the other two levels. The producers located in the lower LT unanimously rated as very important the variables of value of the farm, adoption by partners and family, and market availability of technology. Additionally, we found that variables that presented high variability in the importance rated independently of the technological level.

The variables analysed were reduced to three dimensions that explained 70.1% of the variance of the data in which buyer requirements, adoption by other producers, and the price of the technology were the variables with the greatest contribution (Fig. 4). Producers usually have little technical independence in decision-making, meaning that they usually ask for advice, not only from technical consultants, but also from neighbours or other experienced producers. Decisions are made according to observable economic results that will allow better income. However, producers also consider aspects related to new markets or the possibility of providing a superior product. On the other hand, the support of state or financial institutions decreases uncertainty when adopting a new technology.

The original model evaluated showed a good fit ($P<0.05$; BIC = 15.33; TLI = -0.27) that was improved through the elimination of those variables with a lower proportion of explained variance ($P<0.05$; BIC = 10.38; TLI = -0.57). Two factors were found, namely "decreased uncertainty and market entry" that linked four variables related to the market, "quality and financing"; and "information and financial advantages" that linked six variables related to technical aspects, social influence, and technological aspects (Fig. 5).

We found that the importance assigned to the proposed variables was different among the producers from the different TLs (Tab. 2). Similarly, the grouping, factorial loads and excluded variables were specific to each TL. High TL

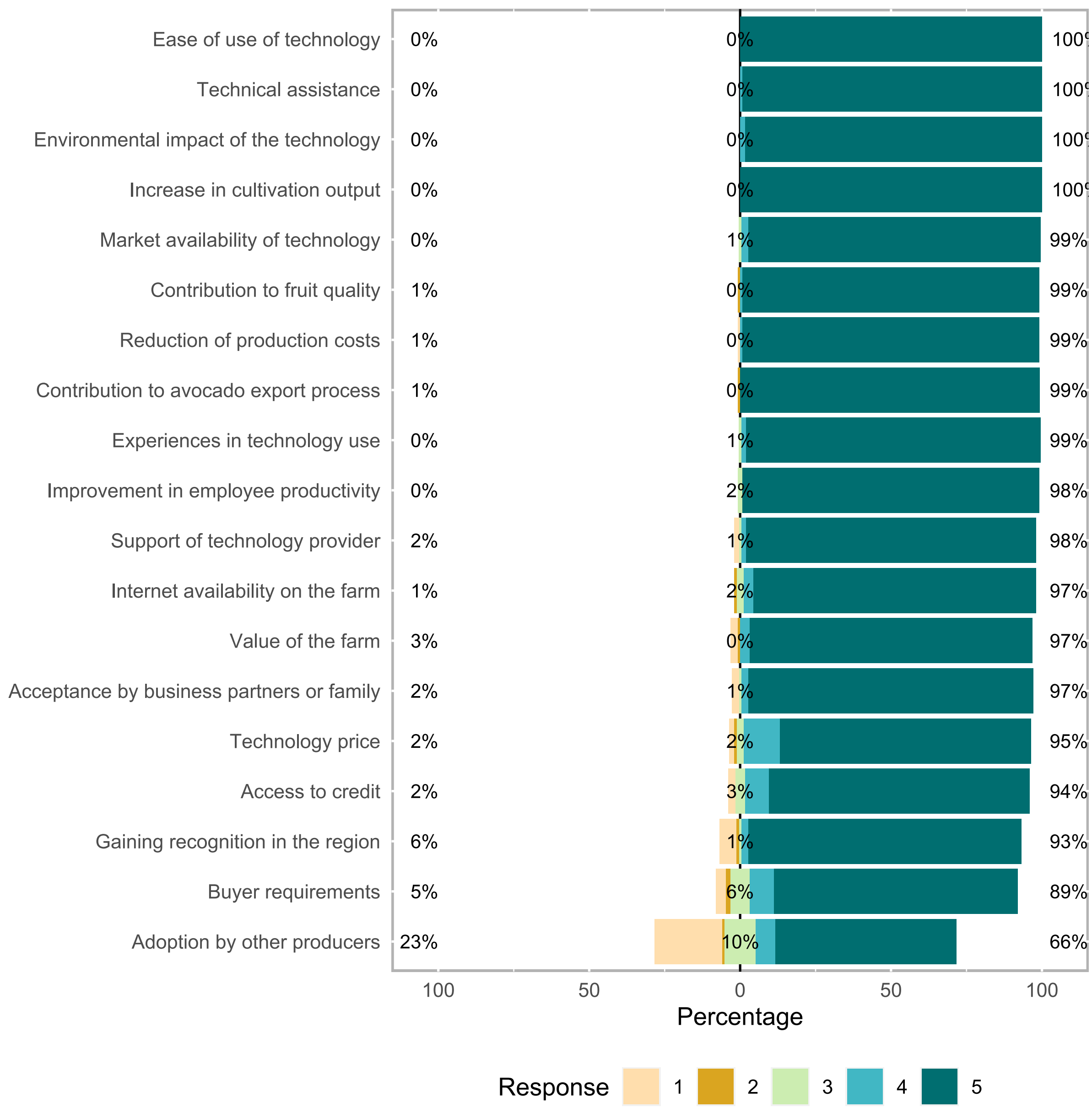

FIGURE 2. Perception of the importance of the variables and factors of technological adoption by avocado producers based on Likert scale analysis.

producers downplayed variables related to finance and to adoption of technology by other producers (P<0.05; BIC = 1632; TLI = -2.60). At this level, the experience of using the technology was more important than adoption by other producers; this reflects the fact that the thinking behind the production system goes beyond the regional or national environment.

The middle TL producers considered three factors with associated variables, excluding the reduction of costs, adoption by other producers, value of the farm, demand by the customer, contribution to the quality of the fruit, and price of the technology (P<0.05; BIC = 3335, TLI = -1.78). The low TL model was initially built with seven variables since a high degree of importance was given to the other variables by all the producers. Based on these variables, we constructed a model in which the variables of internet presence on the farm and support from the technology provider were excluded (P<0.05; BIC = 372; TLI = -7.9). In this research, we regrouped the initial groups based on the perception of the producers, to find a factor that decreased uncertainty.

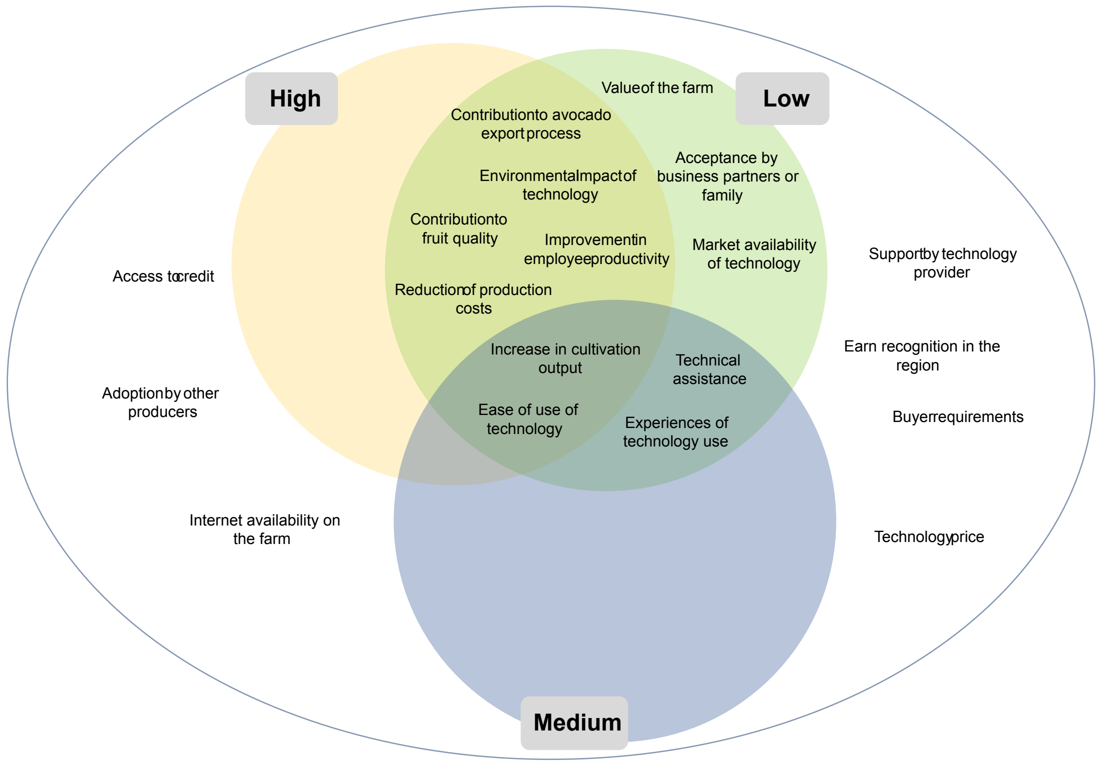

FIGURE 3. Perception of importance of adoption variables according to technological level of avocado production systems. The variables inside the coloured circles were rated as "very important" by 100% of producers in the corresponding technological level. The variables outside the coloured circles are those that were considered less important by the surveyed producers in all the TLs.

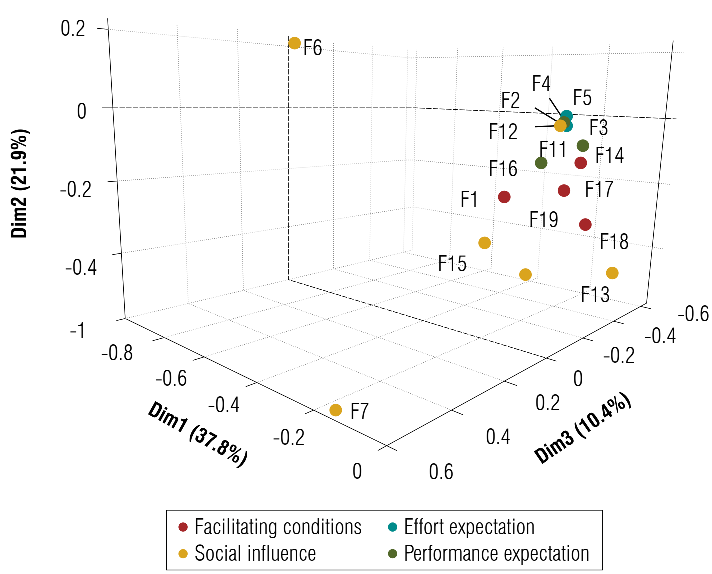

FIGURE 4. Principal component analysis as a tool for exploring the distribution of factors according to the variance of the data. F1 = access to credit; F2 = technical assistance; F3 = contribution to the avocado export process; F4 = reduction of production costs; F5 = availability of the technology in the market; F6 = adoption by other producers; F7 = gaining recognition in the region; F8 = value of the property; F9 = increase in crop yield; F10 = ease of use of technology; F11 = experiences in the use of technology; F12 = environmental impact of technology; F13 = buyer requirements; F14 = contribution to the quality of the fruit; F15 = acceptance by partners or family; F16 = improvement in employee productivity; F17 = internet presence on the farm; F18 = price of technology; and F19 = support from the technology provider.

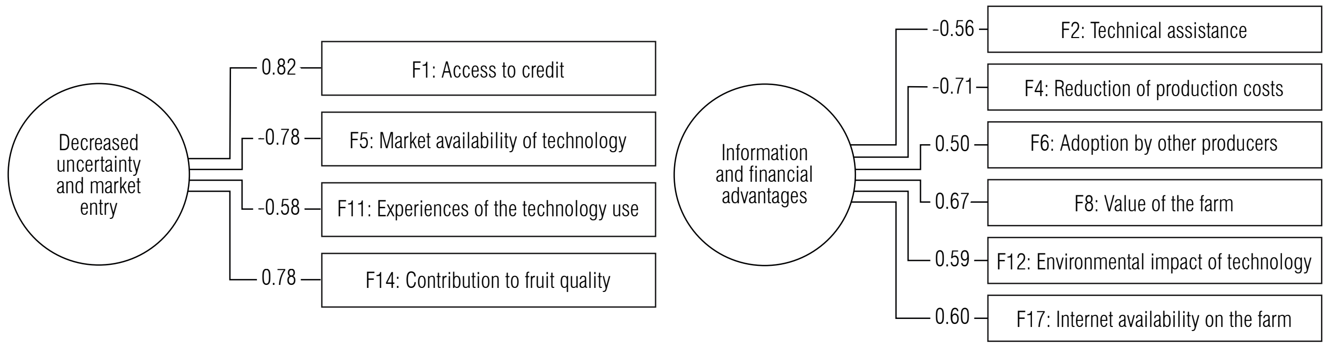

FIGURE 5. Perception factors related to the adoption of technologies in avocado production systems.

TABLE 2. Technological adoption factors and factorial loads in avocado production systems according to technological level.

		High technological level		
Facilitating conditions and social influence	Technical assistance	Acceptance by business partners or family	Market availability of technology	Internet availability on the farm
	0.95	0.84	-0.49	-0.46
Reduction of uncertainty	Support from technology provider	Experiences in the use of technology		
	-0.89	0.87		
		Medium technological level		
Facilitating conditions	Market availability of technology	Access to credit	Environmental impact of technology	Support from technology provider
	-0.87	0.81	0.66	0.64
Social influence	Acceptance by business partners or family	Contribution to avocado export process	Gaining recognition in the region	
	0.88	-0.78	0.76	
Performance expectation	Improvement in employee productivity	Internet availability on the farm		
	-0.89	0.58		
		Low technological level		
Market	Buyer requirements	Access to credit	Technology price	
	0.82	-0.74	0.74	
Social influence	Adoption by business partners or family	Gaining recognition in the region		
	0.69	-0.93		

Note: The numbers in the table correspond to the factorial loads for the structural equation model at each technology level.

Discussion

We found a gender gap that corresponded to what is generally found in agriculture: women showed low participation in decision-making spaces (The Consultative Group on International Agricultural Research (CGIAR) & Leveraging Evidence for Access and Development (LEAD), 2021). However, it should be emphasised that the participation of women in agricultural production systems allows the strengthening of value chains and their resilience (Huyer, 2016). As such, the value chain would benefit from improving the gender gap.

The most frequent age range was between 30 and 60 years, while the least frequent was between 18 and 30. Parra and Knobloch (2022) find that the experience favours good decision-making in this regard. Liu *et al*. (2018) claim that greater experience leads to lower receptiveness to new technologies. This could be related to a decreased transfer of agricultural businesses between generations and to the low proportion of young people dedicated to agricultural work. This is an important aspect given that age is considered a relevant factor for the adoption of technologies.

We found that producers with higher academic training tended to have higher technological levels. Academic training favours the adoption of new technology (Liu *et al*. 2018). However, Curry *et al*. (2021) state that technology adoption and related factors are not limited to academic, financial, or technical aspects, and that a comprehensive vision, considering the way in which technologies, habits and traditions of adopters are communicated, is necessary.

Avocado cultivation, especially of cv. Hass, has grown with greater intensity in particular areas of Colombia. This has led some producers to join forces and manage resources for training in productive and commercial aspects. This growth is reflected in the distribution of producers with respect to technological levels in certain regions, with those areas with the highest growth becoming stronger (Quintero-Ramirez *et al*., 2019). The producers showed high associativity percentages at all technological levels, a characteristic that has a positive effect on innovation and technology networks by favouring interaction with other actors in the chain. Krishnan *et al*. (2021) find that collaborative work and producer organisations promote the implementation of innovations.

Other factors such as type of land tenure, source of income and access to credit are related to the technological level (Kassie *et al*., 2013). However, the data collected in this study did not find such a relationship. We observed that the technological level was high in the production systems with larger areas, matching the findings of previous reports (Doss, 2003). On the other hand, the use of technological and communication tools by production systems allows access to markets via the internet and to technological information related to management practices (Morris *et al*., 2017). Similarly, formality in recruitment processes is decisive in technological and innovation processes, since it allows the evaluation of potential employees and therefore the optimization of processes (Juma, 2015).

Registration as an exporting farm was more frequent than global GAP certification, even though the latter is an international certification requirement to export to certain destinations (Castrillón Correa, 2020). This behaviour can be explained by the fact that registering as an exporting farm is a mandatory national standard for marketing fruit abroad (ICA, 2016). Lippe and Grote (2017) find that the global GAP certification process requires investment that is sometimes not reflected in a monetary incentive for producers; this is why this certification is usually adopted only if it is financed or supported through public-private partnerships.

Tiruneh *et al*. (2015) state that the adoption of a new technology depends on the ability of producers to perceive the advantages of this in the existing socioeconomic conditions. In this research we found that the factors of social influence and facilitating conditions were perceived as less important than expectations of effort and performance. However, social influence has a role in adoption decisions (Tiruneh *et al*., 2015).

The producer perception of the variables evaluated depended on their technological level. Producers with lower TL placed greater importance on those variables that represented financial benefits and ease of access, such as farm value, acceptance by partners and family, and availability of technology in the market. Porteous (2020) finds that the adoption of technologies is linked to commercial and financial incentives for producers that improves their technological level. But, producers face risks when adopting new technology; therefore, reducing the associated uncertainty facilitates decision-making regarding technological matters (Liu *et al*., 2018). The hypothesis of this research was corroborated, since the decision to adopt a technology is more complex and is crossed by aspects of uncertainty and technical analysis in addition to income alone.

The results of this study supported the assertion that the size of the farm and the characteristics of the farmers do not directly influence technological adoption, but rather they influence the perception of producers in decisions regarding the adoption of technology (Tiruneh *et al*., 2015). The need to collect information regarding other variables and dimensions is evident. In this regard, Maertens and Barrett (2013) state that the collection of data on social networks, information flows, and other unobservable variables are relevant for modelling technological adoption. This would involve an analysis of the entire adoption process and not just an evaluation of the technological level and perception at a given moment.

Our results indicated that the adoption of technology among avocado producers is influenced by a great number of factors: age, gender, educational attainment, cultural considerations, risk perception, investment capacity, opportunity cost, technology availability, applicability, among others. Recognizing the unique dynamics of each productive unit, we abstained from prescribing a universal judgment on the efficacy of specific technologies, emphasizing the need for nuanced assessments tailored to local contexts and individual circumstances. This approach enables a comprehensive understanding of the intricate interplay between multifaceted factors influencing technological adoption in the avocado production domain, but not associated with which technology is more adequate or not adequate by the production systems evaluated.

It is imperative to acknowledge the limitations inherent in our study. The representativeness of our sample posed a constraint, as it may not fully encapsulate the broader population perspectives on crucial factors in technological adoption in the avocado production systems. Moreover, the absence of validation with non-surveyed individuals limited the generalizability of our findings. Moving forward, a comprehensive exploration involving a balanced representation of all potential determinants is warranted. Future research should delve into strategies aimed at improving technological adoption, elucidating how this enhancement can catalyse into production efficiency, competitiveness, and sustainability within the avocado cultivation sector. This avenue holds promise for advancing both academic understanding and practical outcomes in agricultural technology adoption.

Conclusion

This study allowed us to explore the relationship between social factors and the perceptions of the producers on the determinants of technological adoption in the avocado value chain. The area of the productive unit, the level of academic training of the producers, and the type of marketing channel were variables related to the technological level of the production systems. Additionally, there was a relationship between the technological level and the perception of adoption factors. Producers with a low technological level valued a greater number of variables as determinants for the adoption of decision-making, while at medium and high technological levels fewer variables were considered, and these were related to commercial, technical, and financial benefits. The results of this research showed the need to study aspects of academic training in the rural sector, given that this is a determining variable in the adoption of technologies. In addition, it was necessary to focus the extension of technology and transfer efforts on the financial benefits of technological adoption, as well as addressing the perception of associated risks.

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Conflict of interest statement

The authors declare that there is no conflict of interests regarding the publication of this article.

Author's contributions

JCZ, JGRG and DB: conceptualization, methodology, validation, data curation. JGRG and DB: review and editing, supervision. JCZ and JGRG: software. DB: project administration. JCZ: formal analysis, investigation, resources, original draft preparation, visualization, funding acquisition. All authors have read and approved the final version of the manuscript.

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