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# Accumulation of degree days and their effect on the potential yield of 15 eggplant (*Solanum melongena* L.) accessions in the Colombian Caribbean

UNIVERSIDAD NACIONAL DE COLOMBIA

## Acumulación de grados días y su efecto sobre el potencial de rendimiento de 15 accesiones de berenjena (*Solanum melongena* L.) en el Caribe Colombiano

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## ABSTRACT

**Keywords:**
Degree days
*Solanum melongena*
Temperature
Yield

The growing degree-days (GDD) provide an estimate of the accumulated thermal energy available for the development of a crop. The use of GDD allows measuring the heat requirements associated with the phenological stages of the crop, which allows in turn, to predict when a certain plant stage will occur knowing the daily temperatures. The aim of this study was to establish relationships among the effect of degree days (DD) to vegetative growth, first flowering and fructification (VG, Fl and Fr), on total yield per plant (TY/P) of eggplant grown under open-field conditions employing a randomized complete block design with 15 genotypes and four replicates. The results showed that: 1) The genotypes that initiated fruit production in less time required fewer GDD (892.14-1,077.71 °C) for this phenological phase, obtaining higher productivity. 2) The genotypes C035 and C040 had an average yield higher than the national average with values of 83.75 and 84.86 t ha$^{-1}$, being identified as future varieties to be produced in the Caribbean region. 3) The Caribbean region is suitable for the establishment of the crop as there were no events with limiting temperatures for this species (higher than 35 °C and lower than 15 °C). 4) The principal component analysis showed associations among the variable YT/P with the genotypes C011, C042, and C015; meanwhile, C032, C025, and C028 were associated with the variables DD to VG, Fl, and Fr. These results would be useful in developing a model to estimate yield with DD.

## RESUMEN

**Palabras clave:**
Grados día
*Solanum melongena*
Temperatura
Rendimiento

Los grados días de desarrollo (GDD) proporcionan una estimación de la energía térmica acumulada disponible para el desarrollo de un cultivo. El uso de los GDD permite medir los requerimientos de calor asociados a las etapas fenológicas del cultivo, lo que a su vez permite predecir cuándo ocurrirá una determinada etapa de la planta conociendo las temperaturas diarias. Este estudio tuvo como objetivo determinar las relaciones entre el efecto de los grados días (GD) hasta el crecimiento vegetativo, la primera floración y fructificación (CV, Fl y Fr) sobre el rendimiento total por planta (RT/P) de berenjena cultivada en campo abierto bajo un diseño de bloques completos al azar con 15 genotipos y cuatro repeticiones. Los resultados mostraron que: 1) Los genotipos que inician producción de frutos en menor tiempo requieren menos grados días (892,14-1.077,71 °C) para esta fase fenológica, obteniendo una mayor producción. 2) Los genotipos C035 y C040 tuvieron un rendimiento promedio superior al promedio nacional con valores de 83,75 y 84,86 t ha$^{-1}$, identificándose como futuras variedades a producir en la región del Caribe. 3) La región Caribe es apta para el establecimiento del cultivo, debido a que no hubo eventos limitantes de temperatura para la especie (temperaturas mayores a 35 °C y menores a 15 °C). 4) El análisis de componentes principales mostro asociación entre los genotipos C011, C042 y C015 con las variables RT/P, y los genotipos C011, C025 y C028 con los GD a CV, Fl y Fr. Estos resultados serían útiles para desarrollar un modelo para estimar el rendimiento con base en los GD.

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In Colombia eggplant, aubergine or brinjal (*Solanum melongena* L.) is one of the species belonging to the Solanaceae family with great importance after tomato, potato and chili pepper. Eggplant is characterized by having a typical external appearance, taste, and the presence of seeds, presenting a great diversity of genotypes that varies according to the country, the region and the target market (Arguedas-García and Monge-Pérez, 2017). In the Colombian Caribbean region, mainly in the departments of Córdoba, Bolívar, Sucre and Atlántico, it is cultivated by small producers in areas ranging between 1,000 and 2,500 $m^2$. This vegetable has positioned itself as necessary in the farmer economy of the region because of factors such as the short cultivation cycle, short-term economic returns, intensive production in relatively small areas, and it requires a large amount of labor generating promotion of rural employment (Araméndiz *et al*., 2008a). At a global level, the crop shows a growing demand with production figures of 46.9 million t in 2012, increasing to 51.3 million t in 2016 (FAOSTAT, 2018). This demand, among other factors, is deeply rooted in the gastronomy of the population of many countries and the benefits attributed to human health, especially regarding antioxidants and minerals, as well as healing properties for diabetes and cholesterol reduction (Sadilova *et al*., 2014).

Aubergine plants show a good adaptation in dry regions and hot climates. According to Baixauli (2001), its optimum development occurs at average temperatures between 20 and 25 °C, with an optimum diurnal temperature between 22 and 26 °C and a nocturnal temperature between 15 and 18 °C. The crop is susceptible to frost, so in regions where the temperature is below 18 °C, it is advisable to cultivate the crop under greenhouse conditions. At low temperatures (11-12 °C), the plants stop their vegetative development, and deformations along with flower and fruit abortion can occur (Concellón *et al*., 2007). At temperatures higher than 32 °C fruit maturation accelerates, and pollen becomes unfeasible and prevents full fertilization when the temperature exceeds 35 °C for prolonged periods, causing deformations in fruits (Araméndiz *et al*., 2008b). Likewise, the crop supports relatively high temperatures provided that the humidity is adequate, tolerating up to 40-45 °C (Araméndiz *et al*., 2008a). According to Lieth (1974), phenology in crops examines the different stages of plant growth and development, clearly distinguishable and observable in chronological order, including the study of the biological phenomena linked to certain periodic rhythms or phases and the relationship with the environment where these occur (Moreno-Pérez *et al*., 2011). In the tropics, the temperature is the environmental variable with the most significant influence on crop growth and development; in this sense, the reactions that directly or indirectly intervene in most of the physiological, biochemical and metabolic processes are strongly linked to temperature (Baker and Reddy, 2001).

The unit that combines time and temperature to estimate the development of an organism from one point to another in its life cycle is commonly referred to as degree days (DD), growing degree day (GDD), heat units (HU) (López *et al*., 2011 and Díaz-Lopez *et al*., 2013) or physiological time (Parra-Coronado *et al*., 2015). In agronomy, its application mainly lies in estimating how long it takes for a particular crop to reach a phenological stage of interest such as anthesis, flowering, fruiting, harvesting, senescence, among others (Orduz *et al*., 2010; Hoyos *et al*., 2012). Other applications are to establish optimum conditions for the growth and development of pests, sowing dates, crop irrigation, and fertilization, among others (Flores-Gallardo *et al*., 2012; Ferrer *et al*., 2014; Ramírez *et al*., 2015). Worldwide, many efforts have been made to study the optimum days and temperatures for eggplant cultivation (Maynard and Hochmuth, 2007; Fealy and Fealy, 2008; Rouphael *et al*., 2010; Sadek *et al*., 2013). However, despite the socio-economic and cultural importance of eggplant in the Colombian Caribbean region, there are no recent studies that evaluate the accumulation of degree days and the productive response of this species. Therefore, this study aimed to establish the number of accumulated degree-days along the crop cycle (from transplant to harvest), and its effect on the productivity of 15 eggplant varieties in the Magdalena state, the Colombian Caribbean region.

## MATERIALS AND METHODS

### Plant material

Fifteen eggplant accessions belonging to the genebank of Corporación Colombiana de Investigación Agropecuaria (Agrosavia) were evaluated as follows: C003, C006, C011, C014, C015, C025, C026, C027, C028, C032, C035, C036, C040, C042, and C049. The accessions were planted in an experimental plot of the Caribia Research Center (CI) of Agrosavia located in Zona Bananera [banana and plantain production zone] of Magdalena State, Colombia, from June to November 2017.

The CI Caribia is located according to the geographic coordinates at 10° 47' N latitude and 74° 10' W longitude at an elevation of 18 m. The region has an average annual temperature of 28 °C, with a relative humidity of 82% and an average annual rainfall of 1,280 mm, placing it according to Holdridge's climate classification (1967) in the Tropical Dry Forest (Bs-T) life zone.

The accessions were planted in the field under a completely randomized design with four repetitions. The experimental unit comprised 40 plants in a plot of 1×x 1 m. A drip irrigation system was used, using drip tapes with a discharge of 0.8 L $h^{-1}$ and irrigation until the soil reached field capacity. The CropWat 8.0 program was used to calculate water needs. For this, the amounts of water lost by the crop or crop evapotranspiration (ETc) were estimated. The ETc was estimated using Equation 1.

$$ETc - ETo \times Kc \qquad (1)$$

Where *Kc* is the crop coefficient; for the current study, the *Kc* values used were the ones reported by Allen *et al*. (2006). Reference evapotranspiration (ETo) was calculated using the FAO Penman-Monteith method (Allen *et al*., 2006), with climatic data obtained from the Davis-Vantage2plus6162 automated climatological station of CI Caribia.

The calculation of degree days was estimated based on the standard equation or simple method (López *et al*., 2011) according to Equation 2:

$$Tm = \left(\frac{T\,max + T\,min}{2}\right);\ DD = \sum_{I=1}^{N}(Tm - Tb) \qquad (2)$$

Where:
*Tm:* mean temperature (°C)
*Tmin*: minimum temperature (°C)
*Tmax*: maximum temperature (°C)
*n*: number of days
*Tb*: base temperature (°C)
*DD*: degree days

The Tb used was the one reported by Maynard and Hochmuth (2007), i.e., 15.6 °C. Four phenological stages established for Solanaceae by Meier (2001) were used with adaptations (Table 1) based on the number of days in which each phenological stage was completed in 50% of the plants sown in each plot.

**Table 1.** List of stages established for 15 *Solanum melongena* L. accessions.

| Stage | Description |
|---|---|
| 19 | Development of leaves (main stem). Nine or more unfolded leaves of the main stem. |
| 51 | Appearance of the floral organ. First visible floral button. |
| 61 | Flowering. First opened flower. |
| 71 | Fruit formation. First fruit reaches the typical shape and size. |

The yield was expressed in tons per hectares (t $ha^{-1}$) during 14 harvests. Fruits that had not reached physiological maturity (unripe state) but that had the typical shape and size of their respective cultivar were considered fruits suitable for harvest. For data analysis, descriptive statistics and multivariate principal components analysis were used, using the Infostat program version 2017.

## RESULTS AND DISCUSSION

### Climatic characterization of the experimental location

Because the municipality of Zona Bananera is in a low altitude region, the temperatures vary according to the altitude of the territory (temperature zones), and this municipality, having heights of less than 1,000 m.a.s.l., has a temperature behavior corresponding to a warm temperature zone, in which the average annual temperature is higher than 24 °C. According to IDEAM, the maximum average temperature of the municipality of Zona Bananera is 28 °C, remaining almost constant throughout the municipality, as well as a minimum of 24 °C (Municipio Zona Bananera, Plan básico de ordenamiento territorial, 2001).

As it can be seen in Figure 1, in the first vegetative growth stage of eggplant, which lasted approximately one month, temperatures were above 15 °C (the temperature that is limiting the crop); therefore, no event caused growth retardation. Likewise, the same occurred with the maximum temperatures, which did not exceed 35 °C, being optimal for the crop. Similarly, this also occurred with the relative humidity showing values between 60 and 100%, typical of the humid Caribbean region.

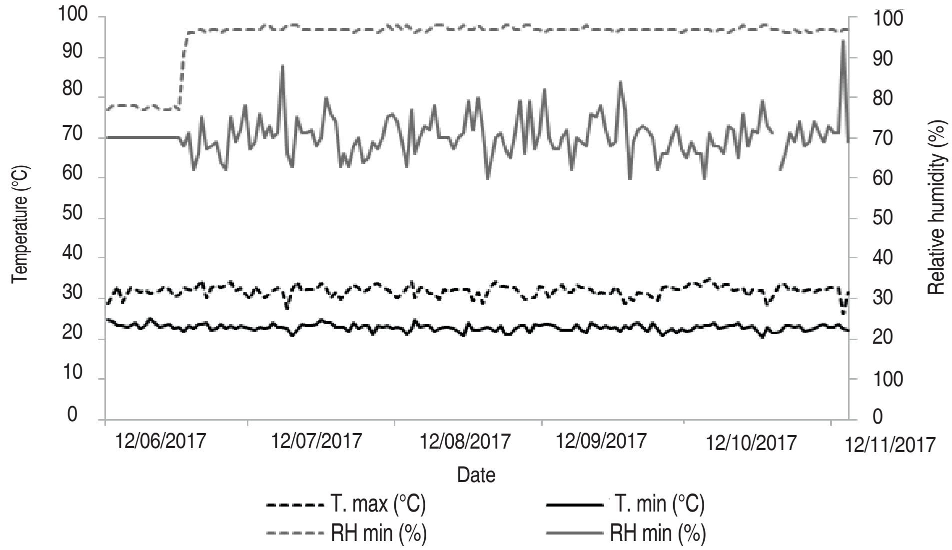


**Figure 1.** Characterization of temperature (°C) and relative humidity (%) during the phenological cycle of eggplant in Zona Bananera, the Caribbean region, Colombia.

Regarding the presence of diseases, even though the environment was suitable for the establishment of some limiting pathogens for eggplant such as *Sclerotium rolfsii*, its incidence was very low with 0.04% of infected plants (17 plants). In Figure 2 and Figure 3, precipitation throughout crop phenology was higher than the reference evapotranspiration (Eto) and much higher than the Eto/2, which indicates that there were no critical drought scenarios.

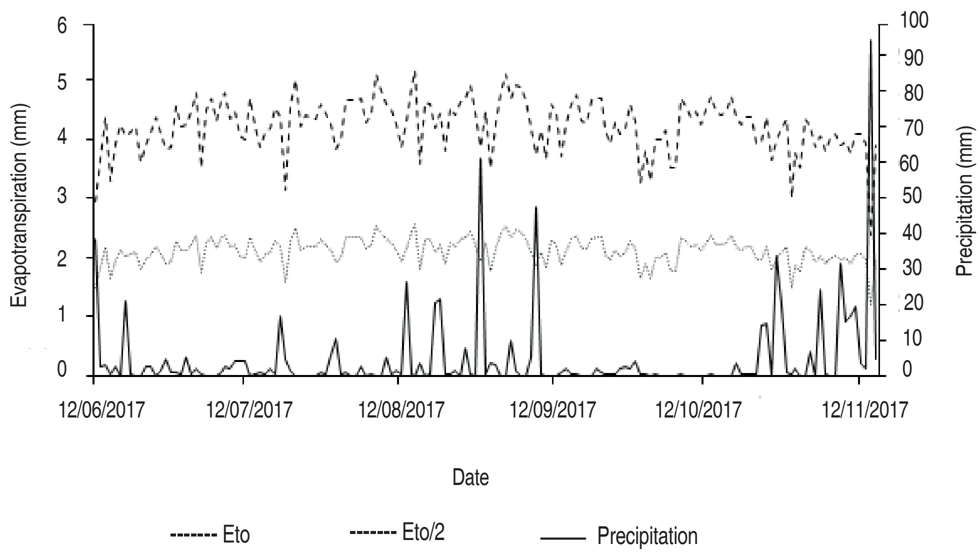


**Figure 2.** Precipitation and reference evapotranspiration during the phenological cycle of eggplant in Zona Bananera, the Caribbean region, Colombia.

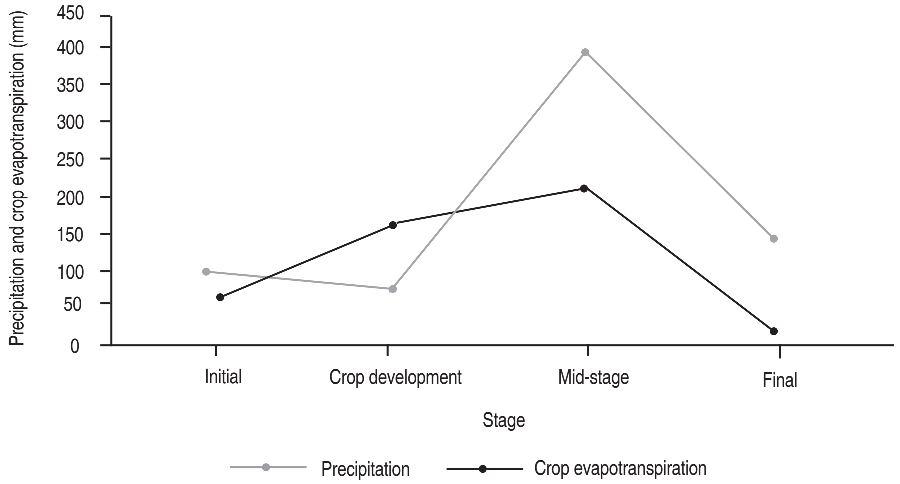


**Figure 3.** Precipitation and crop evapotranspiration during the phenological cycle of eggplant in Zona Bananera, Caribbean region, Colombia.

In the same way, during the four phenological crop stages, total precipitation was similar to crop evapotranspiration, which indicates that, in general terms, the water requirements were supplied through precipitation in the area and the shortage was obtained through irrigation. Moreover, the evapotranspirative demand of the crop during the four phases was 560 mm. However, the soil was monitored with tensiometers, one of 0-20 cm and another of 20-40 cm, to maintain soil humidity at field capacity.

**Accumulation of degree days in 15 eggplant accessions**

The accumulation of degree days for 15 eggplant accessions reached values from 892.14 to 1,077.71 °C (Table 2), with which we could select early or late accessions for these climatic conditions.

**Table 2.** Accumulation of degree days in 15 eggplant accessions for the phenological stages of leaf development, appearance of the floral organ, flowering, and fruit formation.

| Accession | Degree days (°C) | | | |
|---|---|---|---|---|
| | Leaf development | Appearance of the floral organ | Flowering | Fruit formation |
| C003 | 399.56±42.85 | 478.97±79.24 | 733.89±0 | 952.88±0 |
| C006 | 408.06±29.68 | 458.61±28.54 | 674.20±82.31 | 931.64±42.47 |
| C011 | 384.73±42.35 | 447.19±48.58 | 733.89±0 | 931.64±42.47 |
| C014 | 363.55±0 | 452.80±38.77 | 679.44±38.16 | 910.40±49.05 |
| C015 | 372.58±18.05 | 431.78±35.01 | 695.51±45.48 | 931.64±42.47 |
| C025 | 408.06±29.68 | 452.80±38.77 | 752.24±36.72 | 1,077.71±97.77 |
| C026 | 363.55±0 | 411.28±13.42 | 720.48±53.29 | 955.91±74.39 |
| C027 | 402.25±28.03 | 423.43±19.85 | 733.89±0 | 952.88±0 |
| C028 | 399.56±42.85 | 444.45±33.76 | 733.89±0 | 1,019.86±77.35 |
| C032 | 393.23±34.27 | 426.00±48.11 | 733.89±0 | 1,019.86±77.35 |
| C035 | 387.41±29.14 | 516.02±93.47 | 695.51±45.48 | 910.40±49.05 |
| C036 | 408.59±35.99 | 473.16±85.34 | 711.57±44.63 | 952.88±0 |
| C040 | 381.60±20.84 | 423.43±19.85 | 667.95±83.71 | 892.14±76.21 |
| C042 | 378.39±29.68 | 417.61±23.18 | 711.57±44.63 | 931.64±42.47 |
| C049 | 378.39±29.68 | 463.89±67.67 | 733.89±0 | 952.88±0 |

On the other hand, accessions C040, C014, and C035 were those that produced fruits in less time with accumulated values in degree days of 892.14±76.21 and 910.4±49.05, respectively. This behavior is of great importance since these accessions were the ones that had the highest yields with values above 8,000 gram per plant, for a planting density of 10,000 plants per hectare, 80 t ha$^{-1}$ were obtained, i.e., a significantly higher value than the national yield, which is around 16 t ha$^{-1}$ (Araméndiz *et al* 2008b,c) (Figure 4). The opposite occurred with genotypes C015, C011, C032, and C025; the last two are the latest to start producing fruits suitable for harvesting, as observed in the degree days accumulation for this phenological phase (Table 2). However, no significant differences (*P*>0.05) were found between accession for any of the phenological stages evaluated, which gives indications that those that begin to produce earlier fruits will be those that will have the highest final yields.

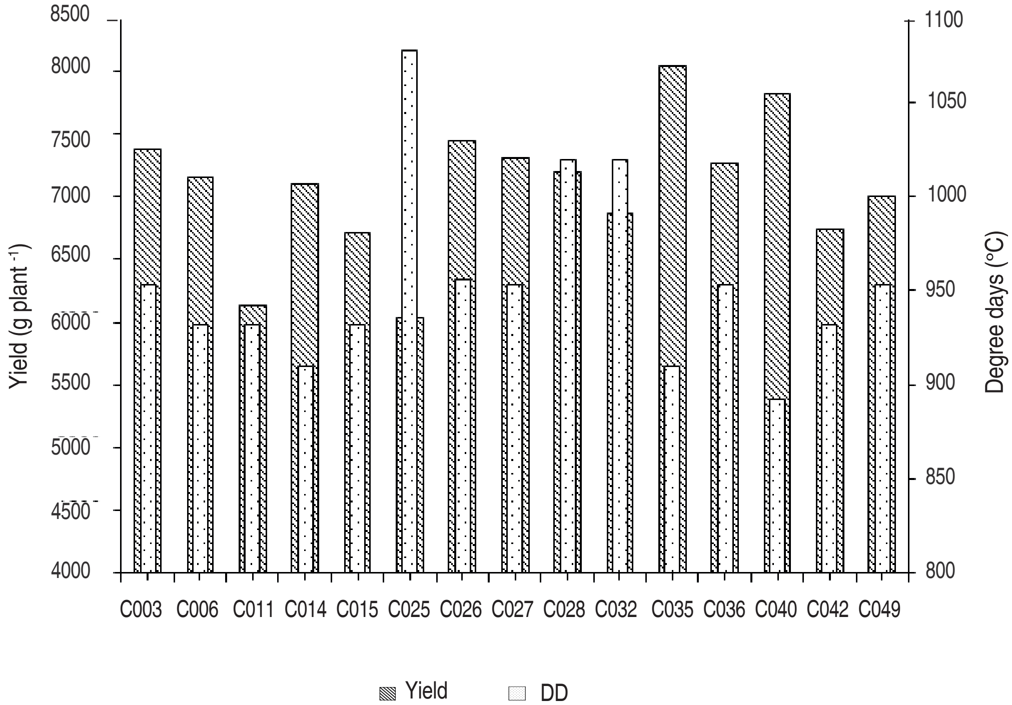


**Figure 4.** Yield (grams per plant) and degree days (°C) to fruits development suitable for harvesting in 15 eggplant accessions.

Accessions C028, C032, and C025, were the latest ones with more than 1,000 °C accumulated to produce fruits suitable for first harvest (Table 2); moreover, these had a strong correlation with degree days to flowering, as observed in the multivariate biplot with the largest and most significant vectors for component 1 (Figure 5).

The accumulation of degrees days was similar for the 15 accessions in the first phenological stage (vegetative growth) with average values of 388.66 °C (Table 2); this effect was because this phenological stage was measured until the plants had produced nine leaves. Furthermore, it should be noted that the maximum vegetative development rate in the crop is reached when flowering begins.

An opposite behavior was reported by Rouphael *et al.* (2010) with a highly positive relationship between the number of leaves and the thermal time during the experiment in three aubergine cultivars. The response of the numbers of the leaves to the thermal time was curvilinear, with values 450 degree days. After 450 degree days, the increase in the number of leaves per plant was linearly related to the thermal time. However, Maynard and Hochmuth (2007) report for aubergine a base temperature of 15.6°C and a maximum temperature of 35 °C. These results could be useful to generate a model for the leaf area development and finally, a cultivation growth model for this crop.

This behavior is since crop development depends to a large extent on the temperature and the photoperiod; meanwhile, in the tropics, the temperature is the environmental variable with the greatest influence on crop development. The regulating role of temperature is through its action on the enzymatic reactions that directly or indirectly intervene in development processes (Baker and Reddy, 2001).

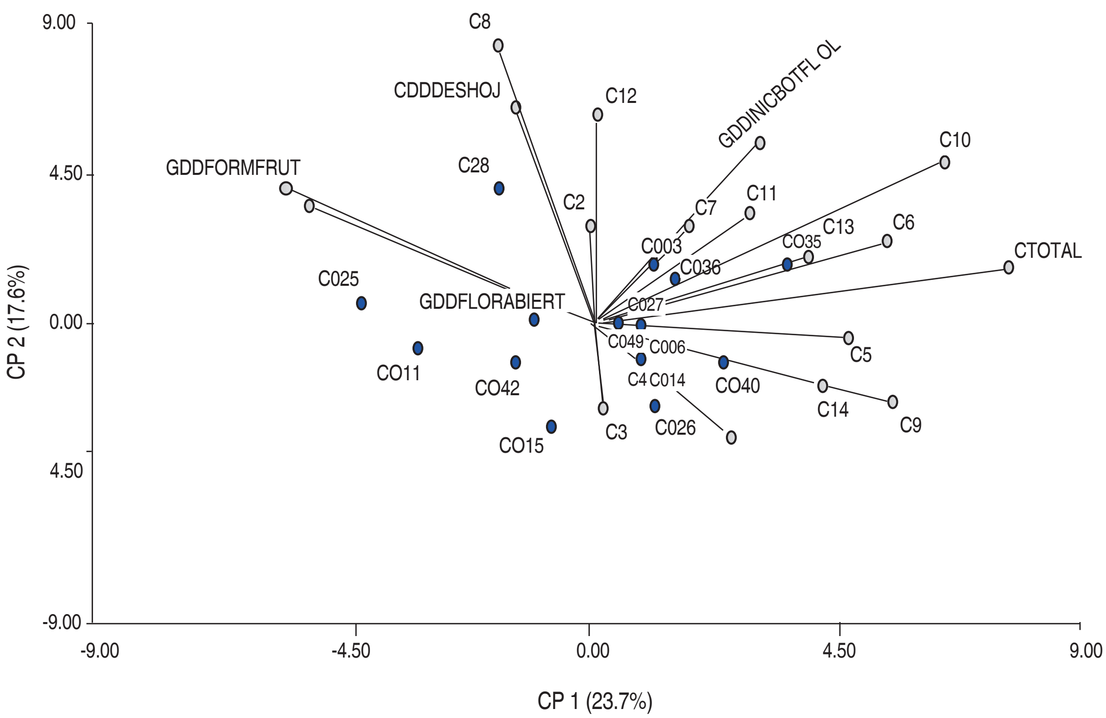


**Figure 5.** Double representation of 15 eggplant accessions with the variables evaluated.

This behaviour is explained by Martín and Jerez (2017), who mentions that temperature is a basic factor that influences the development rate, particularly from emergence to flowering and maturity. Many species are adapted to particular temperature ranges; thus, as the environmental temperature or mean temperature (Tm) decreases, its development rates are reduced to such an extent, that if the temperature falls to the limit, the development stops. This temperature limit is called the base temperature (Tb). On the contrary, as the temperature increases, development rates increase to an optimum temperature (To), from which they decrease and eventually stop at their maximum development temperature (Tmax).

For eggplant cultivation limiting temperatures are those below 15.6 °C and above 32 °C, finding the optimum at 22 °C (Maynard and Hochmuth, 2007; Uzun, 2007). Hence, the climatic offer of the region did not have stressful temperatures for the crop, and it had a rather additive effect, causing some accessions to begin their production in less thermal time or days.

In agriculture, the combination of time and temperature comprises the so-called thermal time (TT) or also known as the sum of heat, degree day, growing degree days, or physiological time. This approach has been used in numerous studies to describe the phenology of crops like corn (*Zea mays* L.), sugar cane (*Saccharum* spp.), melon (*Cucumis melo* L.), chickpea (*Cicer arietinum* L.) and cotton (*Gossypium hirsutum* L.) (Baker and Ready, 2001).

Likewise, Sadek *et al*. (2013) and Fealy and Fealy (2008), specify the importance of heat requirements on eggplant cultivation since these can be quantified and associated with the time when the fructification stage begins. This crop will not continue growing if the average temperature is below the base (12 °C), and the degrees of heat provides a reasonable estimate of the heat energy available for plant growth representing an important factor during the crop cycle.

On this aspect, Uzun (2007) points out a behavior similar to the one reported in this research, in which the heat requirements were different between varieties of eggplant. Meanwhile, these authors show a curvilinear effect of the variables associating yield with the temperature factors and light intensity, the optimum being 17-20 °C and 7-17 MJ $m^{-2}$ $d^{-1}$ for temperature and radiation, respectively; above these values number of fruits per plant as well as average fruit weight decreased, and therefore, yield.

Nevertheless, Kürklü *et al.* (1995) conducted a study to define the response of eggplant at different temperatures in controlled greenhouse environments. The temperatures established in the greenhouses were 14, 18, 22, 26, and 30 °C. Vegetative growth was much higher as the temperature increased to a point where the growth decreased, meanwhile fruit development (size, fruit weight, and yield) had an opposite behavior, increasing their values as the temperature increased to 30 °C. The total harvested yield of eggplant at different temperatures had the highest fruit yield at 19, and 16 °C (approximately 33, 32, and 28 kg, respectively), and plants that grew at 26 and 30 °C produced much less than plants grown at lower temperatures (18 and 15.5 kg, respectively). Therefore, the optimum temperature for fruit production in eggplant is approximately 22 °C.

**Multivariate analysis by principal components**

Authors, as Pla (1986) mentions that it is not valid to evaluate only one component to explain data variability. Because of, it was found that only 23.7% synthesize the variability in the first component; further, applying the criterion of selection of principal components of Kaiser (Pla, 1986), the first three components were used obtaining a value of 54%.

In Figure 5 accessions C032, C025 and C028 have similar behavior and are associated with the variables degree days to leaf development, floral bud starting and flowering; meanwhile, the latter was more associated with the eighth harvest and degree days to leaf development. Similarly, a second group was formed with accessions C011, C042, and C015. In the opposite axes, three large groups are observed, accessions C003, and C036 associated mainly with harvests 6, 7, 10, 11 and 13; whereas, accessions C027, C049, C006, and C014, were associated with harvests 3, 4, 5, 9 and 14; and finally, accessions C040, C035 and C026 showed a strong association to the total variable yield.

García and López (2002) explain that this behavior occurs when plants are exposed to thermal variations on the physical environment, and these have great influence on the different physiological, biochemical and metabolic processes leading to their growth and development; furthermore, these variations determine the leaf area and the accumulation of dry matter during the biological cycle of the plant. Additionally, growth and development are undoubtedly affected by factors other than temperatures, such as the flow and duration of photosynthetically active radiation, the availability of nutrients and water, and the loss of photosynthetic tissue.

In a production system, which is developed under protected environments and where there is permanent availability of nutrients and water, other bioclimatic factors (i.e., temperature, luminosity, and $CO_2$ concentration) can be exploited to increase yield or improve the quality of the final product. Optimizing the conditions that determine maximum crop yield with a minimum expenditure of energy in the systems cultivated in open fields, are fundamental to generate economic and environmentally sustainable technology.

In general terms, eggplant is a plant that requires an adequate temperature during its cultivation to reach yields above the national average (16 t $ha^{-1}$) (Araméndiz, 2008b, c) and fruit quality. Eggplant has non-climacteric fruits (Arguedas-García, 2017). Its optimum vegetative growth occurs with temperatures between 27 and 32 °C during the day, and between 21 and 27 °C during the night, although fruit growth is favored between 22 and 26 °C (Passam and Karapanos, 2008).

Day temperature should oscillate between 25 and 30 °C together with good luminosity to satisfy the needs of the plant, and with it, greater efficiency in the photosynthesis. It should be carried out in a way that its products, when being sent to other parts of the plant, are not used entirety for respiration. It is achievable with better night temperatures (14-16 °C), which are favorable for plant and fruit growth.

## CONCLUSIONS

The accessions that initiate fruit production suitable for harvest in less time require fewer days to initiate this phenological phase, and therefore, generate higher productivity so that some early accessions with high yields can be identified based on degree days. The Caribbean region is suitable for the establishment of eggplant since there were no events with limiting temperatures for this species, which may cause growth retardation, obtaining for all accessions a density of 10,000 plants per hectare and yields above 64 t $ha^{-1}$. The accessions C035 and C040 had an average yield higher than the national average with values of 83.75 and 84.86 t $ha^{-1}$, so these have been identified as future varieties to be produced in the Caribbean region, given that additionally their fruit color, size, and shape characteristics are widely accepted in regional markets.

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