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Scientific Article

Seedling biometrics and relationship with yield of physalis

Biometria das plântulas e relação com o rendimento de fisális

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ABSTRACT - *Physalis angulata* has fruits rich in vitamins A and C, phosphorus, iron and antioxidant substances, while its leaves and roots have physalins, of high pharmacological potential. However, its cultivation is recent and there is a lack of technical knowledge. Characteristics of the seedling determine its vigor and the time of transplantation, which affect the performance of the crop in the field and, consequently, its yield. Therefore, the objective of this study was to know the influence of seedling height and stem diameter on the yield of *P. angulata*, defining the standard for transplantation and the time of permanence in the nursery. To obtain biometric characteristics, *P. angulata* was sown every four days and the seedlings were transplanted on April 6, 2022, at 22, 26, 30, 34 and 38 days after sowing. Descriptive analyses of the seedlings in the nursery were performed, with evaluations at 14, 18, 22, 26, 30, 34 and 38 days after sowing. To assess the performance of seedlings in the field, the 300 seedlings of different sizes transplanted were evaluated for survival and number of fruits per plant (< 150; 150 to < 200; 200 to < 250 and ≥ 250 fruits). For more productive plants (≥ 200 fruits), *P. angulata* seedlings should remain in the nursery for 38 days after sowing, when they will have at least 12.8 cm in height and 4.2 cm in stem diameter.

Keywords: Pharmacological properties. Physalins. Small fruits. *Physalis angulata*. Solanaceae.

RESUMO - *Physalis angulata* possui frutos ricos em vitaminas A e C, fósforo, ferro e substâncias antioxidantes, enquanto suas folhas e raízes possuem fisalinas, de alto potencial farmacológico. No entanto, seu cultivo é recente e há falta de conhecimento técnico. Características da muda determinam seu vigor e a época de transplante, o que afeta o desempenho da cultura no campo e, consequentemente, sua produtividade. Portanto, o objetivo deste trabalho foi conhecer a influência da altura da muda e do diâmetro do caule na produtividade de *P. angulata*, definindo o padrão para o transplante e o tempo de permanência no viveiro. Para a obtenção das características biométricas, *P. angulata* foi semeada a cada quatro dias e as mudas foram transplantadas no dia 6 de abril de 2022, aos 22, 26, 30, 34 e 38 dias após a semeadura. Foram realizadas análises descritivas das mudas no viveiro, com avaliações aos 14, 18, 22, 26, 30, 34 e 38 dias após a semeadura. Para avaliar o desempenho das mudas no campo, as 300 mudas de diferentes tamanhos transplantadas foram avaliadas quanto à sobrevivência e número de frutos por planta (< 150; 150 a < 200; 200 a < 250 e ≥ 250 frutos). Para plantas mais produtivas (≥ 200 frutos), as mudas de *P. angulata* devem permanecer no viveiro por 38 dias após a semeadura, quando terão no mínimo 12,8 cm de altura e 4,2 cm de diâmetro do caule.

Palavras-chave: Propriedades farmacológicas. Fisális. Pequenas frutas. *Physalis angulata*. Solanaceae.

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INTRODUCTION

Physalis, belonging to the Solanaceae family, is an American genus of importance for agriculture and includes 90 species. Current evidence suggests that the cultivation of *P. angulata* is recent, starting only 65 years ago, although the consumption of fruits of this genus has been reported since 5000 BC (VARGAS-PONCE et al., 2016). In Brazil, the main representatives are the species *Physalis angulata* and *Physalis peruviana*.

P. angulata is an annual herbaceous species distributed in tropical and subtropical areas around the world (FERREIRA et al., 2019), and its fruits are rich in vitamins A and C, phosphorus, iron, and antioxidants (KUSUMANINGTYAS; LAILY; LIMANDHA, 2015; ABREU et al., 2017; FERREIRA et al., 2019), being characterized as functional food. Like other small fruits, in addition to fresh consumption, physalis is a great raw material for the preparation of jellies, juices, paste or crystallized sweets, pies and cakes, besides being used in the industry of pulps, frozen fruits, yogurts and ice creams (RUFATO et al., 2012). In addition to the nutritional value, species of the genus *Physalis* sp. contain physalins, which have several pharmacological properties, such as anti-inflammatory (LIN et al., 2020) and immunosuppressive (PINTO et al., 2016; MEIRA et al., 2022), antiparasitic effect as against *Trypanosoma cruzi* (MEIRA et al., 2022), as well as leishmanicidal action (GUIMARÃES et al., 2010) and anticancer action (WANG et al., 2018; BOONSOMBAT et al., 2020), giving this species a high commercial potential (VARGAS-PONCE et al., 2015; LEITE et al., 2021). Thus, *Physalis* cultivation can be an alternative for small and medium-sized rural producers (ABREU et al., 2017), with fruits intended for the fresh market and agroindustry and the leaves, stem and roots intended for the pharmaceutical industry.

However, as occurs for any species in the beginning of cultivation, there is a lack of technical knowledge. However, to meet the demand of the growing market, both in quantity and quality, studies on crop management are necessary.

Establishing a new cultivation by seedlings is recommended, since plantlets obtained from direct seeding are subject to greater post-emergence stress. In order to ensure adequate plant population, in the direct seeding method it is necessary to sow a large amount of seeds and later perform thinning, an operation that is highly labor-consuming. Therefore, seedlings constitute a solution to this issue. However, despite the pharmacological and nutritional importance of *P. angulata*, no studies related to seedling quality standards were found. Currently, there is no recommendation for the production of Physalis seedlings, which are produced with different containers, substrates and times before transplantation to the field. Seedling quality is a prerequisite for good performance in the field (YILMAZ; OZEN; OZEN, 2017; ZHOU et al., 2019), and knowing the relationship between biometric parameters (height and diameter), which affect the time of permanence in the nursery and the vigor of the seedling, is important for post-transplant performance, which influences yield and even fruit quality. If on the one hand excessively long permanence of the seedlings in the nursery generates additional costs with irrigation, fertilization and labor, in addition to costs inherent to the occupation of the production area (FREITAS et al., 2021), on the other hand, early dispatch of the seedlings to the field can cause poor performance after transplantation or until their death.

In view of the above, the objective of the study was to define quality criteria and time of permanence in the nursery of *Physalis angulata* L. seedlings that correlate with highest-yielding plants.

MATERIAL AND METHODS

Characterization of experimental site

The experiment had two stages, nursery and field, carried out at the Center for Agrarian, Environmental and Biological Sciences (CCAB) of the Federal University of Recôncavo da Bahia (UFRB), campus of Cruz das Almas, Bahia, located at 39º06'22" W, 12º40'19" S and 220 m altitude. According to Köppen's classification, this climate is classified as Af (warm climate), with an average annual temperature of 24 °C, average annual relative humidity of 80% and average annual rainfall of 1200 mm.

Experiment setup and conduction

Nursery stage

Five seeds of *P. angulata* were sown in tubes of 12.5 cm in height and 2.9 cm in internal diameter, which contained 55 cm^3 of Plantmax® substrate and humus in a 7:3 ratio. The tubes were arranged on a bench at 0.80 m height, in a greenhouse, with a 50% shade net. Seven days after emergence, thinning was carried out, leaving only one seedling per tube.

To obtain different biometric characteristics of *P. angulata* seedlings, 250 tubes were sown every four days. Irrigation was performed twice a day, in the early morning and late afternoon, with 6 mL of water per tube, to maintain the substrate with 70% saturation.

The seedlings were transplanted on April 9, 2022, at 38, 34, 30, 26 and 22 days after sowing.

Field stage

In order to relate the performance of seedlings in the field to their height and diameter at the time of dispatch, 300 seedlings were transplanted to the field on April 9, 2022.

Prior to transplantation, soil samples were randomly collected in the 0-0.20 m layer for chemical analysis (Table 1), according to methodologies described by Miyazawa et al. (2009). Plowing and harrowing were performed. Holes with 0.20 m diameter and 0.20 m depth were opened at spacing of 0.8 m in the row and 1.8 m between rows. The holes were fertilized with 200 grams of humus (Table 1).

Irrigation was performed using a drip system, with tapes containing drippers with flow rate of 1.6 L h^{-1}, spaced every 0.30 m. Daily, 7 mm of water were applied, half in the morning and half in the afternoon, with each application lasting twenty minutes.

Table 1. Chemical analysis of the soil of the experimental area and of the humus used in the post-transplant fertilization of Physalis angulata L. seedlings.

Chemical attributes	Soil	Humus
pH (H_2O)	5.4	7.3
P (mg dm^{-3})	9.6	901.2
K ($cmol_c$ dm^{-3})	1.4	2.0
Na (mg dm^{-3})	-	-
Ca^{2+} ($cmol_c$ dm^{-3})	3.4	5.4
Mg^{2+} ($cmol_c$ dm^{-3})	1.0	1.8
Al^{3+} ($cmol_c$ dm^{-3})	0.1	0
H+Al ($cmol_c$ dm^{-3})	11.7	2.6
SB ($cmol_c$ dm^{-3})	5.8	9.2
CEC(t) ($cmol_c$ dm^{-3})	5.9	9.2
CEC(T) ($cmol_c$ dm^{-3})	17.5	11.8
OM (%)	2.4	2.2
V (%)	33.0	78.0
m (%)	2.0	0.0

P, K^+ and Na^+: Mehlich 1 extractant (HCl + H_2SO_4); Al^{3+}, Ca^{2+} and Mg^{2+}: 1 M KCl extractant; OM = organic matter; SB = sum of bases; V = base saturation; CEC = cation exchange capacity.

Evaluations performed

Nursery stage

For seedlings from sowing on March 2, 2022 (first sowing), the variables height, stem diameter in the collar region and Dickson quality index (DQI) were measured every four days from 14 to 38 days after sowing (April 9, 2022), when they were transplanted to the field.

For the measurements of height and stem diameter, 12 seedlings were randomly evaluated per replicate, while for dry mass two seedlings were evaluated. Stem diameter was measured using a digital caliper with 0.1 mm precision, and height was measured with a ruler graduated in mm, considering the length between the plant collar and the insertion of the last pair of leaves. DQI was calculated as proposed by Dickson, Leaf and Hosner (1960).

$$\text{DQI} = \frac{\text{Total dry mass (g)}}{\frac{\text{Height (cm)}}{\text{Diameter (mm)}} + \frac{\text{Shoot dry mass (g)}}{\text{Root dry mass (g)}}}$$

To obtain shoot and root dry mass, the roots were previously washed in 500-µm-mesh sieves to remove the substrate. Shoots and roots were placed in separate paper bags and dried in an air circulation oven at 75 °C for 72 hours. The masses were obtained on a scale with precision of two decimal places. The daily current increment (DCI) corresponded to the difference in the element measured (height or stem diameter) within the periods evaluated, and the daily average increment (DAI) was obtained from the ratio between the value of the element measured and the time from the initial evaluation. The intercept point between the current increment and average increment curves indicates when the seedlings should be transplanted (ELOY et al., 2014).

On the day of transplantation, 300 seedlings were randomly measured for height and stem diameter to establish the correlation with the number of fruits per plant obtained 70 days later.

Field stage

From the tenth day after transplantation to the field, survival and number of fruits per plant were evaluated every seven days until 70 days.

Statistical analysis

Nursery stage

For height, stem diameter and Dickson quality index, evaluated every four days, mixed linear models were applied using the lme4 package in R software (R CORE TEAM, 2022), by the maximum residual likelihood method. Subsequently, regression equations were fitted for the variables as a function of the evaluation period (14 to 38 days after sowing). The assumptions of the fitted models were tested by the Shapiro-Wilk test for residual normality, Breusch and Pagan test for homoscedasticity, using the bptest function of the lmtest package, and Durbin-Watson test for residual autocorrelation, using the durbin WatsonTest function, car package. When the assumptions were not met, the generalized least squares method was used, incorporating to the residuals the first-order autocorrelation parameter (AR1), by the gnls function of the nlme package for nonlinear models and lme package for linear models of R software (R CORE TEAM, 2022).

Field stage

Regression analysis by generalized linear models was used to evaluate the number of fruits in response to the diameter and height of the seedlings at the time of dispatch. Contingency tables were obtained by the frequency distribution of the number of plants by classes of height, diameter and number of fruits per plant. Chi-Square test was applied to evaluate the frequency distribution data. All analyses were performed using R software (R CORE TEAM, 2022).

RESULTS AND DISCUSSION

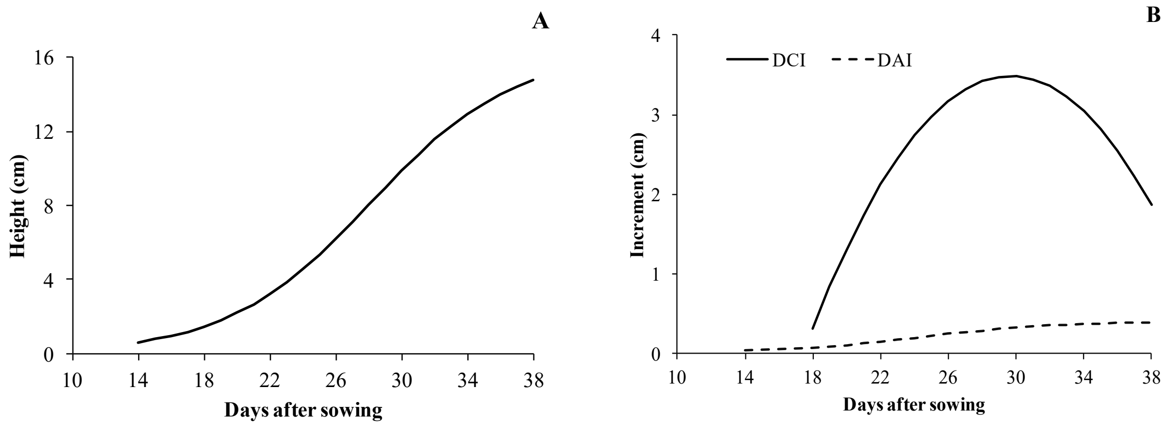
Nursery stage

Growth in height adhered to the logistic model, with a first-order autocorrelation structure (AR1). At 28 days, the seedlings reached 50% of the maximum height, corresponding to 8.15 cm (Figure 1A). Seedling diameter showed linear growth, with maximum value of 3.9 mm and 50% reached at 22.4 days after sowing (Figure 2A).

The daily current increment (DCI) in height increased with the evaluation period until reaching a maximum value at 30 days (maximum point = 29.6 days). The daily average increment (DAI) in height did not intercept the curve of the current increment (Figure 1B). The daily current increment in diameter decreased along the evaluated period until reaching a minimum value at 29 days, and the daily average increment in diameter reached a maximum value at 34 days (maximum point = 33.8 days), with no interception between the current and average increment curves (Figure 2B).

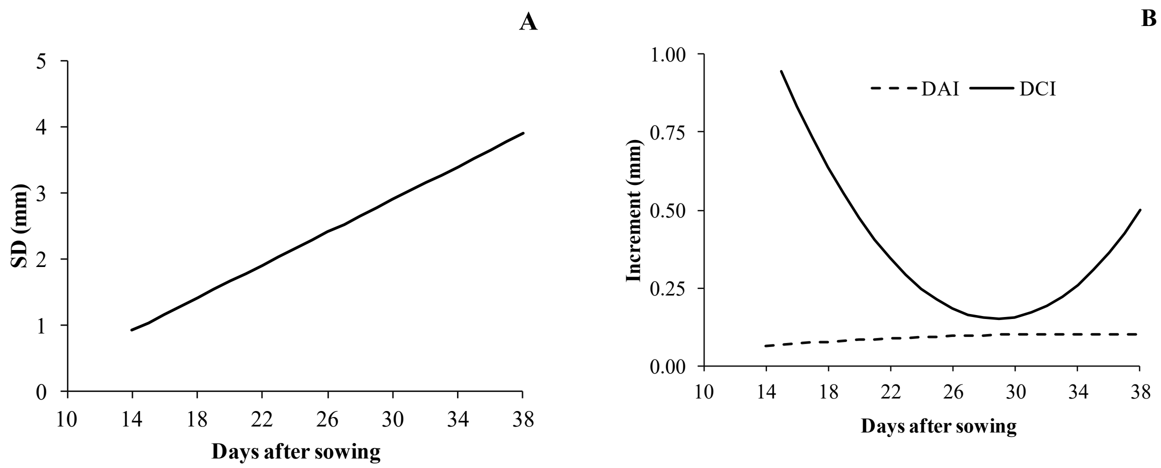
The criterion of intersection of the curves of daily current and daily average increments to determine the optimal age of dispatch of the seedlings has been used for eucalyptus (ELOY et al., 2014). Based on this criterion, as there was no intersection of the curves of *P. angulata* seedlings, the maximum time of permanence in the nursery, 38 days, was not sufficient for seedling growth to stabilize, so longer times should be studied. However, it is important to complement this information with the seedling field performance test, since this extension of the time of permanence entails a higher cost for producing the seedlings, involving for instance the use of agricultural inputs, irrigation, labor time and other measures necessary for maintenance in the nursery stage (MENDONÇA; SOUZA, 2018).

The curves of increment in height and diameter (Figures 1B and 2B) show an evident alternation of investment in growth. In the initial period of measurement, the seedlings invested in the growth in height and, between 20 and 30 days, in the growth in stem diameter. Etiolation and lodging were not observed in the nursery stage. The strategy of the plant in alternating the investment in growth in height and diameter, observed in this study, favors stem strengthening, forming seedlings with no etiolation and of better quality.



Height = 16.3/(1+EXP(-0.2288*(x-28.12))) $R^2 = 0.98$, $p < 0.0001$
DAI = 0.4/(1+EXP(-0.2453*(x-24.3))) $R^2 = 0.96$, $p < 0.0001$
DCI = $-0.233x^2 + 1.38x - 17.02$ $R^2 = 0.72$, $p < 0.0001$

Figure 1. Height of *P. angulata* L. seedlings (A) and daily average increment (DAI) and daily current increment (DCI) in height (B) as a function of time (days after sowing).



SD = $0.124x - 0.8232$ $R^2 = 0.98$, $p < 0.0001$
DAI = $0.0001x^2 + 0.0069x - 0.0116$ $R^2 = 0.80$, $p < 0.0002$
DCI = $0.0415x^2 - 0.2394x + 3.60$ $R^2 = 0.55$, $p < 0.0001$

Figure 2. Stem diameter (SD) in the collar region of *P. angulata* L. seedlings (A) and daily average increment (DAI) and daily current increment (DCI) in stem diameter (B) as a function of time (days after sowing).

The Dickson quality index increased exponentially in the evaluation period (Figure 3). At 38 days, the maximum DQI value was 0.14. Regardless of management and species, the higher the DQI, the higher the quality of the seedlings (CALDEIRA et al., 2012). As observed by Melo et al. (2018), both the species of the seedlings and the time of permanence in the nursery are factors that affect the DQI value. Oliveira et al. (2020) produced *P. peruviana* seedlings for 56 days and obtained DQI values between 0.07 and 0.26.

For a reliable indication as to the minimum seedling quality standard for a given species, it is necessary to test the performance of the plants after the dispatch. Although evaluations performed in the greenhouse are widely used, including height, stem diameter, daily current and average increments, shoot and root dry mass, as well as Dickson quality index, it is necessary to conduct studies related to survival and yield.

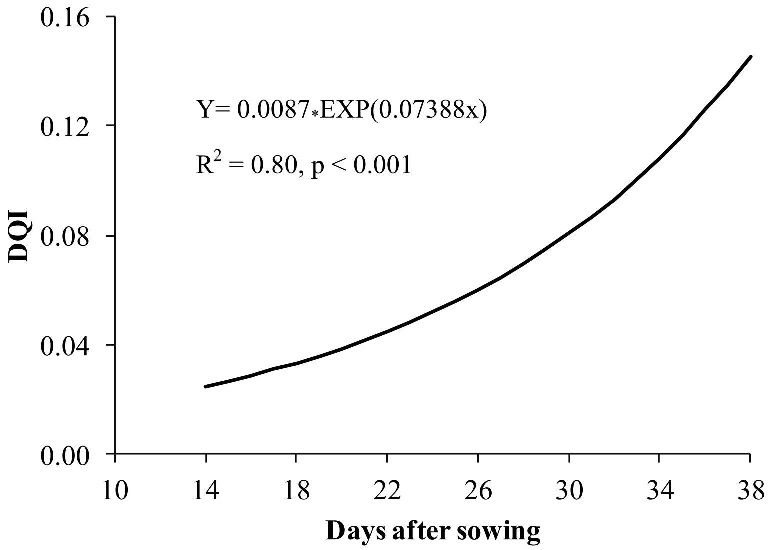


Figure 3. Dickson quality index of *Physalis angulata* L. seedlings as a function of the time of permanence in the nursery (days after sowing).

Field stage

Seedling survival was very high (96%). The biometric characteristics evaluated at the time of transplanting the seedlings did not influence survival.

The number of fruits of *P. angulata* increased linearly as a function of the height and diameter of the seedlings at the time of the transplant to the field (Figure 4). The choice of the best seedlings for transplantation can be performed based on variables that are easy to measure, such as diameter and height. These measurements are non-destructive and allow evaluations to be carried out before the transplant to the field and monitoring the performance of the seedlings after transplantation. This has been pointed out in studies such as that conducted by Lima et al. (2019). Thus, through these non-destructive variables, which allow the monitoring of survival and production in the field, it is possible to determine the quality standard of the seedlings, based on those capable of resisting the stress of the transplanting process and also resulting in higher production.

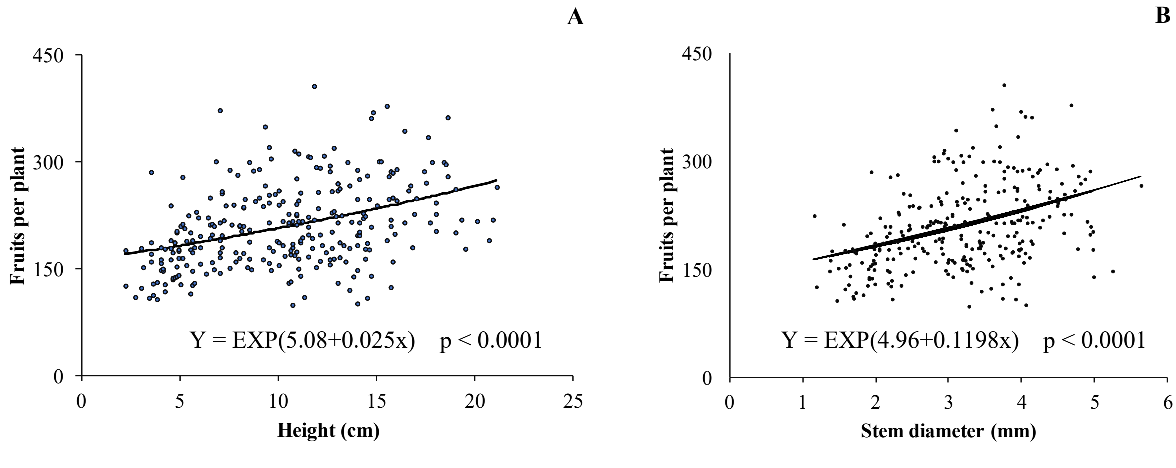


Figure 4. Number of fruits per plant as a function of height (A) and stem diameter (B) of *P. angulata* L. seedlings at the time of transplantation to the field.

The distribution of the number of plants was dependent on the classes of height and number of fruits per plant (Chi-Square = 63.37, $p < 0.0001$). In the class with the highest number of fruits per plant (> 250), the greatest contribution came from plants with a height greater than 12.8 cm at the time of transplantation (Figure 5). The height variable is a measure of the potential performance of seedlings in the field, because its prediction can be evaluated throughout the cycle, from initial growth to final yield (GOMES et al., 2013).

It was observed that seedlings with greater height resulted in more productive plants, with the greatest vigor in 91 and 70% of the plants from seedlings taller than 12.8 cm and that produced more than 150 and 200 fruits per plant, respectively (Figure 5). More vigorous seedlings promoted rapid growth and post-transplant development, which better met the requirements for photoassimilates of flowers, fruits and seeds (SOLDATELI et al., 2020). The production factors water, nutrients, temperature and luminosity proved to be not limiting and allowed the expression of the vigor of the seedlings in the yield of *P. angulata*.

Of the total plants formed from seedlings with height of less than 6.4 cm, 35% produced less than 150 fruits and 82% produced less than 200 fruits per plant. Seedlings with 6.4 ├8.5, 8.5 ├10.6 and 10.6 ├12.8 cm in height showed similar performance and promoted a higher percentage of plants (average of 70%) with production between 150 and 250 fruits (Figure 5).

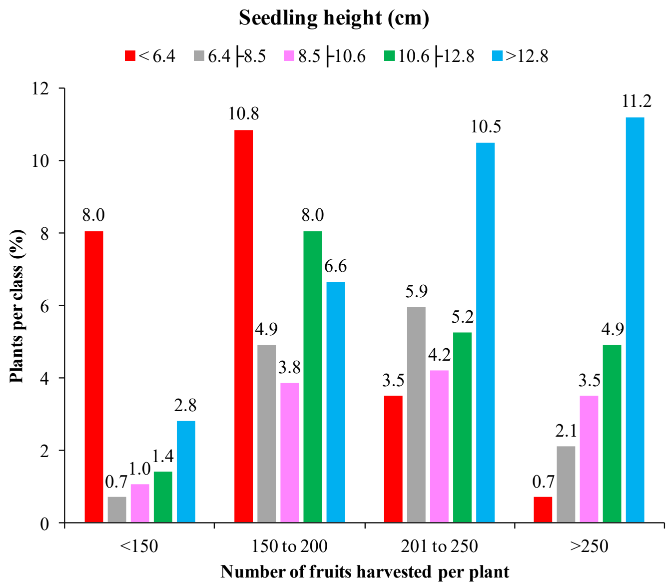


Figure 5. Percentage of *Physalis angulata* L. plants as a function of seedling height and number of fruits harvested.

Therefore, *P. angulata* L. seedlings should not be transplanted to the field with a height of less than 6.4 cm. Seedlings with lower heights have smaller leaf area, lower photosynthetic capacity and less developed roots with lower effectiveness in nutrient absorption, which can compromise the initial development and fruit production (PERIN et al., 2018; DIEL et al., 2022). In the study by Rodrigues et al. (2013), it was observed that *P. peruviana* L. seedlings with smaller dimensions had low vegetative development in the field and, consequently, reduced fruit production.

The distribution of the number of plants was dependent on the classes of diameter and number of fruits per plant (Chi-Square = 60.50, $p < 0.0001$). In the class with the highest number of fruits per plant (> 250), the largest contribution came from the class of seedlings with diameter of 3.7├4.2 mm. However, of the total number of plants obtained from seedlings with diameter equal to or greater than 4.2 mm, 86 and 94% had yields higher than 200 and 150 fruits per plant, respectively. On the other hand, of the total of plants obtained from seedlings with diameter of 3.7├4.2 mm, fewer plants, 60 and 90%, reached the same production (Figure 6).

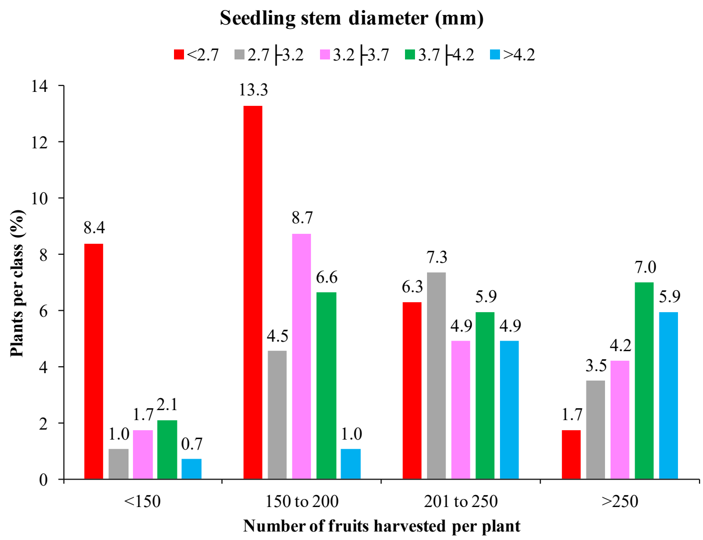


Figure 6. Percentage of *Physalis angulata* L. plants as a function of seedling stem diameter and number of fruits harvested.

The results agree with those reported by Gomes et al. (2013), who state that larger stem diameter indicates better development of shoots and roots. Stem diameter affects the efficiency of water and nutrient transport via xylem. The same authors state that plants with larger diameters have a more efficient vascular system, allowing a greater absorption of water and nutrients from the soil, in addition to ensuring greater support for the plant (ZIMMERMANN, 2014).

Therefore, in view of the results observed for height and diameter, although there was lower percentage of the total plants with diameter of 4.2 mm in the class of highest yield (7%) than with diameter of 3.7├4.2 mm. When considering the two largest classes, *P. angulata* seedlings with higher growth in height and stem diameter promoted higher yields.

Based on the equations for seedling growth in height (Figure 1A) and diameter (Figure 2A), the seedlings needed to remain in the nursery for 38 days in order to promote greater height (16.3 cm) and diameter (4.2 mm), resulting in more productive plants. The results obtained showed seedlings with greater height and diameter than those obtained by Melo et al. (2020), who conducted a study to evaluate substrates for the production of *P. peruviana* seedlings and, with 47 days of nursery, obtained seedlings with average height of 7.38 cm and average diameter of 2.24 mm.

The definition of seedling quality standards based on easily measured variables is useful information for the management of agricultural crops. Thus, it is essential that producers are aware of these factors so that the selected seedlings are able to ensure good economic and production returns.

CONCLUSION

To maximize fruit production in *P. angulata*, seedlings should be transplanted with height equal to or greater than 12.8 cm and stem diameter equal to or greater than 4.2 mm, for which they had to remain in the nursery for 38 days after sowing.

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