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Fruit growth and fruit drop in banana passion fruit plants (*Passiflora tripartita* var. mollissima)

Crecimiento y caída de frutos en curuba (*Passiflora tripartita* var. mollissima)

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Flowers and fruits of banana passionfruit in development.

Photo: F. Casierra-Posada

ABSTRACT

Growth is an irreversible increase in the size of plant organs that may involve changes in their form, and is accompanied by processes such as morphogenesis and cell differentiation. The mathematical expression of fruit growth in cultivated plants allows one to estimate aspects related to production, and contributes to defining protocols applicable to the agronomic management of the crop. A field trial was carried out in Caldas (Boyaca, Colombia), to describe the dynamics of different variables involved in the growth and fall of fruits in Banana passion fruit plants (*Passiflora tripartita* var. mollissima). Mathematical models were developed for variables commonly used to describe fruit growth. The evaluated variables presented values of R^2 higher than 0.98, except for the absolute growth rate of fruit length and at the time of fruit drop, whose R^2 values were 0.82 and 0.76, respectively. The results showed that the relative growth rate presented maximum values up to 22 days after floral opening, whereas the absolute growth rate presented the highest value between 15-22 days after floral opening. The length and width of the fruits showed a sigmoid-shaped curve, typical of other previously reported Passifloraceae. The maximum fruit fall occurred at 15 days after the floral opening and it was found that only 38.9% of the flowers develop fruits that reach the time of harvest. This information contributes to the technical management and optimal production of banana passion fruit.

Additional key words: relative growth rate, absolute growth rate, length/width ratio, fruit weight, total soluble solids.

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RESUMEN

El crecimiento es un aumento irreversible en el tamaño de los órganos de las plantas que puede implicar cambios en su forma, y está acompañado de procesos como la morfogénesis y la diferenciación celular. La expresión matemática del crecimiento del fruto en plantas cultivadas es una herramienta que permite estimar aspectos relacionados con la producción, y además contribuye a definir protocolos aplicables al manejo agronómico del cultivo. Se desarrolló en el municipio de Caldas (Boyacá, Colombia), un ensayo en condiciones de campo, con el objetivo de describir la dinámica de diferentes variables implicadas en el crecimiento y caída de frutos de curuba (*Passiflora tripartita* var. mollissima). Se calcularon modelos matemáticos para la estimación de algunas variables, usadas comúnmente para describir el crecimiento de frutos. Las variables evaluadas presentaron valores de R^2 superiores a 0,98 con excepción de la tasa de crecimiento absoluto de la longitud del fruto y la caída instantánea de frutos, cuyos valores de R^2 fueron de 0,82 y 0,76, respectivamente. Los resultados mostraron que la tasa de crecimiento relativo presentó los valores máximos hasta 22 días después de la apertura floral, mientras que la tasa de crecimiento absoluto presentó el mayor valor entre 15-22 días después de la apertura floral. La longitud y el ancho de los frutos mostraron una curva de forma sigmoide, típica de otras Passifloraceae reportadas previamente. La máxima caída de frutos de presentó a los 15 días después de la apertura floral y se encontró que sólo el 38,9% de las flores desarrollan frutos que alcanzan el momento de la cosecha. Esta información es de gran importancia cuando se pretende efectuar un manejo tecnificado del cultivo, con el propósito de optimizar la producción de curuba.

Palabras clave adicionales: tasa de crecimiento relativo, tasa de crecimiento absoluto, relación largo/ancho, peso del fruto, sólidos solubles totales.

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INTRODUCTION

The genus *Passiflora* belongs of the Passifloraceae family originating from the tropical American region (Esquerre-Ibañez *et al*., 2014). Malacrida and Jorge (2012) reported about 500 species, while Ocampo *et al*. (2007) mention a number closer to 630. Production of the banana passion fruit can be found throughout the Andean Mountain Range, from Venezuela and Colombia to Bolivia, and in countries of Central America and Oceania (Esquerre-Ibañez *et al*., 2014). Most of the 58 endemic species in Colombia are found between altitudes of 1,500 and 2,500 m, belonging mainly to the sections Tacsonia and Decaloba, in the genus Passiflora (Casierra-Posada and Jarma-Orozco, 2016). The fruit of Passifloras is a fleshy berry, with dimensions of 6-11 × 3-4.5 cm. *Passiflora tripartita* var. mollissima is easy to distinguish from other species of the super-section Tacsonia, due to the abundant pilosity of its organs, its pink to magenta pendulous flowers with their long floral tube, as well as, for its oblong shape, pubescent and pale yellow when mature (Esquerre-Ibañez *et al*., 2014). The pulp is formed by an orange aryl that wraps the numerous seeds and corresponds to 60% of the weight of the fruit. The fruit is made up of 77.93% moisture, 0.55% ash, 0.06% total nitrogen, 0.36% total protein, 21.13% total carbohydrates and 86.26 kcal 100 g^{-1} (Chaparro *et al*., 2015). In addition, it is important to mention that the fruits of this species exhibit climacteric behavior (Téllez *et al*., 2007). In fruit extracts alcohols, terpenic alcohols, diols, C13 norisoprenoids, and aromatic compounds have been detected. These fruits are also an important source of vitamins A, B, and C, antioxidant compounds, and phenols that have anti-inflammatory properties (Casierra-Posada and Jarma-Orozco, 2016).

Casierra-Posada and Cardozo (2009) found that crop management can be improved by following models of growth in fruit. Fruit growth represents an important element directly related to crop productivity and therefore, management of relevant techniques related to harvesting, storage and marketing. Franco *et al*. (2014) point out that the mathematical modelling of fruit growth in *Passiflora edulis* is an important contribution to the development of the crop. This tool allows estimate aspects related to harvest, with the purpose of defining protocols applicable to its agronomic management.

Due to its specific biochemical and molecular properties and nutritional importance, tomato (*Solanum lycopersicum*) has been established as a model fruit to study growth and development (Stikić *et al*., 2015). Stikić *et al*. (2015) report that the diameter of the fruit follows a sigmoid growth pattern, and describe the events that take place in each of the phases of fruit growth. Casierra-Posada *et al*. (2007) report a series of regression equations that can be used to estimate different parameters of fruit growth of three *Solanum lycopersicum* cultivars. These equations can measure time after flowering, and present the growth dynamics of the transversal diameter of the fruits, the polar diameter / transverse diameter ratio, the total soluble solids (TSS), the relative growth rate, (RGR) and the absolute growth rate (AGR).

Based on these approaches, the objective of this study was to describe the dynamics of different variables, commonly used to quantify the growth and fall of fruits in Banana passion fruit plants as a function of time. In addition, with the observed information, the mathematical models that express the most accurate values of the observed variables were calculated. The larger purpose of this study was to disseminate experimental information relevant to the management of this crop, given that much of the information presented in this work did not previously exist or was based solely on empirical observations.

MATERIALS AND METHODS

The experiment was performed under field conditions, in Caldas (Boyaca, Colombia), located at 5°33'24'' N and 73°54'29'' W at an altitude of 2,709 m a.s.l. The region has an average annual temperature of 15.7°C with a relative humidity of 86.2%. The crop was traditionally managed, involving manual weed management, spraying against sanitary problems, specifically against anthracnose and pruning. 107 flowers of 10 two years old banana passion fruit plants (*Passiflora tripartita* var. mollissima) were marked and investigated. After the opening of the flower, the length and width of each fruit were measured every 7 d, using a Vernier scale. This information was collected 8 d after the floral opening to the time of harvest maturity (when 50% yellow pericarp was reached). With the collected information, the absolute growth rate (AGR) of fruit length, the absolute growth rate of fruit width, the relative growth rate (RGR) of fruit length, and the relative growth rate of fruit width, were calculated according to the methodology proposed by (Hunt, 1990). The length to width ratio of fruits was also measured as the product of the length by the width of each fruit; the accumulated fruit drop, was measured as the difference between the accumulated value of two measurements. The fruit drop was measured as the number of fallen fruits recorded in a week. In the fruits of the marked flowers reaching the point of maturity (37 fruits), the weight of each fruit was recorded. Finally, at the time of harvest, 30 fruits of unmarked flowers from the same plants that had 50% of the yellow pericarp and 30 fruits with full yellow pericarp maturation were analysed. In these two fruit groups the total soluble solids were determined using a handheld refractometer RHB0-90 (Spectrum Technologies, Plainfield, IL, USA).

With recorded data on weekly fruit size, a curvilinear regression analysis was performed using the IBM®SPSS® version 20.0 application. All the regression functions offered by the application were calculated and the one with the highest coefficient of determination (R^2) was selected.

RESULTS AND DISCUSSION

The most adjusted regression equations for the estimation of the evaluated variables are presented in table 1. All calculated mathematical models were statistically significant ($P \leq 0.01$). For most parameters, it was found that the cubic model was the most appropriate based on the highest value of R^2. With the use of these equations it is possible to estimate each of the studied variables, as a function of the time, expressed as days after the opening of the flower. The values of the determination coefficients (R^2) found for the set of equations vary between 0.82 and 0.99, so the fraction of the total variation in Y is scarce, because the value calculated for each parameter (Y) with the use of the respective equation, is largely adjusted to the actual observed data. Additionally, the models found by regression analysis can be used for both time series forecasts and for predictions of causal relationships. In particular, when the dependent variable changes as a result of time it is a time series analysis, as is the case of the present work. On the other hand, the assessment of the predictive capacity of each found regression equation can be done using the determination coefficient. Therefore, it is possible to use these models for predictive purposes, and in this way, an efficient crop management can be achieved from an agronomic and economic perspective.

The use of empirical models for the non-destructive estimation of plant organ growth is common. These mathematical models are based on allometry, and use statistical relationships between a variable of interest and one or several variables used as predictors. However, it should be considered that the abiotic and biotic factors, as well as the interaction between them, can potentially affect the observed allometric values (Niklas, 1994). With these factors considered, Jorquera-Fontena *et al*. (2017) suggest that it is possible to use stable mathematical models that express the relationship between fresh weight and fruit diameter, regardless of the genotype and growing season of any species. Based on the high values of the coefficient of determination and the statistically significant calculated models, it is possible to use these models on the plants of *P. tripartita* in this study (Tab. 1) to estimate each of the evaluated variables as a function of time.

Vanclay (1994) and Hunt (1982) agree that growth estimates using mathematical models require the calculation of absolute growth rate (AGR) and relative growth rate (RGR). For these calculations, it is necessary to measure the dry mass or the leaf area sequentially. Generally speaking, growth in plants is quantified based on linear or exponential equations as a logistic model. Jorquera-Fontena *et al*. (2017) mention that using mathematical models with fruit diameter as an input can be an economical and rapid alternative to accurately evaluate fruit weight.

The values found for the relative growth rate (RGR) define three phases of fruit growth (Fig. 1). The first phase was until 22 d after floral opening, and was the period in which the growth occurred with great intensity. Between 22 and 83 d, the value of RGR decreases, however the diameter of the fruit increases as seen in figure 2. Finally, from 83 d until harvest the RGR, as well as growth in length and width of fruits remained low.

As in our study, Franco *et al*. (2014) used RGR values to determine that the fruits of *Passiflora edulis* have three growth phases with periods and duration that differ from those found for *P. tripartita* in our work, since despite their relationship, each species is genetically different and grows in different climates. Franco *et al*. (2014) mention that the identified phases for fruit growth are related to the development of the seeds of *P. edulis*, and in addition, in the first 35 d after flowering an expansion of the intercellular spaces occurs within the fruits of *P. edulis*. Beadle (1993) mentions that, in general, fruit growth can be represented by curves that depict absolute and relative growth rates, allowing one to forecast fruit size and growth, which facilitates the optimization of crop management.

In most plants, the first phase of early development in the growth of the fruits is formed by three stages. During the initial stage, the development of the ovary occurs. This is the time when abortion can occur or

Table 1. Regression equations calculated for the different parameters used to determine the growth and fall of fruits in *Passiflora tripartita* var. mollissima.

Parameters	Regression equation	R^2	Sig.
Length to width ratio of fruits	$y=3.59342245-0.0401180768x+4.494465608*10^{-4}x^2-1.688337575*10^{-6}x^3$	0.99	**
Fruit length (cm)	$y=-0.654821057+0.31808913x-3.4014327271*10^{-3}x^2+1.2611478*10^{-5}x^3$	0.99	**
Fruit width (cm)	$y=-0.464272449+0.121931204x-1.11153295*10^{-3}x^2+3.50382483*10^{-06}x^3$	0.99	**
Absolute growth rate of fruit length (cm d^{-1})	$y=0.234691753-2.90363953*10^{-3}x-2.20259548*10^{-5}x^2+2.892063*10^{-07}x^3$	0.82	**
Absolute growth rate of fruit width (cm d^{-1})	$y=0.152819178078798*e^{(-0.0344477039208571x)}$	0.90	**
Relative growth rate of fruit length (cm cm^{-1} d^{-1})	$y=0.0978758768-3.72563941*10^{-3}x+4.787098*10^{-5}x^2-2.0284870*10^{-7}x^3$	0.97	**
Relative growth rate of fruit width (cm cm^{-1} d^{-1})	$y=0.10855909-3.87240302*10^{-3}x+4.7093444*10^{-5}x^2-1.90790283*10^{-7}x^3$	0.97	**
Accumulated fruit drop (%)	$y=e^{(4.32428478209895-(15.0267000241898/x))}$	0.98	**
At time fruit drop (%)	$y=19.0927760-0.5017661609x+3.861872302*10^{-3}x^2-7.66605349*10^{-6}x^3$	0.76	**

y: parameters to calculate. x: days after floral opening. e: Euler's constant (2.718281828459045235360)

** $P\leq 0.01$

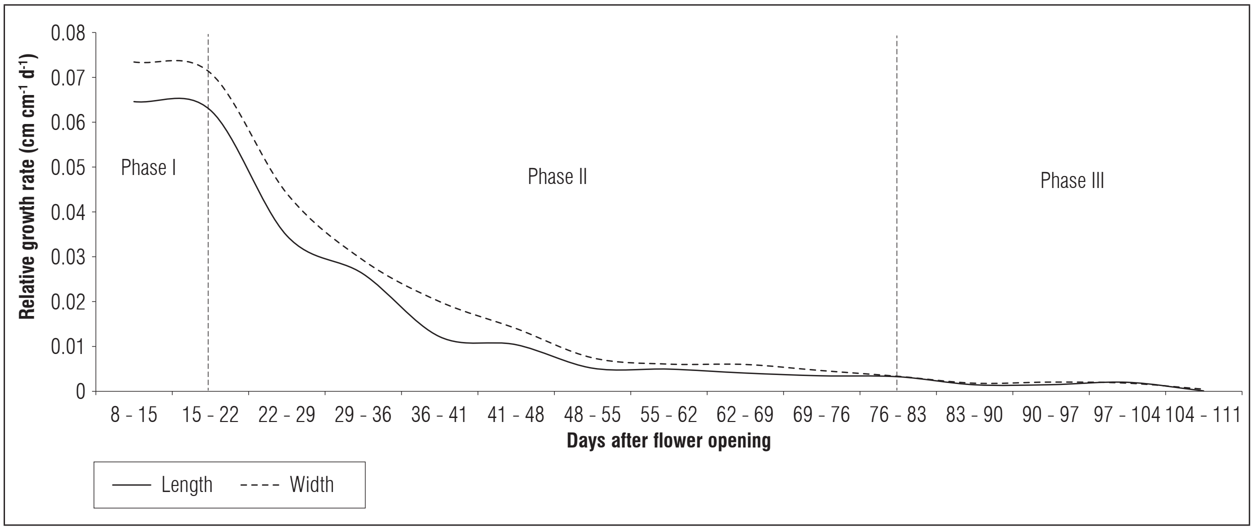

Figure 1. Relative growth rate of the length and width of fruits in banana passion fruit plants (*Passiflora tripartita* var. mollissima).

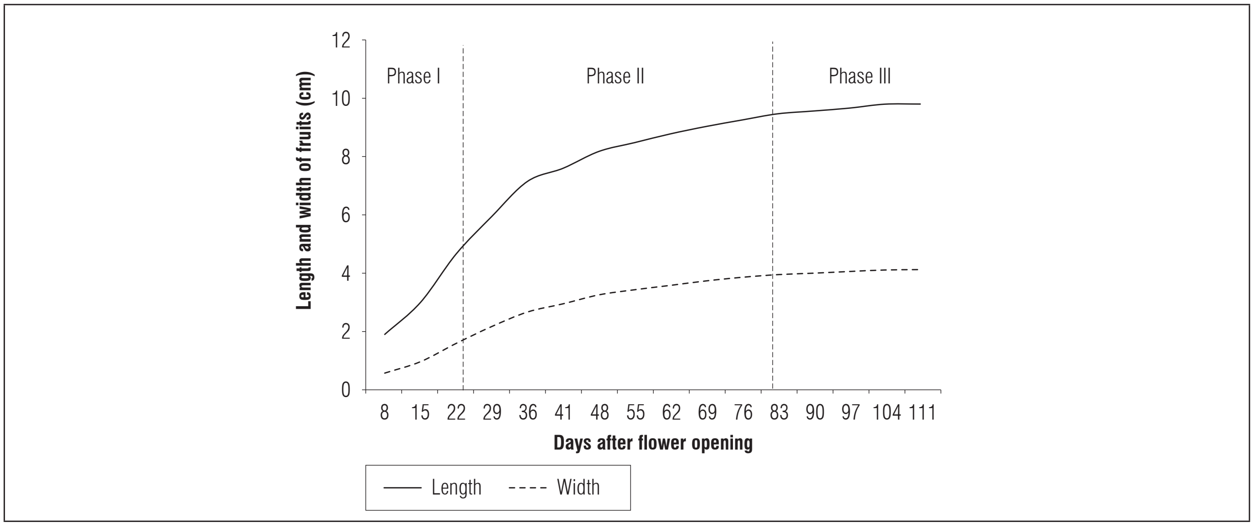

Figure 2. Length and width of the fruits of fruits in Banana passion fruit plants (*Passiflora tripartita* var. mollissima).

when the following stages continue, such as the phase of cell division and the major development phase of the fruit, which is generally known as the fruit set. In the second phase, fruit growth is the result of cell division. The third phase begins after cell division finishes. During this last phase, fruit growth occurs because of cell expansion, until the fruit reaches its final size or harvest maturity. This last stage of growth is the most obvious and physiologically the most representative because of the strong sink activity of the expanding cells. However, although this timeline occurs in most fruit species, some show variation (Gillaspy *et al*., 1993). The results of this current study are in accordance with the Gillaspy *et al*. (1993) three phases of growth. The steps in which phase I was divided could not be proven since the growth monitoring began 8 d after the floral opening.

The absolute growth rate (AGR) of fruit length and width showed maximum values between 15-22 d after floral opening, which is the time that makes of the first phase. Maximum values of the AGR in this period are 0.23 and 0.09 cm d^{-1} for growth in length and width, respectively. Later, during phase II, a

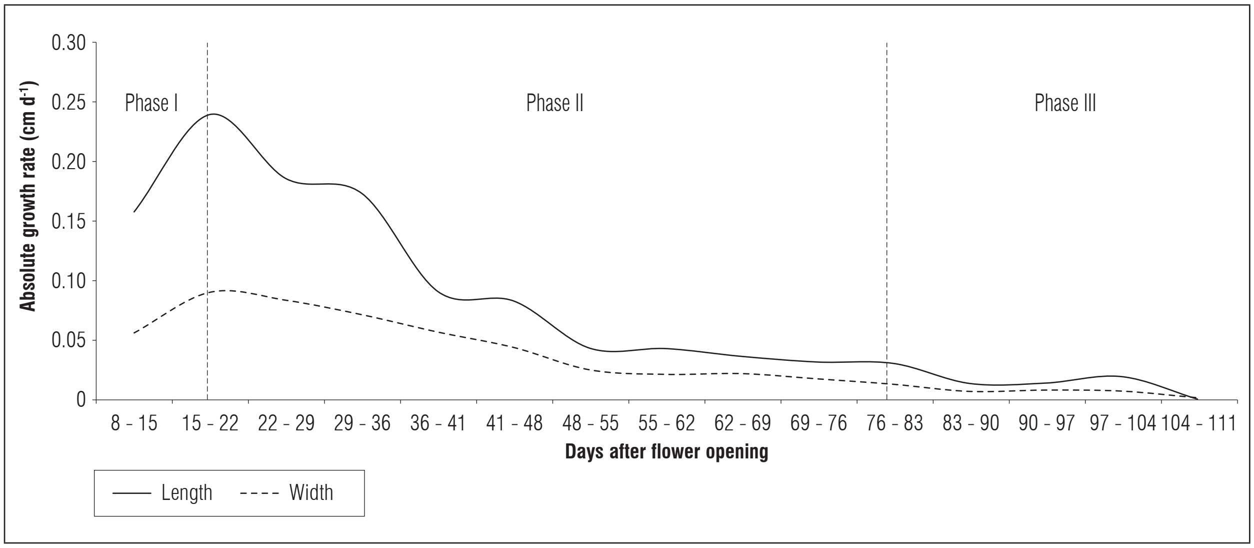

Figure 3. Absolute growth rate of fruit length and width of banana passion fruit plants (*Passiflora tripartita* var. mollissima).

reduction in the values of this variable was observed until the end of this phase (83 d after the opening of the flower). The mean AGR values during phase II were 0.07 and 0.03 cm d^{-1} for the AGR of the length and width of the fruits, respectively. Finally, during phase III, the AGR values were significantly reduced and presented an average of 0.011 and 0.005 cm d^{-1}, respectively for fruit length and width (Fig. 3).

Casierra-Posada *et al*. (2004) suggest the use of fruit growth dynamics in *Prunus persica* to identify the best time to perform some agricultural tasks, such as pruning and fruit thinning. Casierra-Posada and Cardozo (2009) mention that it is important to recognize that the agricultural practices to improve the accumulation of dry matter in fruits should be carried out in the periods in which the RGR and the AGR values are higher, since it is the time when the fruit is most sensitive. These practices include foliar fertilization and water and light management. These approaches would function in the case of fruit species that have a uniform phenology with well-defined phenological phases throughout the growing season. According to Campos (2001), *P. tripartita* can exhibit constant production from 18 months after planting, since flowering takes place in new branches that grow throughout the year. The periods of maximum production occur between December and January and between July and August in the region of Boyaca, Colombia. Based on Campos (2001) and on the results of this study, the periods in which the maximum values of RGR and AGR occur, should be calculated in the crop, using the equations presented in table 1, starting from the period in which a high percentage of open flowers in the crop is observed.

The curve of the length of the fruit is a sigmoid shape in phases I and II. The first phase corresponds to the stage of cell division and ends 22 d after the floral opening. In this period the slope of the long and wide curve of the fruit was 0.19 and 0.07, respectively. In the second phase the growth of the fruit occurred between 22 and 83 d after floral opening. In this period, the slopes of the curves for length and width of the fruits were 0.06 and 0.02, respectively. In the last phase, the physiological maturation of the fruits occurred, occurring between 83 and 111 d after floral opening, with slopes for the fruit length and width curves of 0.01 and 0.005, respectively (Fig. 2).

As in the present work, Arjona *et al*. (1991) found a sigmoid curve for the diameter of the fruits of *Passiflora edulis* and *P. incarnata*. Franco *et al*. (2014) also report that the growth dynamics of the polar and longitudinal diameter of *P. edulis* fruits are sigmoid. Stikić *et al*. (2015) mention that the dynamics of fruit growth usually occurs in sigmoid form, in which the increase in fruit diameter is represented as a function of time. This curve has, in most cases, three distinct regions that indicate cell division, followed by a cell elongation phase and finally a stable phase when the growth practically stops. The average region of the curve shows the period of exponential growth where fruits exhibit the greatest growth in diameter.

Reina (1995) mentions that in a sample of 20 fruits of *P. tripartita*, the fruits had an average length of 9.0 cm and diameter of 4.2 cm. Campos (2001) mentions that for the same specie, the fruit reaches 11 cm in length with 4.5 cm in diameter 90 d after the opening of the flower. It was found in the present work that to achieve fruits of 9.9 cm in length and 4.1 cm in diameter, 111 d are required, as shown in figure 2. These differences among the reports of other authors are probably due to the environmental conditions of the regions where the sampling was carried out as well as the respective management of the crop.

The length to width ratio is decreasing throughout the fruit growth period. The value of this relationship starts with 3.2, and at the time of harvest, it decreases to 2.3. With these values it can be understood that the fruit length is greater than width, since the beginning of its growth period (Fig. 4), since the value of this ratio, in all cases, is higher than 1.0. Based on their own results and those of other authors, Casierra-Posada *et al*. (2003), mention that this relationship is the most important parameter for expressing the fruit form. They found that in *Malus domestica*, the value of the length / diameter ratio of the fruits is drastically reduced between 30 and 98 d after full bloom and then tends to stabilize until the time of harvest. This reduction in the longitudinal diameter/ equatorial diameter ratio implies that in the first days of fruit development, longitudinal growth prevails over the equatorial, but in the last third of its development period, the value of this ratio approaches 1.0, which results in an equivalence between the length and the equatorial diameter, resulting in round fruits.

In the case of *P. tripartita*, the value of length to width ratio, at the time of harvest (111 d after floral opening) was 2.3, indicating an oblong shape typical of the fruits of this specie. According to Casierra-Posada *et al*. (2007), the form that the fruit acquires during the first stages of its growth is an effect of growth regulators produced by immature seeds, among which gibberellins play a relevant role. Corner (1976) mentions that the morphological characters of fruits and seeds provide useful information on the evolutionary relationships in flowering plants, therefore, the values found for this parameter may be useful for those interested in the evolutionary state of this specie.

The fruit fall was more intense at 15 d after the opening of the flower, with a value of 20.9% and continued until the 62 d. Afterwards, no more fallen fruits were observed and at this time, the accumulated value of the fruit fall was 61.1%, implying that only 38.9% of the flowers develop fruits that reach the time of harvest (Fig. 5).

Estornell *et al*. (2013) suggest that abscission includes four major events. First, cell differentiation must occur in the abscission zone, when there is an induction of response to changes in metabolism. Then cell separation occurs, and finally, a protective layer develops on the exposed surface. Sexton and Roberts (1982) point out that cell separation resulting in fruit drop is the simplest process to observe, based on visual and identifiable changes in the abscission zone and easier to study as an obvious event during growth and development of the fruits. According to Arseneault and Cline (2016), pre-harvest fruit fall is

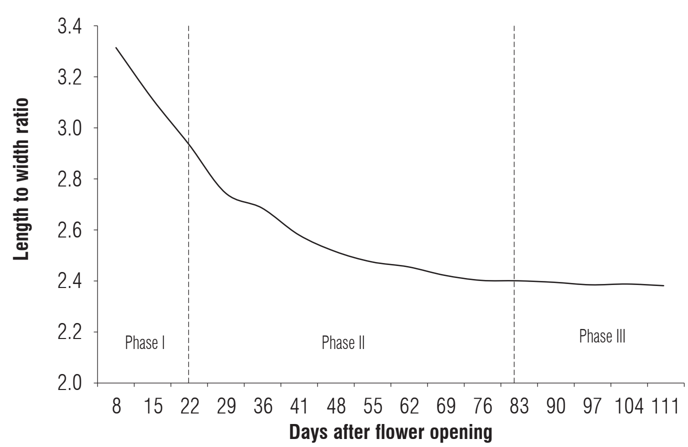

Figure 4. Length to width ratio in fruits of banana passion fruit plants (*Passiflora tripartita* var. mollissima).

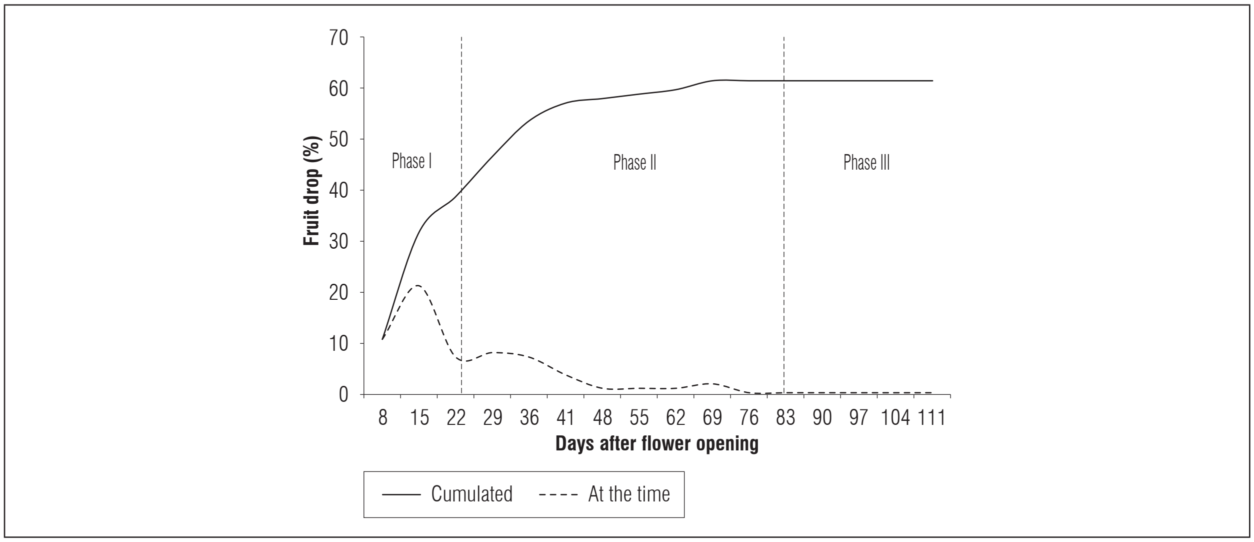

Figure 5. Fruit drop in banana passion fruit plants (*Passiflora tripartita* var. mollissima).

a challenge for production in fruit species. In addition, these authors indicate that the perception of alterations in metabolism leads to regulatory changes that induce degradation of the cell wall, in which the polygalacturonase and cellulase hydrolytic enzymes are involved. Ethylene has a clear association with the promotion of abscission, while the function of other plant hormones is unclear and will depend on the species under study.

After the fruit set, there is a strong competition for nutrients, which can reach a level where the fruit becomes dominant, resulting in a decrease in vegetative growth (Smith and Samach, 2013). The negative effect of fruit on vegetative growth has been observed in different fruit species. Thus, the fruit bearing process can be interrupted at different stages of fruit growth and development, so most flowers do not set to fruit and a significant number of fruits fall before reaching the harvest maturity (Valdebenito *et al*., 2017). Campos (2001) reports that between 20-25% of the flowers of *P. tripartita* reach the state of fruit for harvest, however, in the present study 38.9% of the flowers managed to mature into fruits that could be harvested.

It was found that when the fruits had 50% yellow pericarp, the average value of the total soluble solids (TSS) was 10.9±1.4 °Brix, whereas when the fruit pericarp was completely yellow, the TSS was of 12.5±0.8 °Brix. In addition, an average value of 101.2±11.8 g was recorded as the weight of the fruits evaluated. Reina (1995) reports an average weight of 79.9 g per fruit, in a sample of 20 fruits of *P. tripartita*. In these fruits a TSS content of 11.8 °Brix was found. The results agree with the findings of this study, in relation to the physicochemical parameters evaluated. Finally, it should be made clear that the fruits in which the information was recorded for the monitoring of the parameters to express the growth of the fruits, were harvested when they had 50% of yellow pericarp.

CONCLUSIONS

A series of mathematical models were calculated to describe fruit growth. The values of the coefficients of determination (R^2) for the set of variables evaluated ranged from 0.82 to 0.99, indicating the high degree of adjustment of the calculated equation with the data observed in the field. Both the length and width increase in fruits of Banana passion fruit presented sigmoid curves, typical of other Passifloraceae. Based on the relative growth rate, three phases of growth were defined, in which the first phase occurs up to 22 d after floral opening; the second phase between 22 and 83 d, and the last phase 83 d until the time of harvest (111 d after floral opening). The relative growth rate presented the maximum values up to 22 d after the floral opening, while the absolute growth rate presented the highest value between 15-22 d after the floral opening. The maximum fruit fall occurred at 15 d after the floral opening and only 38.9% of the flowers were found to develop fruits that reached the time of harvest. This information can be used when making decisions related to the agronomic management of the crop to improve its production. Based on these findings, and especially on the dynamics of RGR between 15-22, special care must be taken in the agronomic management of the crop at this time, in which the fruits achieve their highest growth rate. Thus, in the first few weeks after fruits appear, the crop needs immediate availability of nutrients and water, so that these factors do not affect fruit growth. Additionally, based on the information related to fruit fall, it is possible to forecast the number of fruits to be harvested in relation to the flowering intensity.

Conflict of interests: the manuscript was prepared and reviewed with the participation of the authors, who declare that there exists no conflict of interest that puts in risk the validity of the presented results.

BIBLIOGRAPHIC REFERENCES

Arjona, H.E., F.B. Matta, and J.A. Garner. 1991. Growth and composition of passion fruit (*Passiflora edulis*) and maypop (*P. incarnata*). HortScience 26(7), 921-923.

Arseneault, M.H. and J.A. Cline. 2016. A review of apple preharvest fruit drop and practices for horticultural management. Sci. Hortic. 211, 40-52. Doi: 10.1016/j.scienta.2016.08.002

Beadle, C.L. 1993. Growth analysis. pp. 36-46. In: Hall, D.O., J.M.O. Scurlock, H.R. Bolhàrd-Nordenkampf, R.C. Leegood, and S.P. Long (eds.). Photosynthesis and production in a changing environment: A field and laboratory manual. Chapman and Hall, London, UK.

Campos, T. 2001. La curuba: su cultivo. IICA, Bogota, Colombia.

Casierra-Posada, F., D.I. Hernández, P. Lüdders, and G. Ebert. 2003. Crecimiento de frutos y ramas del manzano 'Anna' (*Malus domestica* Borkh.) en los altiplanos colombianos. Agron. Colomb. 21, 69-73.

Casierra-Posada, F., V.E. Barreto, and O.L. Fonseca. 2004. Crecimiento de frutos y ramas de duraznero (*Prunus persica* L. Batsch, cv. 'Conservero') en los altiplanos colombianos. Agron. Colomb. 22 (1), 40-45.

Casierra-Posada, F., M.C. Cardozo, and J.F. Cárdenas-Hernández. 2007. Análisis del crecimiento en frutos de tomate (*Lycopersicon esculentum* Mill.) cultivados bajo invernadero. Agron. Colomb. 25(2), 299-305.

Casierra-Posada, F. and M.C. Cardozo. 2009. Análisis básico del crecimiento en frutos de tomate (*Lycopersicon esculentum* Mill, cv. 'Quindío') cultivados a campo abierto. Rev. Fac. Nal. Agr. Medellín 62(1), 4815-4822.

Casierra-Posada, F. and A. Jarma-Orozco. 2016. Nutritional composition of Passiflora species. pp. 517-534. In: Simmonds, M.S.J. and V.R. Preedy (eds.). Nutritional composition of fruit cultivars. Academic Press, San Diego, CA, USA.

Chaparro, D.C., M.E. Maldonado, M.C. Franco, and L.A Urango. 2015. Características nutricionales y antioxidantes de la fruta curuba larga (*Passiflora mollisima* Bailey). Biotecnol. Sector Agropecu. Agroind. 13(1), 120-128.

Corner, E.J. 1976. The seeds of the dicotyledons. Vol. I and II. Cambridge University Press, Cambridge, UK.

Esquerre-Ibañez, B., C. Rojas-Idrogo, S. Llatas-Quiroz, and G.E. Delgado-Paredes. 2014. El género *Passiflora* L. (Passifloraceae) en el departamento de Lambayeque, Perú. Acta Bot. Malacitana 39, 55-70.

Estornell, L.H., J. Agustí, P. Merelo, M. Talón, and F.R. Tadeo. 2013. Elucidating mechanisms underlying organ abscission. Plant Sci. 199-200C, 48-60. Doi: 10.1016/j.plantsci.2012.10.008

Franco, G., J.R. Cartagena, and G. Correa. 2014. Analysis of purple passion fruit (*Passiflora edulis* Sims) growth under ecological conditions of the Colombian lower montane rain forest. Rev. UDCA Act. Div. Cient. 17(2), 391-400.

Gillaspy, G., H. Ben-David, and W. Gruissem. 1993. Fruits: A developmental perspective. Plant Cell 5, 1439-1451. Doi: 10.1105/tpc.5.10.1439

Hunt, R. 1982. Plant growth curves: The functional approach to plant growth analysis. Edward Arnold, London, UK.

Hunt, R. 1990. Basic growth analysis. Plant growth analysis for beginners. Unwin Hyman, Boston, MA, USA. Doi: 10.1007/978-94-010-9117-6

Jorquera-Fontena, E., M. Génard, A. Ribera-Fonseca, and N. Franck. 2017. A simple allometric model for estimating blueberry fruit weight from diameter measurements. Sci. Hortic. 219, 131-134. Doi: 10.1016/j.scienta.2017.03.009

Malacrida, C.R. and N. Jorge. 2012. Yellow passion fruit seed oil (*Passiflora edulis* f. *flavicarpa*): physical and chemical characteristics. Braz. Arch. Biol. Technol. 55 (1), 127-134. Doi: 10.1590/S1516-89132012000100016

Niklas, K.J. 1994. Plant allometry: The scaling of form and process. University Chicago Press, Chicago, IL, USA.

Ocampo, J.A., G. Coppens d'Eeckenbrugge, M.T. Restrepo, A. Jarvis, M.H. Salazar, and C.M. Caetano. 2007. Diversity of Colombian Passifloraceae: biogeography and an updated list for conservation. Biota Colomb. 8(1), 1-45.

Reina, C.E. 1995. Manejo, poscosecha y evaluación de la calidad de curuba (*Passiflora mollissima*) que se comercializa en la ciudad de Neiva. Universidad Surcolombia. Facultad de Ingeniería, Neiva, Colombia.

Sexton, R. and J. Roberts. 1982. Cell biology of abscission. Annu. Rev. Plant Physiol. 33, 133-162. Doi: 10.1146/annurev.pp.33.060182.001025

Smith, H.M. and A. Samach. 2013. Constraints to obtaining consistent annual yields in perennial tree crops. I: heavy fruit load dominates over vegetative growth. Plant Sci. 207, 158-167. Doi: 10.1016/j.plantsci.2013.02.014

Stikić, R., Z. Jovanović, B. Vucelić-Radović, M. Marjanović, and S. Savić. 2015. Tomato: a model species for fruit growth and development studies. Bot. Serbica 39(2), 95-102.

Téllez, C.P., G. Fischer, and O.C. Quintero. 2007. Comportamiento fisiológico y fisicoquímico de frutos de curuba (*Passiflora mollissima* Bailey) encerados y almacenados a dos temperaturas. Rev. Colomb. Cienc. Hortíc. 1(1), 67-80. Doi: 10.17584/rcch.2007v1i1.1146

Valdebenito, D., S. Tombesi, A. Tixier, B. Lampinen, P. Brown, and S. Saa. 2017. Spur behavior in Almond trees (*Prunus dulcis* [Mill.] DAWebb): effects of flowers, fruit, and “June drop” on leaf area, leaf nitrogen, spur survival and return bloom. Sci. Hortic. 215, 15-19. Doi: 10.1016/j.scienta.2016.11.050

Vanclay, J.K. 1994. Modelling forest growth and yield. CAB International, Wallingford, UK.