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Growth dynamics and yield of eggplant (*Solanum melongena* L.) modeled with logistic curves

Dinámica de crecimiento y rendimiento de la berenjena (*Solanum melongena* L.) modelados mediante funciones logísticas

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ABSTRACT

Eggplant is a traditional horticultural crop in the Colombian Caribbean; therefore, a descriptive and quantitative study was conducted to characterize its growth dynamics, biomass accumulation, and yield. The study used the Early Long Purple genotype, planted at 1.50 m between rows and 80 cm between plants, and included 960 replications over an area of 1,152 m². The objective was to characterize and quantify growth variables, dry matter accumulation, and yield in order to describe growth dynamics and identify key stages for agronomic management of the crop. The variables evaluated from transplanting until 135 days later included: plant height, main stem diameter, number of leaves, leaf area, total dry matter per plant, and yield. The measurements obtained were fitted to a logistic model using the PROC NLIN procedure of SAS software (Statistical Analysis System). Descriptive statistics, including mean, standard deviation, coefficient of variation, maximum value, and minimum value, were obtained. Coefficients of determination greater than 90% were found, with sigmoidal growth patterns. The maximum values observed were: 68.33 ± 0.81 cm for plant height, 10.85 ± 0.49 mm for stem diameter, 79.27 ± 1.13 leaves per plant, 3,392.10 ± 0.78 cm² of leaf area, 46.68 ± 1.25 g of total dry matter per plant, and a yield of 63.64 ± 0.05 $t \cdot ha^{-1}$. In conclusion, the greatest vegetative growth occurred between 30 and 60 days after transplanting (DAT). Therefore, this period represents an optimal window for implementing agronomic management practices aimed at maximizing dry matter accumulation and promoting balanced crop growth and development.

Keywords: biomass production; crop physiology; dry matter content; horticultural crops; mathematical models; plant growth analysis

RESUMEN

La berenjena es un cultivo hortícola tradicional en el Caribe colombiano; por lo tanto, se llevó a cabo un estudio descriptivo y cuantitativo para caracterizar su dinámica de crecimiento, acumulación de biomasa y rendimiento. El estudio utilizó el genotipo Early Long Purple, plantado a 1,50 m entre hileras y 80 cm entre plantas e incluyó 960 repeticiones en un área de 1.152 m². El objetivo fue caracterizar y cuantificar las variables del crecimiento, la acumulación de materia seca y el rendimiento del cultivo. Las variables evaluadas desde el trasplante hasta 135 días después incluyeron: altura de planta, diámetro del tallo principal, número de hojas, área foliar, materia seca total por planta y rendimiento. Las mediciones obtenidas se ajustaron a un modelo logístico utilizando el procedimiento PROC NLIN del software SAS (Statistical Analysis System). Se obtuvieron estadísticas descriptivas, incluyendo media, desviación estándar, coeficiente de variación, valor máximo y valor mínimo, empleando una hoja de cálculo de Excel. Se encontraron coeficientes de determinación mayores al 90%, con patrones de crecimiento sigmoidales. Los valores máximos observados fueron: 68,33 ± 0,81 cm para la altura de planta, 10,85 ± 0,49 mm para el diámetro del tallo, 79,27 ± 1,13 hojas por planta, 3.392,10 ± 0,78 cm² de área foliar, 46,68 ± 1,25 g de materia seca total por planta y un rendimiento de 63,64 ± 0,05 t·ha⁻¹. En conclusión, el mayor crecimiento vegetativo ocurrió entre 30 y 60 días después del trasplante (DDT). Por lo tanto, este período es óptimo para implementar prácticas de manejo que promuevan una mayor acumulación de materia seca y un crecimiento y desarrollo óptimos.

Palabras clave: análisis del crecimiento vegetal; contenido de materia seca; cultivos hortícolas; fisiología de cultivos; modelos matemáticos; producción de biomasa.

INTRODUCTION

The eggplant (*Solanum melongena* L.), also known as aubergine and brinjal, is a solanaceous vegetable whose fruits have global nutritional, medicinal, and economic importance (Caruso *et al*., 2017). It is consumed cooked, fried, roasted, as chips or powder, in various culinary preparations such as "vegetable caviar," salads, stews, soups, desserts, juices, pizzas, empanadas, moussaka, and lasagna, among others (Barraza, 2022). Every 100 grams of edible portion provides only 25 calories, 48.26 mg of phenolic compounds, 26.6 mg of Phosphorus (P), 198.5 mg of Potassium (K), and 0.062 mg of Copper (Cu) (Raigón *et al*., 2008; Naeem & Uğur, 2019). The powder is used as a dietary supplement for its antioxidant content, as well as in baking, bread-making, cookies, tortillas, energy bars; it is also mixed with juices or water. In traditional medicine it is used in infusions, capsules, or supplements for its anti-inflammatory, anticancer, digestive health, cholesterol-lowering, and antihypertensive properties (Quamruzzaman *et al*., 2020; Majeed, 2024). For all these important characteristics, eggplant continues to increase its relevance among vegetables due to its nutraceutical value (Cardoso *et al*., 2008). Beyond its recognized nutritional and functional properties, eggplant also plays an essential role in the daily diet of the Colombian Caribbean population, where it is consumed regularly as a staple vegetable in a wide variety of traditional dishes.

In the Colombian Caribbean region, and particularly in the middle Sinú River valley, eggplant cultivation represents a traditional component of local agricultural systems, with a productive history spanning several decades. Although eggplant is not a recently introduced crop in the region, its agronomic management is still largely based on empirical practices transmitted across generations, with limited support from systematized technical information generated under local conditions. In this context, the Faculty of Agricultural Sciences of the University of Córdoba, through its Agronomic Engineering program, has historically played a key role in professional training and in the generation of applied knowledge aimed at strengthening regional production systems. Nevertheless, despite the agronomic, cultural, and socioeconomic relevance of eggplant in the middle Sinú Valley, there is a limited quantitative characterization of its growth, biomass accumulation, and yield, particularly for commonly cultivated genotypes such as Early Long Purple, under the prevailing edaphoclimatic conditions. This lack of locally generated information constrains the optimization of crop management practices and supports the need for studies that describe and model the physiological behavior of eggplant in a representative area of the Colombian Caribbean.

According to FAOSTAT (FAO, 2025), global eggplant production in 2023 was 60,793,941.25 tons, with China producing 39,244,168.23 tons, which accounts for 65%. In Colombia, 14,918.2 tons were produced, mainly in the Caribbean region. In this region, 82% of producers are dedicated to its cultivation (González Bell, 2018), primarily in the departments of Atlántico (Adarraga Mejía *et al*., 2022), Bolívar, Sucre, Magdalena, and Córdoba. In Córdoba, the middle Sinú Valley area is one of the most important and representative zones of its production system, as it is part of its traditional agriculture, food customs, and cultural roots, mainly influenced by Syrian Lebanese cuisine (Barraza, 2022), which uses its fruits with a culinary versatility characteristic of towns such as Sahagún, Lorica, Cereté, and Montería.

In Montería, the main eggplant-producing areas are located in the district of Aguas Negras. In Cereté, the main producing areas are found in the towns of La Coroza, La Pozona, Martínez, Mateo Gómez, Pelayito, Severá, Berenjena, and El Retiro de los Indios. These areas supply markets year-round, mainly in Montería, Cereté, Sahagún, Sincelejo, Cartagena, and Barranquilla (Barraza, 2022), where eggplant is valued as a daily-use vegetable in the preparation of mainly fried foods, scrambles, salads, soups, juices, and rice dishes.

In the middle Sinú Valley region, eggplant crops are traditionally cultivated as part of a peasant economy system managed by small-scale farmers who generally lack specialized technical assistance. Agronomic management practices are carried out manually, relying on traditional knowledge passed down through generations. Among the most common practices are transplanting, hilling, weeding, fertilization, and controlling cultural pests and diseases (Cardona, 2018). Supplemental irrigation is generally not applied, with crops mainly established under rainfed conditions (2,255 mm of annual rainfall), which contributes to both the sustainability and profitability of production (Barraza, 2022). Among the genotypes cultivated, the local variety Criolla Lila and the Early Long Purple variety stand out. The latter has gained attention from farmers in recent production cycles due to its dark purple fruits, which are the most popular (Khandaker *et al*., 2020). Additionally, this variety presents characteristics that make it attractive for both domestic and export markets, such as medium size, slender shape, and few seeds, which reduces waste during preparation. This contrasts with other genotypes that produce larger fruits with numerous seeds, which are generally less desirable to consumers and not fully utilized.

Among the main topics that justify research for a better understanding of eggplant cultivation, particularly for the Early Long Purple genotype, is the study of its growth process, which can be understood through the quantification of morphometric variables over time, such as plant height, main stem diameter, number of leaves, and total dry matter accumulation (Sathe & Raskar, 2022; Abrham & Shumbulo, 2024; Mostfa *et al*., 2025). These variables can provide valuable insights for monitoring whether crop growth is developing according to the expectations established by growth models, from which key agronomic management aspects are derived to better harness the crop's potential and achieve maximum photosynthate production. If the mathematical models obtained show a high degree of fit between the observed and estimated values of the studied variables, they can be considered suitable for analyzing the quantitative growth pattern as a reliable indicator of net photoassimilate accumulation over time. These photoassimilates are decisive in plant metabolism for achieving optimal yield, as lower amounts lead to reduced dry matter, which inhibits the growth rate and consequently results in lower production and quality (Maghfoer *et al*., 2014; Khandaker *et al*., 2020; Abrham & Shumbulo, 2024).

In this context, the growth analysis approach provides a consistent framework to interpret the factors influencing net photoassimilate accumulation throughout the crop's biological cycle (Gardner *et al*., 1990). This method, widely applied in agronomic research, enables the quantification of plant growth dynamics through morphometric variables and their adjustment to nonlinear models, such as Gompertz, Richards, or Logistic curves (Hsieh *et al*., 2021; Li *et al*., 2022), which describe biological growth patterns with high precision and predictive capacity (Li *et al*., 2024).

Based on the above and considering the widely reported usefulness of mathematical models for understanding the growth cycle and crop responses to their environment (Hsieh *et al.*, 2021), it is possible to develop objective scientific tools capable of effectively predicting critical agricultural dates such as sowing and harvesting. This will facilitate the planning of agronomic management practices and enhance the efficiency of the eggplant crop production system.

Therefore, considering that eggplant is the most representative crop of the peasant economy in the Department of Córdoba, and in line with Adarraga Mejía *et al*. (2022), it holds significant cultural, economic, and nutritional importance in the Colombian Caribbean, as it forms part of the population's daily diet. Its productivity is steadily increasing, and it is cultivated year-round, generating significant weekly income for producers. The present study hypothesized that the growth variables, dry matter accumulation, and yield of eggplant follow a sigmoidal pattern that can be accurately described by a logistic model under the conditions of the middle Sinú Valley, thereby contributing to a better understanding of the crop in this region.

MATERIALS AND METHODS

Experiment location

To determine the growth and yield of eggplant, a descriptive and quantitative experiment was conducted between August 2023 and February 2024 at the experimental vegetable crop field of the Faculty of Agricultural Sciences, University of Córdoba, Colombia. The site is located at 8°31'N, 75°58'W, at an altitude of 13 m a.s.l., corresponding to a Tropical Dry Forest (TDF) according to the Holdridge life zone classification, with an average annual temperature of 28°C and mean annual precipitation of 1,230 mm (Climate Data, 2025).

Plant material and studied variables

Seeds of the Early Long Purple genotype were sown in seedling trays filled with peat substrate, producing seedlings (experimental units) 40 days after sowing (DAS). They were transplanted completely at random in the cultivation field to avoid positional bias, with a spacing of 1.50 m between rows and 80 cm between plants. A total of 960 individual plants (replications) were used, considered as replicates of the single treatment under study. The total experimental area was 1,152 m².

Agronomic management practices

Irrigation and manual weeding were performed as needed until harvest. Fertilization requirements were met according to soil analysis, which showed a silty clay loam (SCL) texture, pH 6.47, organic carbon 2.54%, P 26.7 mg kg^{-1}, and K 0.707 cmol kg^{-1}. Fertilizer sources used were urea, diammonium phosphate, and potassium chloride, applied in three stages: transplanting (40 DAS), beginning of flowering (70 DAS), and onset of fruiting (80 DAS).

Studied variables

From transplanting to 135 days afterward, the variables shown in Table 1 were measured every 15 days, recording the average value obtained from four marked experimental units in the three central rows of the crop.

Table 1. *Measured variables*

Variable	Unit	Method used
Plant height	cm	Measured with a tape measure from the base to the apex of the main stem.
Main stem diameter	mm	Measured 2 cm above soil using a digital Vernier caliper (0.01 mm precision).
Number of leaves	count	Count of expanded, functional leaves per plant (excluding senescent/damaged).
Leaf area	cm^2	Digital processing using scanner (Epson V850 Pro) and DDA software (Ferreira *et al*., 2017).
Total dry matter per plant	g	Oven-dried at 70 °C until constant weight, then weighed.
Yield	$t \cdot ha^{-1}$	Harvested and weighed; extrapolated to one hectare.

Statistical Analysis

Using SAS software, the nonlinear regression procedure PROC NLIN was applied to fit the growth models using the logistic model (equation 1):

$$y = \frac{A}{1 + B \cdot e^{-cx}}$$

y : response variable as a function of *x*
x : time (days after transplanting)
A : asymptote, value of *y* when *x* tends to infinity
$B \cdot e^{-Cx}$: damping factor
B : corresponds to an amplitude factor; it has no biological meaning and only applies at the initial time when *x* = 0
C : stability factor related to the value of *x*
e : Euler's number

The logistic growth model was applied to the variables plant height, stem diameter, number of leaves, leaf area, total dry matter, and yield to describe their growth dynamics and identify their inflection points, which indicate the stage of maximum growth rate and serve to characterize the development pattern of the crop. Model parameters (A, B, C) were estimated through nonlinear regression (PROC NLIN, SAS) and interpreted to characterize asymptotic behavior, initial conditions, and growth rate for each variable.

Using an Excel spreadsheet, descriptive statistics were obtained for each variable to characterize the behavior of the morphological growth and yield variables evaluated, including the mean ($\bar{x}$), standard deviation (σ), coefficient of variation (CV), maximum value, and minimum value.

RESULTS

The results obtained for the morphometric growth variables in the cultivation of Early Long Purple eggplant showed a sigmoid graphical representation fitted to the logistic model, which reflects the vegetative growth pattern of the plant and its structures, with coefficients of determination above 90% (Table 2), which provided a high degree of fit between the observed and estimated values. This makes them suitable for analyzing the quantitative pattern of this biological phenomenon as an indicator of net photoassimilate accumulation over time.

The evaluation intervals were defined based on the inflection points identified in the logistic growth curves and the observed changes in growth rates. These ranges

(0–15, 15–45, and 45–135 DAT) correspond to the physiological phases of establishment, active growth, and deceleration of the crop. Although numerical differences between consecutive intervals were small in some cases, this division allowed for the identification of relevant physiological trends and facilitated the interpretation of the logistic model.

Table 2. *Logistic models of growth and yield variables of eggplant cultivation*

Variable	Logistic model	R^2
Plant height (cm)	$y = 63.8398/(1+8.4232 \cdot e^{-0.0609})$	0.99
Stem diameter (mm)	$y = 10.9273/(1+3.2486 \cdot e^{-0.0457})$	0.99
Number of leaves	$y = 79.7524/(1+23.3995 \cdot e^{-0.0611})$	0.99
Leaf area (cm^2)	$y = 3393.13/(1+9.0525 \cdot e^{-0.0763})$	0.99
Dry matter per plant (g)	$y = 46.8708/(1+41.7807 \cdot e^{-0.0684})$	0.99
Yield ($t \cdot ha^{-1}$)	$y = 65.0/(1+5.1817 \cdot e^{-0.0491})$	0.99

Note. R^2: coefficient of determination

Plant height

The growth trajectory (Figure 1) revealed three main phases in the increase of plant height. The first phase, from 0 to 15 DAT, showed slow growth at a rate of 0.52 $cm \cdot day^{-1}$. The second phase, between 15 and 45 DAT, exhibited an acceleration in plant height, with rates ranging from 0.84 $cm \cdot day^{-1}$ to 0.95 $cm \cdot day^{-1}$. The third phase, between 45 and 135 DAT, was characterized by a deceleration in plant height growth, with rates progressively decreasing in the later time intervals to values below 0.95 $cm \cdot day^{-1}$. This indicates that the magnitude approached the asymptotic value of the logistic model, close to 63.7 cm (Table 3).

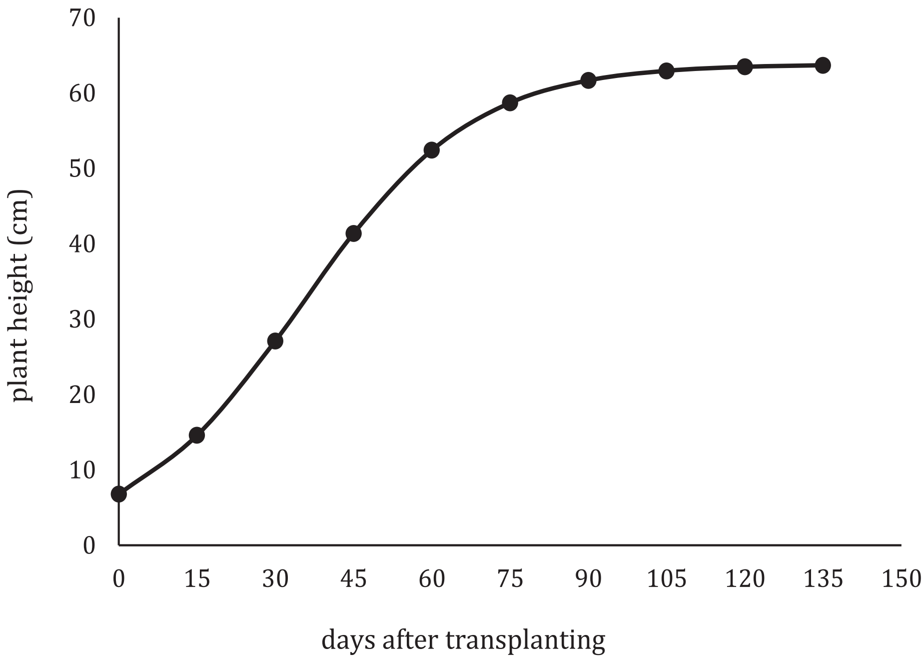

Figure 1. *Plant height growth of Early Long Purple eggplant*

Table 3. *Descriptive statistics to characterize the behavior of morphometric variables and yield of eggplant cultivation.*

Variable	$\bar{x}$	σ	CV (%)	Min value	Max value
Plant height	50.60	0.81	22.41	4.67	68.33
Main stem diameter	8.00	0.49	24.29	2.57	10.85
Number of leaves	48.54	1.13	32.19	3.27	79.27
Leaf area	2163.32	0.78	10.16	337.54	3392.10
Total dry matter	27.63	1.25	41.16	1.10	46.68
Yield	61.42	0.05	1.22	54.48	63.54

Note. $\bar{x}$: mean; σ: standard deviation; CV: coefficient of variation; Min value: minimum value; Max value: maximum value, Plant height (cm), main stem diameter (mm), number of leaves (count), leaf area (cm²), total dry matter per plant (g), yield ($t \cdot ha^{-1}$).

Main stem diameter

The growth analysis carried out with the data fitted to the logistic model showed three growth phases (Figure 2). In the initial phase, between 0 and 15 DAT, a slow and progressive increase was observed in the diameter of the main stem, with a growth rate of 0.10 $mm \cdot day^{-1}$. The second phase occurred from 15 to 45 DAT, where more active growth was recorded, with a rate of 0.12 $mm \cdot day^{-1}$.

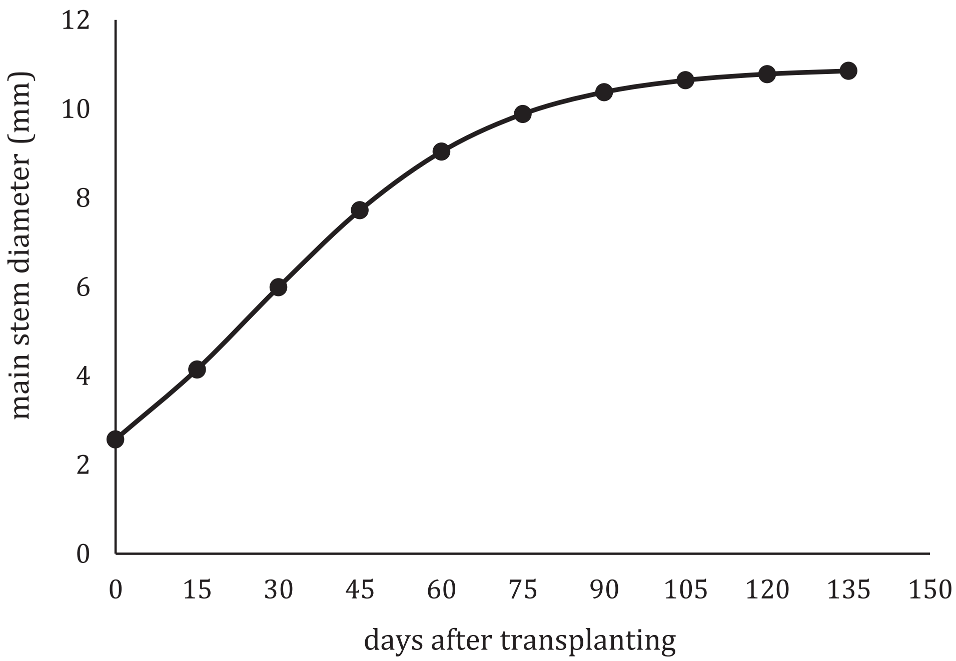

Figure 2. *Growth of the main stem diameter of Early Long Purple eggplant plants*

Subsequently, the third phase took place between 45 and 135 DAT, during which a progressive deceleration of growth was observed. The rates decreased from 0.09 $mm \cdot day^{-1}$ to 0.005 $mm \cdot day^{-1}$, approaching the asymptotic value of the model, and stabilized at around 10.85 mm (Table 3).

Number of leaves

In Figure 3, it can be observed that between 0 and 15 DAT there was an initial phase of slow growth, during which the number of leaves increased from 3.27 to 7.70, with a growth rate of 0.295 leaves·day^{-1}. Subsequently, between 15 and 30 DAT, the growth rate increased to 0.608 leaves·day^{-1}, and the number of leaves reached a total of 16.8.

From 30 to 60 DAT, a greater accumulation in the number of leaves was evident, with rates reaching up to 1.196 leaves·day^{-1}, resulting in an increase of 33 leaves during this period, in which the inflection point of the logistic model was also reached.

From 60 DAT onward, the number of leaves gradually declined, so that the growth rate dropped to 0.562 leaves·day^{-1} between 75 and 90 DAT, and continued decreasing until reaching 0.048 leaves·day^{-1} between 120 and 135 DAT. At this stage, the curve approached the asymptotic phase of the model, stabilizing at 79 leaves per plant (Table 3).

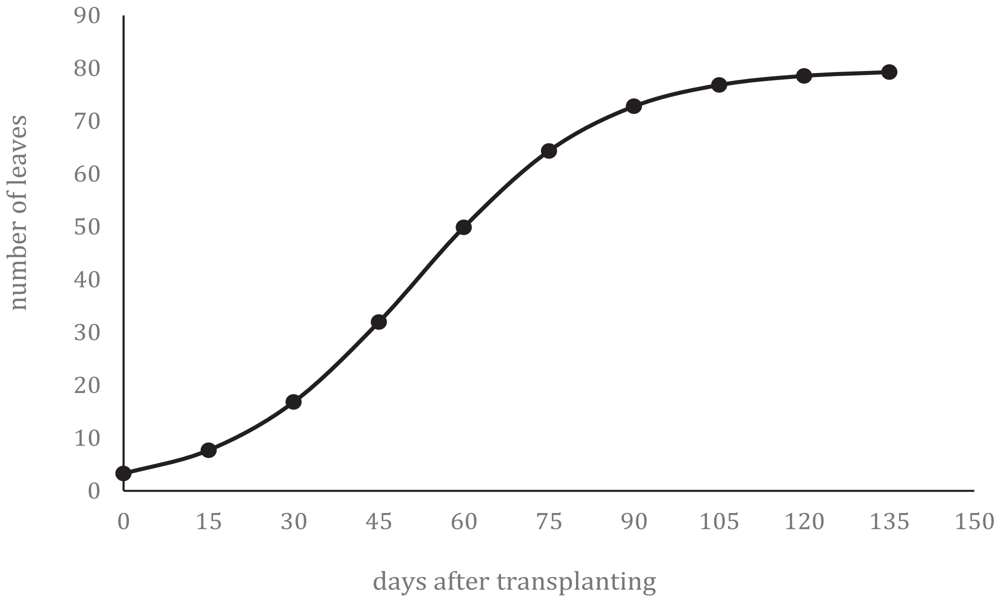

Figure 3. *Growth of the number of leaves of Early Long Purple eggplant plants*

Leaf area

In Figure 4, it can be observed that during the establishment phase, from the moment of transplanting until 30 days after, the leaf area increased from 337.54 cm² to 1769.44 cm², with an average expansion rate of 47.73 cm²·day^{-1}.

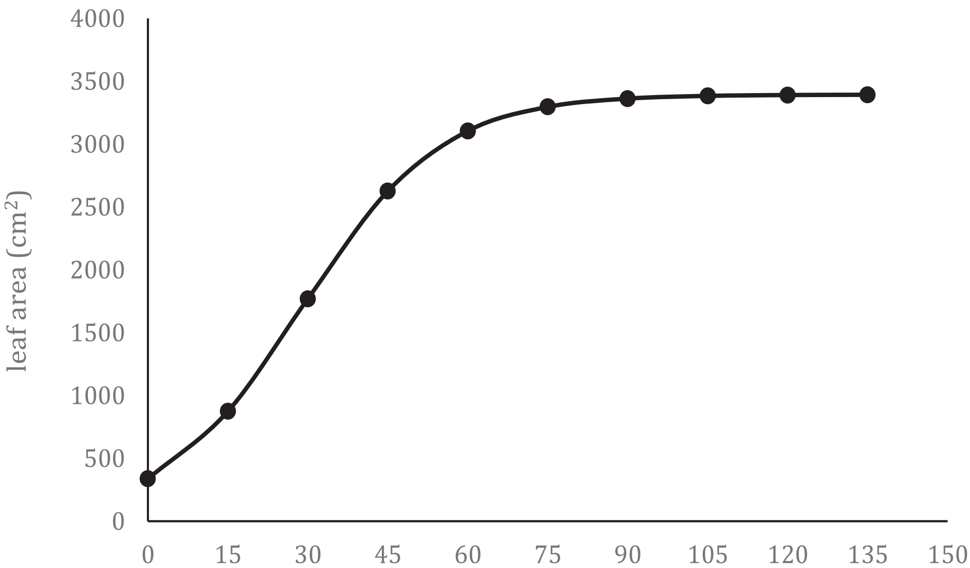

Figure 4. *Leaf area growth of Early Long Purple eggplant plants*

Afterward, up to 60 DAT, the leaf area continued to increase significantly, reaching 3104.37 cm^2; however, the average leaf expansion rate decreased slightly to 44.50 $cm^2 \cdot day^{-1}$.

Finally, from 60 to 135 DAT, leaf area growth progressively declined, showing a sustained reduction in the expansion rate, with an average value of 3.84 $cm^2 \cdot day^{-1}$. A trend toward stabilization was observed, reaching a value close to 3392 cm^2 (Table 3).

Total dry matter per plant

In Figure 5, it can be observed that during the crop cycle, a typical sequence of cumulative growth in total dry matter per plant occurred.

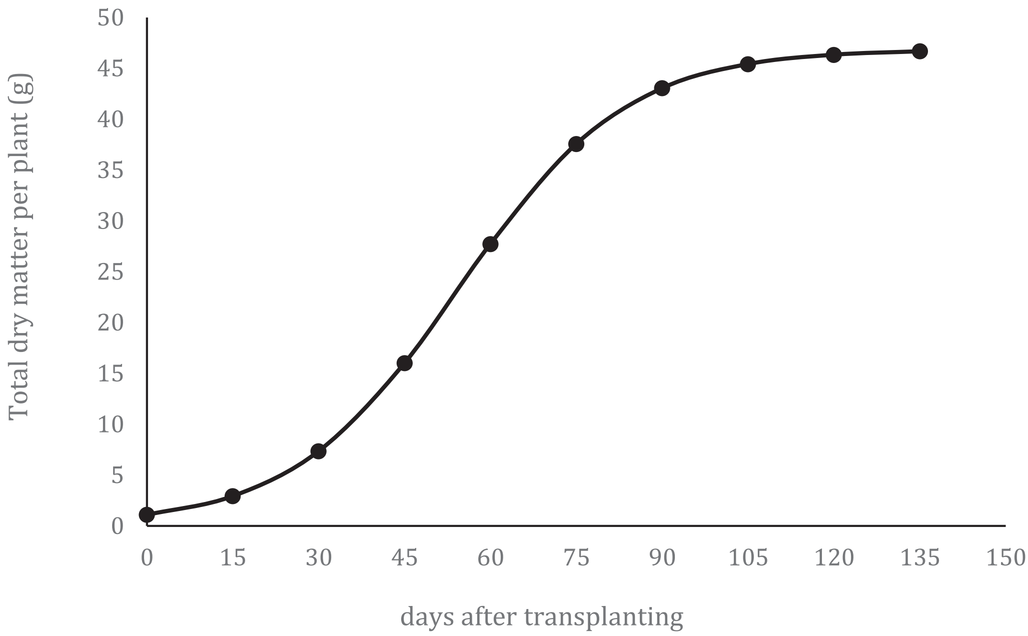

Figure 5. *Total dry matter accumulation per plant of Early Long Purple eggplant crop*

From transplanting until 30 days after, dry matter accumulation was relatively low but constant, increasing from 1.10 g to 7.36 g, with an average rate of 0.21 $g \cdot day^{-1}$.

From 30 to 60 DAT, a period of greater biomass accumulation was recorded, with a rapid increase reaching 27.74 g, at an average rate of 0.68 $g \cdot day^{-1}$.

From 60 to 135 DAT, a progressive deceleration in total dry matter accumulation per plant was observed. Although total dry matter continued to increase until reaching 46.68 g at the end of the cycle (Table 3), the average accumulation rate during this period was 0.27 $g \cdot day^{-1}$, which is lower than that observed between 30 and 60 DAT.

Yield

Figure 6 shows that eggplant yield between 67 and 130 DAT followed a progressive trajectory, with a sigmoidal growth pattern.

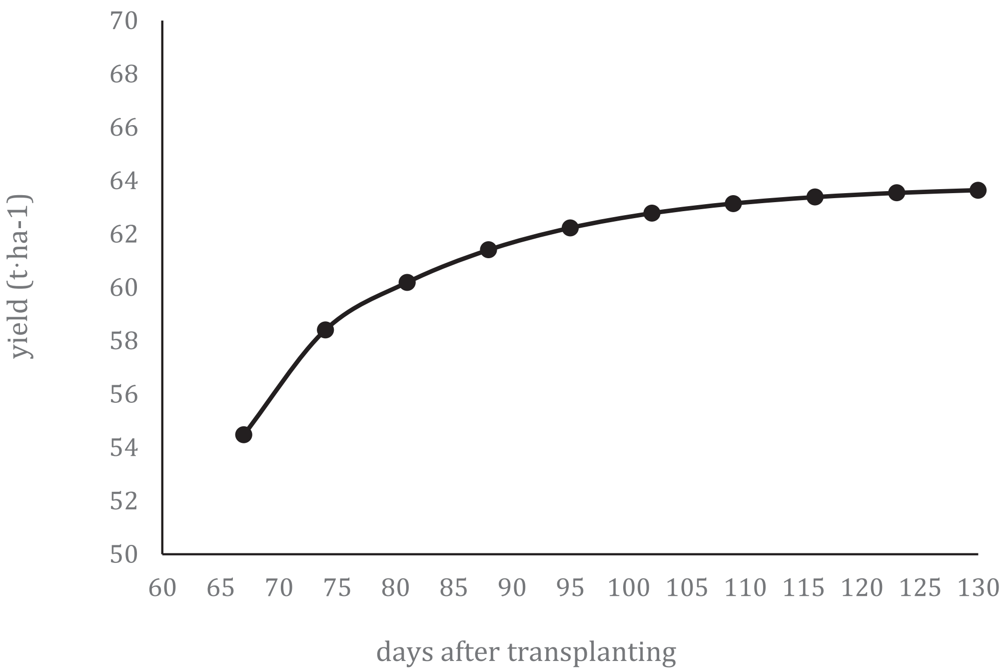

Figure 6. *Yield of Early Long Purple eggplant crop*

Between 67 and 81 DAT, yield increased from 54.48 t·ha^{-1} to 60.19 t·ha^{-1}, with an average accumulation rate of 0.41 t·ha^{-1}·day^{-1}.

During the period from 81 to 102 DAT, yield continued to increase, reaching 62.78 t·ha^{-1}, but at a more moderate rate, with an average of 0.12 t·ha^{-1}·day^{-1}.

From 102 DAT onward, a stabilization trend in yield was observed, increasing from 62.78 t·ha^{-1} to 63.64 t·ha^{-1} (Table 3), with an average rate of 0.03 t·ha^{-1}·day^{-1}.

DISCUSSION

The sigmoidal graphical representation of the variables coincided with that reported by Abbas *et al*. (2025), and it can be considered that they reflect the growth observed in the variables as a net accumulation of photo assimilates over time (Kürklü *et al*., 1998). This justifies the need, through the implementation of agronomic practices, to maximize growth under an optimal management perspective of production factors, which contributes to efficiency and increased productivity (Cemek *et al*., 2005).

Plant height

According to Lima *et al*. (2014), the growth rates observed in the different phases show that, in the first (0 to 15 DAT), the low values may correspond to the fact that the crop was beginning to recover from the change that occurred during field adaptation caused by the transplanting process, gradually consolidating its establishment. Subsequently, in the second phase (15 to 45 DAT), the growth rate increased, reaching high vegetative development, possibly due to greater physiological activity derived from photosynthesis. As noted by Aminifard *et al*. (2010) and Souza *et al*. (2018), plant height in eggplant cultivation can be considered an indicator of overall vigor, which depends on plant growth and vitality, and responds significantly to the application of nutrients, which can participate in or stimulate various vital physiological processes (Mostfa *et al*., 2025), especially nitrogen, which influences protein synthesis and the production of new plant tissues, since the energy required for nitrogen incorporation is provided by carbon metabolism. Therefore, in the initial phase of eggplant growth and establishment, it is necessary to ensure the correct and sufficient application of nutrients, so that the absence of any of them does not compromise the physiological responses of the plants (Lisboa *et al*., 2024).

In the third phase (45 to 135 DAT), the deceleration of the plant height growth rate was possibly related to the onset of senescence after fruit production (Khah, 2011; Ienciu *et al*., 2018). In this phase, no agronomic practices are carried out to obtain optimal crop physiology (Sanyang *et al*., 2025).

These results suggest that monitoring plant height during the early growth stages can serve as a reliable indicator of crop vigor and field performance, allowing for timely adjustments in fertilization and irrigation to optimize growth under field conditions.

Main stem diameter

The slow growth of the main stem diameter during the first growth phase (0 to 15 DAT), according to Lima *et al*. (2014) and Hsieh *et al*. (2021), is characteristic during crop establishment and may be associated with limited meristematic activity, which restricts biomass accumulation. In this sense, once transplanting has occurred, growth may decrease significantly due to the plant's response to environmental conditions, which influence growth rates during the recovery and adaptation period to the new establishment site.

On the other hand, the more active growth observed between 15 and 45 DAT corresponded to a vital growth phase for eggplant cultivation, given that there is a significant linear correlation between the growth of this important vegetative trait, the number of lateral branches, irrigation water, plant water consumption, fruit number, and yield (Ertek *et al*., 2006; Mirdad, 2011).

The importance of growth in the main stem diameter lies, in accordance with Lima *et al*. (2014) and Bello *et al*. (2024), in the fact that its increase can provide greater support to the eggplant plant, improve the transport of water, solutes, and nutrients, and increase sap flow, favoring photosynthesis and nutrient storage that contribute to the development of the plant and its fruits, which may lead to greater productivity and consequently, higher profitability for the producer.

Additionally, as stated by Souza *et al*. (2018), a significant interaction between nitrogen and potassium has been found in relation to stem diameter, highlighting the role of nitrogen as the second most absorbed nutrient by the eggplant crop after potassium. Its adequate supply can promote greater plant height and stem diameter due to the maintenance of proper metabolic activity for the growth process.

In the case of the third stage (45 to 135 DAT), the decrease in growth rate and its progressive deceleration were related to senescence and the completion of the biological cycle.

In practical terms, the continuous evaluation of stem diameter provides valuable information about the plant's structural development and its capacity to support fruit load, which is essential for decision-making regarding nutrient management and pruning intensity in commercial eggplant production.

Number of leaves

During the phase from 0 to 15 DAT, the limited number of leaves may be related to low meristematic activity typical of the slow initial growth, which suggests that at this stage it is crucial to consolidate the definitive and effective crop population by carrying out the necessary replanting. Meanwhile, agronomic practices that must be implemented later, once the crop has become established in the field, can be planned.

For example, fertilization should not yet be carried out at this stage, since the plant requires few nutrients, and those available in the soil are sufficient to support growth (Maghfoer *et al*., 2014).

The increase in the growth rate that occurred between 15 and 30 DAT may indicate greater physiological activity of the crop, suggesting the onset of significant leaf expansion. In this sequence, between 30 and 60 DAT, the inflection point reached in the logistic model would be showing the period of highest photosynthetic efficiency. In this regard, Maghfoer *et al*. (2014) indicate that with an increase in the number of leaves, the photosynthetic process will also increase, promoting greater growth since higher apical meristematic activity is favored. Therefore, during this period it is important to consider that, due to the high nutritional requirements of eggplant cultivation, an adequate and sufficient supply of nutrients must be provided, especially nitrogen and phosphorus, which are necessary for proper shoot development and for sustaining crop growth and yield (Hasibuan, 2023; Duri *et al*., 2025). In particular, the combination of nitrogen with substances produced by photosynthesis such as glucose, ascorbic acid, amino acids, and proteins leads to increases in dry matter accumulation, stem elongation, leaf expansion rate, number of leaves, fruit thickness, fruit weight, and yield level (Aminifard *et al*., 2010).

From 60 DAT onward, the decrease in the leaf number growth rate until stabilization may be a pivotal indicator that the crop has reached the end of its cycle and is generally characterized by a slow cellular breakdown, in which t

he processes of division and elongation are affected (Bello *et al*., 2024), ultimately leading to plant senescence.

The number of leaves, therefore, can be considered a sensitive field indicator of photosynthetic activity and nutrient balance, useful for defining fertilizer applications and adjusting management schedules to sustain vegetative growth and maximize yield potential.

Leaf area

The increase in leaf area observed between transplanting and the following 30 days shows that rapid leaf expansion is essential for the establishment of seedlings in the field, since the increase in leaf surface area enhances the area available for photosynthesis in these primary photosynthetic organs of the plant (Maghfoer *et al*., 2014) and reflects the crop's capacity to produce photo assimilates and maximize dry matter accumulation (Suminarti *et al*., 2025).

Subsequently, up to 60 DAT, the decline in the average leaf expansion rate possibly suggests that the formation of new leaves began to stabilize, giving way to a transition process toward leaf maturity.

Finally, from 60 to 135 DAT, the reduction in the leaf area growth rate suggests that the plant was approaching its limit of leaf expansion, either due to physiological or environmental constraints, or to redirect the allocation of photosynthates toward reproductive structures. According to Suminarti *et al*. (2025), this may result in reduced fresh root weight in the crop, affecting nutrient and water uptake, and interfering with the growth process, since cell division, elongation, and expansion are impaired.

From a field perspective, monitoring leaf area expansion helps determine the most efficient timing for nutrient and water applications, as maintaining adequate canopy development ensures better light interception and supports higher productivity in eggplant crops.

Total dry matter per plant

From transplanting until 30 days after, it is likely that the biomass produced was mainly allocated to the growth and development of fundamental structures for establishment, such as leaves, young stems, and roots, as it was also observed in the case of leaf area during this phase.

The rapid increase in biomass accumulation observed between 30 and 60 DAT may be related to elevated photosynthetic and metabolic activity, since such accumulation reflects the crop's ability to utilize the factors present in its growth environment and is a function of the plant organs (Suminarti *et al*., 2025). In particular, leaves play a central role, as the greater the increase in leaf area growth, the larger the photosynthetic surface available to increase the production of photosynthates that can be translocated to the organs, thereby contributing to greater dry weight accumulation by the plant (Maghfoer *et al*., 2014). As it was observed, this period coincided with the phase of sustained vegetative growth recorded for plant height, main stem diameter, number of leaves, and leaf area.

Regarding the progressive decrease in dry matter accumulation observed between 60 and 135 days after transplanting (DAT), this may indicate that the crop was undergoing a transition toward physiological maturity. The small increments in dry matter accumulation observed until the end of the cycle suggest that the carbohydrates and other photosynthates produced were being preferentially translocated to the fruits to meet their growth and development requirements (Jamili *et al*., 2022), rather than for vegetative growth. This is consistent with what is expected in determinate-growth species such as eggplant, in which biomass accumulation follows an accelerated progression up to an inflection point, after which it stabilizes as the plant matures. According to Suminarti *et al*. (2025), this stabilization occurs because carbohydrate synthesis is interrupted due to a decrease in photosynthetic rate, which was also evidenced during this period by a significant reduction in leaf number and leaf area. This reduction limits metabolic processes and light interception by the plant (Maghfoer *et al*., 2014; Merta & Raksun, 2023), which in turn decreases its capacity to produce dry matter, thereby constraining the crop growth rate.

Total dry matter accumulation serves as an integrative indicator of crop performance in the field, allowing producers to assess whether agronomic practices effectively promote biomass partitioning toward fruit and overall yield formation.

Yield

The yield trajectory of the crop coincided with that reported by Díaz-Pérez and Eaton (2015). At this stage of the crop, the importance of the descriptive and quantitative characterization of growth variables is highlighted, considering that plant height and main stem diameter showed their highest growth activity between 15 and 45 DAT, the number of leaves between 15 and 60 DAT, and leaf area and total dry matter per plant between 30 and 60 DAT. This indicates that the agronomic management conditions provided up to 60 DAT may have influenced subsequent production and yield, which explains the increase observed between 67 and 81 DAT. This finding, in agreement with Nazir *et al*. (2022) and Abbas *et al*. (2025), demonstrates that the optimal yield of eggplant reflects the growth process during the stages of planting, germination, development of the first true leaves, initial growth, and vegetative growth. These stages contribute to the efficient and active transfer of biomass to the developing fruits, suggesting high physiological efficiency in the translocation of assimilates to the fruits to increase their dry matter levels, which is desirable to occur during the early stages of development (Haggag *et al*., 2024; Staykov *et al*., 2025). Therefore, it can be inferred that the increase in fruit yield might be due to enhanced growth and yield attributes (Kuzhalarasi *et al*., 2024).

In this respect, the results obtained were consistent with the findings of Abbas *et al*. (2025), in the sense that, during the vegetative stage, the eggplant plant produced more leaves, increased in height, gained resistance through stem thickening, and initiated flowering simultaneously, leading to pollination, fruit set, and harvest. This highlights the importance of carrying out cultural practices for crop management in a timely and adequate manner, since according to Napitupulu *et al*. (2023), the low productivity of eggplant plants is closely related to suboptimal cultivation techniques. Therefore, irrigation, staking, hilling, weeding, and, in particular, the supplemental application of mineral nutrients determine the highest total yield (Napitupulu *et al*., 2023; Duri *et al*., 2025). Furthermore, as emphasized by Abney and Russo (1997) and Rehman *et al*. (2019), future studies on crop growth should consider the interaction between cultivation methods and the environment, as this may provide a better understanding of crop development and contribute to sustaining eggplant yield.

The increase in eggplant yield observed between 81 and 102 DAT, albeit at a more moderate rate, may be related to the fact that fruits had already reached commercial size, reducing the proportion of new biomass incorporated, and thus, fruit weight gain tended to stabilize. In line with Suminarti *et al.* (2025), the capacity to produce new fruits decreases when plants do not have sufficient assimilates available, which is characteristic of the continuous harvest period in eggplant. During this period, multiple harvests are carried out before physiological maturity, at different immature stages before complete seed development (Caruso *et al*., 2017).

The stabilization trend in yield observed from 102 DAT onward may indicate that the crop was physiologically reaching its maximum productive potential. According to Jamili *et al*. (2022) and Abbas *et al*. (2025), understanding this phenomenon through mathematical modeling provides a basic resource for future research on topics such as cultivation under controlled environments, postharvest, and studies on growth and yield simulation, among others, in which investment is essential to meet the increasing demand for eggplant fruits with higher yield and quality.

When considering all evaluated variables together, consistent trends were observed among them, since increases in plant height and main stem diameter were accompanied by a greater number of leaves and expansion of leaf area, which in turn supported higher total dry matter accumulation and consequently higher yield. This overall pattern indicates that vegetative growth dynamics are closely associated with yield performance in eggplant. From a practical standpoint, these results highlight the importance of ensuring balanced nutrient supply, adequate irrigation, and proper agronomic management during the early vegetative stages, as these factors determine the physiological performance and yield potential of the crop under field conditions.

As a result, it was found that the logistic model proved to be highly useful for the interpretation and the descriptive and quantitative characterization of the growth of morphological variables that supported the yield obtained in eggplant. This is because it is a nonlinear model with parameters related to biological characteristics (Hsieh *et al.*, 2021) and a sigmoidal curve trajectory. Furthermore, as noted by El-Sayed *et al*. (2021), this model allows for the objective planning of appropriate and timely management practices, which will be reflected in improved yield, also considering that the genotype and the environment can influence the crop's response to agronomic practices (Merta & Raksun, 2023; Duri *et al*., 2025).

CONCLUSIONS

The physiology of growth and yield of the eggplant crop, studied through morphometric variables, exhibited a sigmoidal growth pattern fitted to the logistic model, demonstrating the presence of well-defined growth phases. These phases are useful for the early, rational, and efficient planning of agronomic management practices, helping to maximize the physiological potential of the evaluated genotype. This approach also offers the possibility of applying the model to test other production systems or adaptation to different environmental conditions, as well as its practical application to the cultivation and research of other horticulturally important species, considering that this model reflects the collective growth behavior of plants under uniform management conditions and could be used to predict responses to variations in production factors or environmental conditions.

AUTHOR CONTRIBUTIONS

Conceptualization, F.V.B.-A. and A.V.B.-M.; Methodology, F.V.B.-A., A.V.B.-M. and L.A.B.-M.; Software, F.V.B.-A.; Validation, F.V.B.-A., A.V.B.-M. and L.A.B.-M.; Formal Analysis, F.V.B.-A.; Investigation, F.V.B.-A.; Resources, F.V.B.-A. and A.V.B.-M.; Data Curation, F.V.B.-A.; Writing—Original Draft Preparation, F.V.B.-A.; Writing—Review & Editing, A.V.B.-M. and L.A.B.-M.; Visualization, F.V.B.-A.; Supervision, F.V.B.-A.; Project Administration, F.V.B.-A.; Funding Acquisition, F.V.B.-A.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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