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Seeds

Impact of the maturity stage on harvest point of fruits and physiological quality of *Physalis peruviana* L. seeds

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Abstract -The objective of this work was to evaluate the physical-chemical and physiological changes during the maturation of fruits and seeds of *P. peruviana* and to determine the best stage for harvesting in the Brazillian semi-arid conditions. The fruits of *P. peruviana* were collected at five stages of maturation based on the color of the epicarp: stage 1: light green fruit; stage 2: yellowish-green; stage 3: light yellow with green color in the area that connects to the calyx; stage 4: yellow; stage 5: yellowish-orange. Physical and physico-chemical (length, diameter, fresh weight, fruit and calyx color, and total soluble solids) characteristics were evaluated. The physiological characteristics of the seeds were evaluated for water content and dry weight, germination percentage, germination speed index, emergence percentage, emergence speed index were also determined. The highest values of fruit weight, width, length and total soluble solids were recorded from stage S5, although it did not differ from stages S3 and S4. *P. peruviana* seeds reached their maximum physiological quality from S3 stage. On the other hand, the harvesting of fruits with characteristics meeting the minimum standards required for sale and consumption *in natura* should be carried out when the fruit and the calyx appear completely yellow, in the S4 stage. These findings point out which attributes may help improve current methods for monitoring ripening of physalis, in particular the commercially important specie *P. peruviana*.

Index terms: Solanaceae, seed quality, physiological maturity, small fruits.

Impacto do estágio de maturação sobre o ponto de colheita dos frutos e qualidade fisiológica de sementes de *Physalis peruviana* L.

Resumo - O objetivo deste trabalho foi avaliar as alterações físico-químicas e fisiológicas durante a maturação de frutos e de sementes de *P. peruviana* e determinar o melhor estágio de colheita nas condições semiáridas brasileiras. Os frutos de *P. peruviana* foram coletados em cinco estádios de maturação, de acordo com a cor do epicarpo. Estágio 1: fruto verde-claro; estágio 2: verde-amarelado; estágio 3: amarelo-claro com coloração verde na área que se conecta ao cálice; estágio 4: amarelo; estágio 5: laranja-amarelado. Foram avaliadas as características físicas e físico-químicas (comprimento, diâmetro, massa fresca, cor do fruto e do cálice e sólidos solúveis totais). As características fisiológicas das sementes foram avaliadas quanto ao teor de água, ao peso seco, à percentagem de germinação, ao índice de velocidade de germinação, à percentagem de emergência e ao índice de velocidade de emergência. Os maiores valores para peso, largura, comprimento e sólidos solúveis totais do fruto foram registrados no estágio S5, embora não tenha diferido dos estágios S3 e S4. Sementes de *P. peruviana* atingiram sua qualidade fisiológica máxima a partir do estádio S3. Por outro lado, a colheita de frutos com características que atendam aos padrões mínimos exigidos para comercialização e consumo *in natura* deve ser realizada quando o fruto e o cálice se apresentam totalmente amarelos, no estágio S4. Esses achados apontam quais atributos podem ajudar a melhorar os métodos atuais de monitoramento do amadurecimento de physalis, em particular da espécie comercialmente importante *P. peruviana*.

Termos para indexação: Solanaceae, qualidade da semente, maturidade fisiológica, frutos pequenos.

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Introduction

Physalis peruviana L. is a highly functional fruit, native to tropical South America, belonging to the Solanaceae family (MAJCHER et al., 2020). Popularly known as goldenberry, cape gooseberry or simply physalis, the fruits are highly appreciated in many regions of the world due to their organoleptic characteristics (flavor, odor and color), nutritional value (vitamins A, B and C) and content of health-promoting pharmacological compounds (PUENTE et al., 2019). The fruits are consumed mostly *in natura*, but are also processed into jams, beverages, yogurts and sauces (BALLESTEROS-VIVAS et al., 2019; MARCHIORETTO et al., 2020). Cultivation of the species is thus an interesting alternative for farmers.

Various research works on the chemical composition of cape gooseberry extract have demonstrated the presence of several bioactive compounds, particularly withanolides from the whole plant (YANG et al., 2020), leaves (LAN et al., 2009), roots (YU et al., 2021) and calyxes (BALLESTEROS-VIVAS et al., 2019), having medicinal properties, including antimicrobial (HEGAZY et al., 2019) anti-cancer (HSIEH et al., 2021), antioxidant (PUENTE et al., 2021), anti-inflammatory and immunomodulatory (TORO et al., 2014; MIER-GIRALDO et al., 2017), anti-diabetic and hypocholesterolemic (VAILLANT et al., 2021), among others.

P. peruviana plants exhibit a wide range of edaphoclimatic adaptations, although the most suitable conditions for fruit production are found in temperate and subtropical regions (MARCHIORETTO et al., 2020). In Brazil, the cultivation of *Physalis* is recent and is typically by small farmers, with the species *P. peruviana*, being grown the most. Most cultivation occurs in the Center-South of the country due to suitable climatic conditions (NUNES et al., 2018), as well as good public acceptance, equal or even greater than other “small fruits” (TREVISANI et al., 2016). However, expand the planting of this fruit tree in Brazil, it is necessary to carry out research that to develop methods of cultivation and management in different regions of the country, as well as to determine the process of fruit ripening and viability of seeds of, since the sexual route is the main form of the species’ propagation.

Some studies have shown that the environmental conditions during plant development have a relevant influence on the attributes of *Physalis* fruits during ripening and on productivity (TANAN et al., 2021, RODRIGUES et al., 2021). Although there is plentiful information to determine the fruit and seed maturity of *P. peruviana* (SBRUSSI et al., 2014. DINIZ and NOVEMBRE 2019), there are few studies on the maturation process in different ecotypes and regions of Brazil (RODRIGUES et al., 2021). Studies of this nature is important from the biological viewpoint and for accurate identification of the time when seeds reach their maximum germination potential and vigor (MILANEZ et al., 2016; MEDEIROS et al., 2020), as well as the ideal point for harvesting the fruit of economically important species, such as *Physalis* (DINIZ and NOVEMBRE, 2019; RAMOS et al., 2021). On the other hand, when the harvest is carried out at an inappropriate time, it causes considerable losses in seed quality, in addition to inducing quantitative losses. This is particularly important to maximize the shelf life and economic return for producers.

Therefore, the main objective of this study was to evaluate for the first time the physical and physiological changes during the maturation of fruits and seeds of *P. peruviana* and to determine the best stage for harvesting of cape gooseberry fruits in the Brazillian semiarid conditions.

Material and Methods

Location of the experiments and origin of plant material

The work was conducted in the experimental field of the Horto Florestal of Feira de Santana State University (UEFS) located in the municipality of Feira de Santana, in a semi-arid region of the state of Bahia, Brazil (7°32′12″S; 37°29′18″W and altitude of 234 m). According to the Köppen and Geiger (1928) classification, the climate of the region is BSh (hot semiarid climate, characterized by a short rainy season in summer, with average annual temperature of 24.0 ºC, average annual rainfall of 848 mm, concentrated from June to August, and average relative humidity of 65%. The soil of the region is classified as red-yellow podzolic, eutrophic equivalent and the physical and chemical properties of soil (Table 1) were determined in the Soils and Plant Nutrition Laboratory of Embrapa : organic matter = 24.0 g kg^{-1}, pH= 6.1, Ca = 2.8 cmolc dm^{-3}; K = 0.15 cmolc dm^{-3}; Mg = 1.05 cmolc dm^{-3}; Na = 0.05 cmolc dm^{-3}; potential acidity (H + Al) = 1.98 cmolc dm^{-3}; sum of bases (SB) = 4.04 cmolc dm^{-3}; cation exchange capacity ($CEC_{(T)}$) = 6.02 cmolc dm^{-3}; base saturation (V%) = 67%; P = 15 mg dm^{-3}, determined according to the methods recommended by (EMBRAPA, 2018).

Table 1. Chemical and physical attributes of the soil used in the experiment.

OM*	pH	P	K	Ca	Mg	Al	Na	H+Al	SB	$CEC_{(T)}$	V
g kg^{-1}	H_2O	mg/ dm					cmolc /dm³				%
24.0	6.1	95	0.15	2.8	1.05	0.1	0.05	1.98	4.04	6.02	67

*Methodology according to EMBRAPA (2018). OM – organic matter; H + Al – potential acidity; SB – sum of bases; CEC(T) – total cation exchange capacity; V – base saturation.

Plant material

For the production of P. *peruviana* seedlings (Figure 1a), seeds collected from ripe fruits (Figure 1b-c) and stored in the seed germination laboratory of UEFS we47re used. The seeds were sown in 300 mL plastic cups filled with the commercial substrate Vivatto Slim Plus® (Figure 1d) and kept in a greenhouse with 40% brightness with daily irrigation. Thirty days after, 60 seedlings were transplanted to the field. The seedlings were distributed in rows with spacing of 0.8 m between plants and 2.0 m between rows (Figure 1e).

Chemical fertilization was performed with NPK fertilizer (nitrogen, phosphorus and potassium) in 1:3:2 proportion (weight basis), respectively, according to recommended by Santos et al. (2019). During the cultivation, the branches were supported as recommended by Muniz et al. (2011). The plants were watered with a drip irrigation system with spacing of 0.8 m between drippers (Figure 1e). For the control of diseases, a solution of emulsified neem oil (1%, v/v) was applied at the beginning of development of plants, when a higher incidence of diseases was observed.

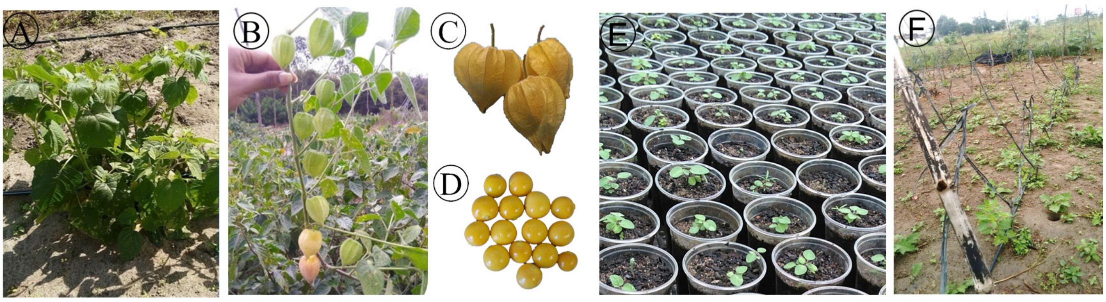

Figure 1. Details of obtaining *P. peruviana* seedlings in a greenhouse until transplanting to the field. A) Plants bearing fruits. B) Collection of ripe fruits. C-D) Extraction of seeds from ripe fruits. E) Seedlings emerged from Vivatto substrate. F) Seedlings planted in the field. Bar = 10 mm.

Physicochemical characterization and fruit ripening

One hundred twenty days after transplanting in the field, fruits were collected at different maturation stages, positions and orientations on the plant. In the laboratory, the fruits were grouped into five maturation stages according to the characteristics of the calyx and fruits, as indicated by the Colombian Institute of Technical Standards and Certification 4580 (ICONTEC, 1999), by means of visual selection based on color of the epicarp of the fruit where: stage 1: light green fruit; stage 2: yellowish-green; stage 3: light yellow with green color in the area that connects to the calyx; stage 4: yellow; stage 5: yellowish-orange.

After visual selection, the predominant colors of the epicarp of the fruits and calyx were determined based on the RHS color chart (ROYAL HORTICULTURAL SOCIETY, 2001). The fruits (n = 45) were evaluated in relation to the following physicochemical attributes: fresh weight (FW) in g, diameter (FD) in mm, fruit length (FL) in mm, and total soluble solids (TSS) in °Brix using a refractometer. The experimental design was completely randomized, consisting of 45 repetitions, for each stage of maturation, with each repetition being one fruit.

Physiological quality of seeds

Water content and dry weight of seeds

After the fruit physicochemical characterization, the seeds were extracted and washed. A portion of the seeds (n = 200) was divided into four replications of 50 seeds of each maturation stage. The seeds were dried in a forced-air oven at temperature of 103 ± 2 ºC during 17 ± 1 h for determination of water content (%) by the difference between initial and final weight (ISTA, 2019). Together with the water content, the seed dry weight was determined (in mg), as the final average weight of the four subsamples of 50 seeds.

Seed germination test

In the germination test, 200 seeds were used for each treatment. The seeds were submitted to desiccation for 72 hours at ambient conditions and were then distributed in Petri dishes containing two sheets of germitest paper moistened with a volume of water equivalent to 2.5 times the weight of the paper substrate. Subsequently, the Petri dishes were kept in a biochemical oxygen demand (BOD) incubator with photoperiod of 12 hours, adjusted with alternating temperature of 20-30 °C for 21 days (RAMOS et al., 2021). Seed germination was evaluated daily, and seeds were considered germinated when the radicle was 2 mm.

The germination percentage (G%), mean germination time (MGT) and germination speed index (GSI) were also determined. For the seed germination test, a completely randomized design was used with 50 seeds per maturation stage and 4 repetitions, totaling 200 seeds.

Seed vigor test

For the vigor test, seeds of the same treatments described above were sown in Styrofoam trays, containing commercial substrate Vivatto Slim Plus® and placed in a controlled environment (40% light and daily irrigation). It is interesting to note that the appearance of cotyledons above the soil line and the expansion of initial structures (cotyledons 1st leaf pair) were considered as emerged and normal seedlings, respectively. Here, the daily emergence data were used to calculate the percentage of normal seedling emergence (E%), the mean emergence time (MTE) and emergence speed index (ESI), calculated according to Ranal and Santana (2006). For the seed vigor test, a completely randomized design was used with 50 seeds per maturation stage and 4 repetitions, totaling 200 seeds.

Statistical analysis

The data were checked for normality using the Shapiro-Wilk test and for homogeneity of variance using the Levene test. Data on germination and emergence percentage were transformed into arcsine ($\sqrt{x/100}$) for normalization. The results were then submitted to ANOVA and the means were compared by the Scott-Knott at 5% probability. All the analyses were performed with the "agricolae" package implemented in the R software (R DEVELOPMENT CORE TEAM, 2021).

Results and Discussion

In this study, the physical and physiological changes during the maturation of fruits and seeds of *P. peruviana* were observed. Among them, the color of the fruits that varied according to the development and maturity (Table 2, Figure 2a-e). In the first two stages of ripening, the color of the fruits varied from green (144A - Table 2, Figure 2a) in stage 1 to yellowish-green (145A) in stage 2 (Table 2, Figure 2b). The fruits collected in stages 3 (Table 2, Figure 2c) and 4 (Table 2, Figure 2d) were yellow of varying shades (12A to 19B, respectively). In the last stage, S5, the fruits were yellowish-orange (22A – Table 2, Figure 2e).

Table 2. Fruit and calyx color of *P. peruviana* harvested in the five stages of fruit development determined using the Royal Horticultural Society (RHS) Color Chart.

	Royal Horticultural Society (RHS) Color	
Stages	Calyx	Fruit
S1	Dark green (144A)[1]	Dark green (144)
S2	Dark green (144A)	Yellowish-green (145A)
S3	Dark green (144A)	Yellow (12A)
S4	Yellow (12A)	Yellow (19B)
S5	Yellowish-brown (163A)	Yellowish-orange (22A)

code.

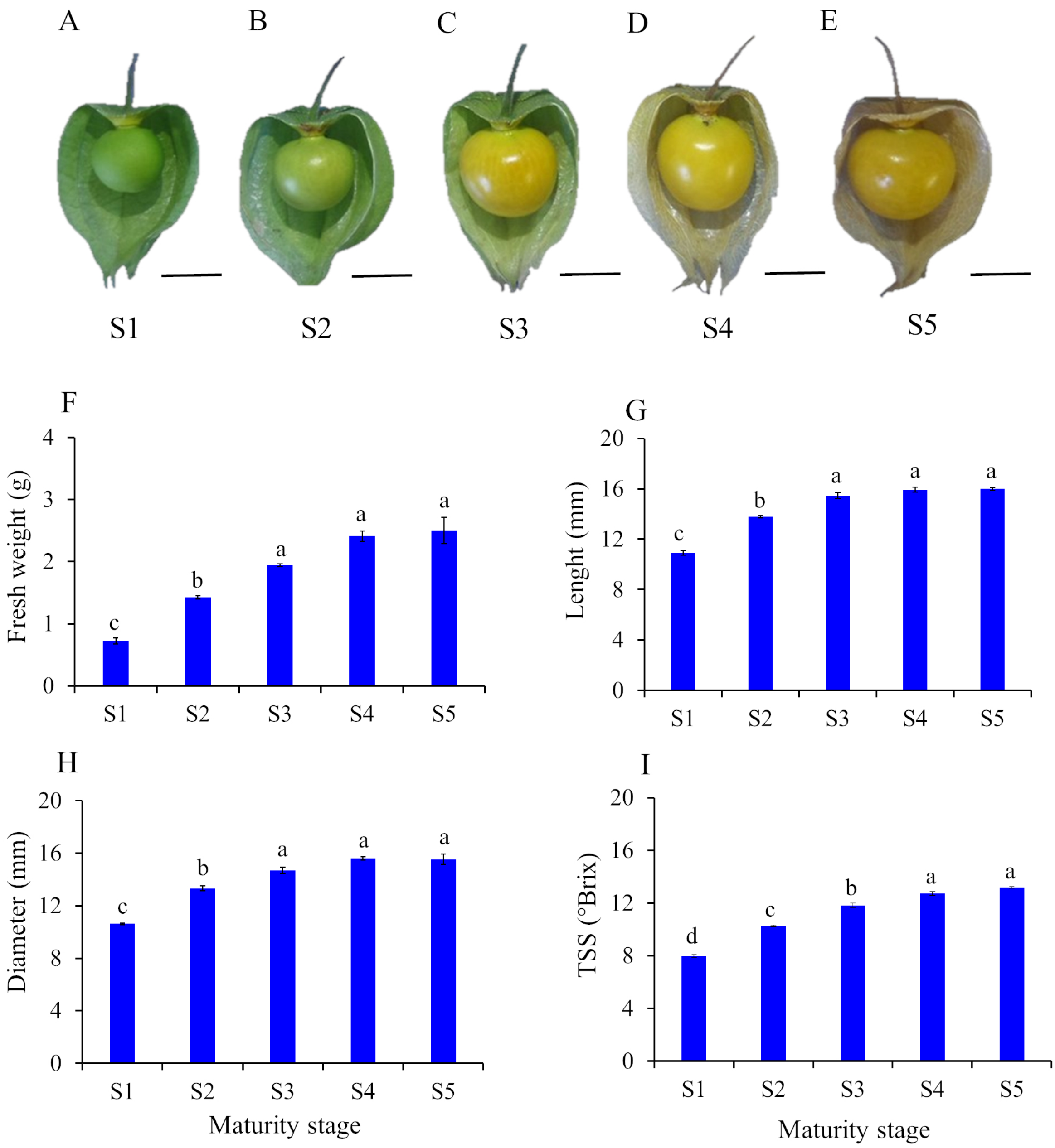

Figure 2. Physicochemical characteristics of *P. peruviana* fruits evaluated at different stages of physiological maturation. A-E) Development stages of the fruit. A) green. B) yellowish-green. C-D) yellow. E) yellowish-orange. F) Fresh weight. G) Fruit length. H) Fruit diameter. I) Total soluble solids. Each value represents the mean ± SE (standard error). Means followed by the same letter belong to the same group by the Scott-Knott test ($p \leq 0.05$). Bar = 10 mm (A-E).

Color is an important characteristic that can be used as an indicator of quality and ripeness of most fruits (PÉREZ-HERRERA et al., 2021; RAMOS et al., 2021). Here, the yellow coloration was more accentuated in the final stages of fruit ripening, since in this stage there is a greater accumulation of β-carotene (WEN et al., 2020). This pigment provides coloration (orange, red, and yellow) to fruits and flowers, making them more attractive to seed dispersers (SATHASIVAM et al., 2020). The results obtained in this study are consistent with those reported by Ramos et al. (2021), who observed changes in the color of *Physalis* fruits throughout the ripening process based on the RHS Color Chart. This demonstrates that this Color Chart can be an efficient tool to identify the appropriate harvest point, with easy application in the field.

Regarding the quality of the cape gooseberry fruits, a significant increase ($p \leq 0.05$) in the fresh weight (FW), fruit length (FL), fruit diameter (FD) and total soluble solids (TSS) were observed during ripening (Figure 2f-i). From stage 3 onwards, similar behavior was observed for the variables FW, FL, FD and TSS. This results indicates that the fruits of *P. peruviana* reached maturity in stage 3. Our findings are consistent with observations of other authors who reported that when the fruit reaches maturity, it does not increase in size, thus being the ideal stage for harvesting (HORVITZ et al. (2017). Diniz and

Novembre (2019) also observed an increase in the weight and diameter of the fruits of *P. peruviana* while the calyx still had a yellowish-green color and yellow fruits. On the other hand, Rodrigues et al. (2012) and Sbrussi et al. (2014) observed an increase in these variables until the calyx showed a greenish yellow color. The association between the results obtained in the present study and by these authors demonstrate that these differences in relation to the maturation point may be related to environmental conditions during fruit development.

The highest averages observed here for FW (25 g), FL (16 mm) and FD (15.6 mm) obtained at stage S5 (Figure 2 f-h), although it did not differ from stage S4. These results were similar to the averages observed by Rodrigues (2018) in plants cultivated in São Domingos, Paraíba, Brazil, with FW of with 2.39 g and FD of 15.43 mm. However, they are lower than the results obtained in other Brazilian regions, such as Lavras, Minas Gerais, with FW of 3.0 g, FL of 17.45 mm and FD of 18.55 mm (RODRIGUES et al., 2012), and Londrina, Paraná, with FL of 18.4 mm and FD of 19.8 mm (SBRUSSI et al., 2014). Although our results were lower compared to other regions of Brazil, the fruits still have commercial potential, being within category B according to the Colombian Technical Standard (NTC 4580) for fruits of *P. peruviana*, in which the fruits are classified in five sizes (S1: ≤ 15.0; S2: 15.1 - 18.0; S3: 18.1 - 20.0; S4: 20.1 - 22.0 and S5: ≥ 22.1 mm).

As for the content of total soluble solids (TSS), there was a significant increase ($p \leq 0.05$) with the ripeness stage (Figure 2i). The highest averages were observed in the last two stages (S4 and S5) with 13.7 °Brix and 14.2 °Brix, respectively, although they did not differ statistically. The results found here were close to those of Rodrigues et al. (2014) who reported 13-14 °Brix in *P. peruviana* mature fruits. According to the ICONTEC NTC 4580 standard (2019) for the sale of *P. peruviana* fruits, the TSS content must be at least 14 °Brix. Therefore, the values obtained in our study satisfy the standard necessary for harvest and marketing.

The content of soluble solids is a characteristic of great relevance for most species of *Physalis*, which are mainly consumed fresh, since it is related to the fruit's flavor (Barroso et al., 2017). However, the harvest of *P. peruviana* fruits that have the appropriate characteristics for sale and consumption must be carried out at S4 stage, since this did not differ statistically from stage S5 and will possibly have a longer shelf life.

Regarding the seed maturation process, the water content (WC) differed significantly between the maturation stages (Figure 3). In the S1 stage, when the seeds were immature, the water content was 52%. This characteristic declined significantly until reaching 32% in stage S3 and remained stable above 30% in the most advanced stages of maturation (S4 and S5). Studies carried out on other *Physalis* species have also shown a high water content even after reaching physiological maturity, such as *P. ixocarpa* with 50% (BARROSO et al., 2017) and *P. angulata* with WC above of 30% (SANTIAGO et al., 2019). These findings indicate that high WC is an intrinsic characteristic of the seeds of species of the *Physalis* genus.

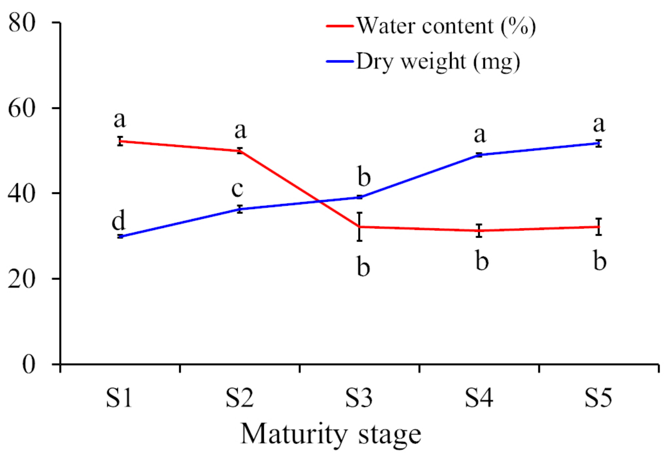

Figure 3. Water content (%) and dry weight (mg) of seeds from of five stages of development of *P. peruviana* fruits. The different letters above the error bars indicate statistically different means according to the Scott-Knott test ($p \leq 0.05$).

In the early stages of seed maturation, high water content is necessary both for the translocation of plant metabolites to the seeds and for cell expansion. However, at the end of this process, this content decreases, reducing the metabolic processes, and the seeds enter the quiescent state, more suitable for dispersal (BEWLEY and NONOGAKI, 2017). In fleshy fruits, such as those of *Physalis*, due to the composition of the pulp, the water content of the seed remains high (DINIZ and NOVEMBRE, 2019). In this case, due to the moisture inside the fruit, the seeds do not undergo accentuated desiccation or major oscillations in their water content (DEMIR et al., 2002). Thus, upon reaching physiological maturity, the orthodox seeds that develop into fleshy fruits remain with water content in the range of 30 to 50% (CARVALHO and NAKAGAWA, 2012).

The seed dry weight (SDW) showed opposite behavior to that obtained for water content (Figure 3), since there was a significant increase in SDW ($p \leq 0.05$) throughout the ripening of fruits. In the S1 stage, an SDW value of 29.9 mg was recorded while in the last S5 stage this variable was 48.9 mg, although this was not different from the S4 stage. These findings are consistent with those obtained by other authors, who have reported that during seed development, in the early stages there is a large increase in the seed dry weight due to the deposition of reserves in the storage tissues (BEWLEY and NONOGAKI, 2017). In the present study, we observed a strong increase in SDW until stage S4, indicating the seeds were developing until this stage. After this stage, there was no significant increase in SDW, indicating they had reached mature mass.

Other authors have reported very different results to those obtained in our study. Sbrussi et al. (2014) did not find an increase in the seed weight during the ripening of fruits. Diniz and Novembre (2019) observed an increase in the seed weight of *P. peruviana* until the fruits showed a greenish-yellow color and a greenish-yellow calyx. These different results occurred due to the influence of climatic conditions on the speed of changes in the characteristics of cape gooseberry fruits during development, as well as the possible genetic differences in the material used for propagation (FISCHER et al., 2007).

With regard to seed germination potential, a significant increase ($p \leq 0.05$) of this variable was observed with advancing maturation stages (Figure 4a). The lowest germination percentages occurred at the maturation stage S1, due to the seeds' physiological immaturity in this phase. Carvalho and Nakagawa (2012) reported that for determination of seed physiological maturity, physical and physiological characters should be considered, including seed water content, germination and vigor. Thus, the high seed water content in stage S1 and the low germination indicate the low seed vigor at this stage is due to physiological immaturity.

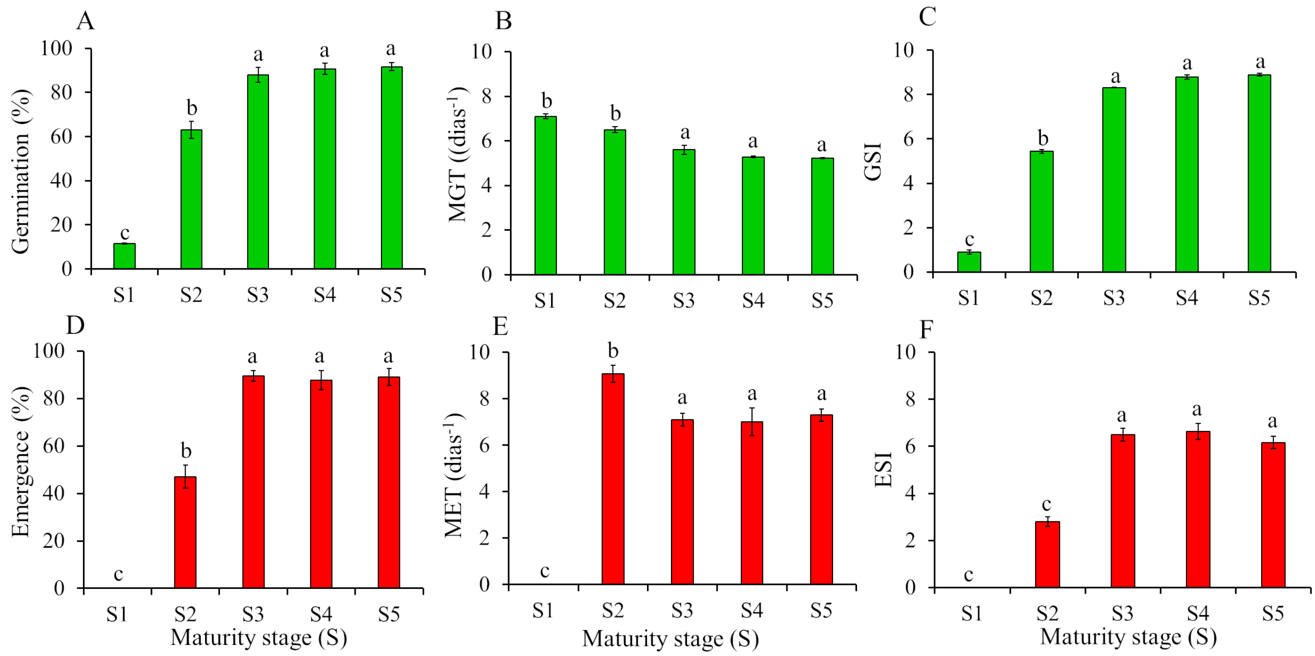

Figure 4. Germination (G%), mean germination time (MGT), germination speed index (GSI), emergence percentage (E%), mean emergence time (MTE) and emergence speed index (ESI) of *P. peruviana* seeds obtained from fruits with different maturation stages. The different letters above the error bars indicate statistically different means according to the Scott-Knott test ($p \leq 0.05$).

In the present study, values of seed germination above 90% were observed in the stage S5, although it did not differ statistically from stages S3 (88%) and S4 (90.5%) (Figure 4a). The same behavior was observed in relation to the mean germination time (Figure 4b) and germination speed index (Figure 4c), since the seeds extracted from fruits with yellowish-orange color (stage S5) showed a higher germination percentage in the shortest time interval.

The seedling emergence percentage, mean emergence time and the emergence speed index were also significantly affected by the fruit maturation stage (Table 2; Figure 4d-f). The emergence of seeds collected from fruits at stage S1 was zero (Figure 4d). This result may be related to the fact that the embryo at this stage is not fully formed (BEWLEY and NONOGAKI, 2017). Our findings showed that the seeds collected from the S4 stage had the highest percentages of seedling emergence (91%), the shortest mean time (7 days) and the best speed index (6.6) indicating that in this stage the seeds were much better formed and were more vigorous (Figure 4d-f). Our results are in line with those of Diniz and Novembre (2019), who also found higher GER (%), E (%), GSI and ESI in *P. peruviana* seeds from yellow fruit and calyx. In contrast, Sbrussi et al. (2014) did not observe an influence of fruit maturation stage on the germination percentage, emergence and emergence speed index of *P. peruviana* seeds.

The joint analysis of water content, dry weight, seed germination and seedling emergence indicated that the seeds of *P. peruviana* reached physiological maturity in fruits at stage 3, but the maximum accumulation of dry weight was observed from stage 4 onwards (Figure 5). Carvalho and Nakagawa (2012) reported that the physiological maturity has been reached when the seeds had maximum dry weight and a marked reduction in water content, coinciding with the maximum germination capacity and vigor.

In the present study, the seeds reached physiological maturity before maturity based on the maximum accumulation of dry matter. A similar result was found in other species of Solanaceae, such as pepper (*Capsicum baccatum var. pendulum*) (FIGUEIREDO et al., 2017).

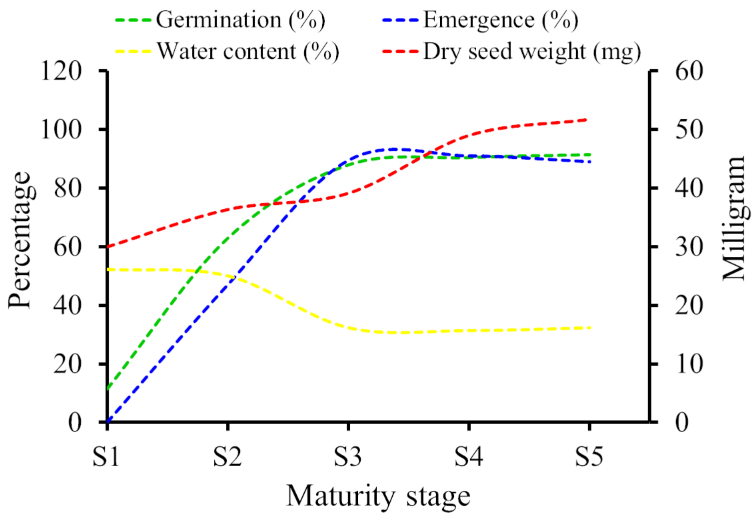

Figure 5. Relationship of the traits water content, dry weight, germination and seedling emergence from dry seeds of *P. peruviana*.

Fruit maturity is one of the main indicators of seed maturity because the point when the fruit reaches maturity coincides with the moment when the seeds reach maximum germination. It is interesting to highlight that in our study, the seeds of *P. peruviana* reached physiological maturity stage 3, but the maximum accumulation of dry weight was observed from stage 4 onwards (Figure 5). However, in this stage (S3) the fruits had lower physicochemical characteristics than those required for fresh consumption as well as for industrial processing. Therefore, it is necessary to harvest the fruits in the S4 stage, when completely yellow.

The cultivation of *P. peruviana* is an alternative source of income in Brazil, especially for small farmers, since it has low production cost and good financial return due to appealing food characteristics and medicinal potential. Therefore, the cultivation of this species should be expanded to different regions. In this respect, genotypes with larger and heavier fruits and greater productivity should be developed, in accordance with the edaphoclimatic conditions of the cultivation region (FISCHER et al., 2007). Thus, research related to the fruit and seed maturation process is essential to identify the moment when fruits reach the ideal harvest point and the seeds reach maximum physiological quality, besides to save agricultural inputs, labor and possible losses due to environmental conditions.

Conclusions

The present study demonstrated that the coloration and external appearance of the peel is a good indicator of the maturity of *P. peruviana* fruits and can be used to determine the harvest point. The optimal harvest time for the production of cape gooseberry fruits under the conditions of this experiment occurred when the fruits and the calyx were completely yellow, in the S4 stage. *P. peruviana* seeds reached their maximum physiological quality from S3 stage. However, the intensification of these studies will contribute to improving the quality of seedlings and consequently increasing the productivity and useful life of *P. peruviana* orchards.

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References

BALLESTEROS-VIVAS, D.; ÁLVAREZ-RIVERA, G.; SÁNCHEZ-CAMARGO, A.; DEL P.; IBÁNE, E.; PARADA-ALFONSO, F.; CIFUENTES, A. A multi-analytical platform based on pressurized-liquid extraction, *in vitro* assays and liquid chromatography/gas chromatography coupled to high resolution mass spectrometry for food by-products valorisation. Part 1: Withanolides-rich fractions from goldenberry (*Physalis peruviana* L.) calyces obtained after extraction optimization as case study. **Journal of Chromatography A**, Amsterdam, v.1584, n.1, p.155–164, 2019.

BARROSO, N.S.; SOUZA, M.O.; RODRIGUES, L.C.S.; PELACANI, C.R. Maturation stages of fruits and physiological seed quality of *Physalis ixocarpa* Brot. Ex Hormen. **Revista Brasileira de Fruticultura**, Jaboticabal, v.39, n.3, p.1-9, 2017.

BEWLEY, J.D.; NONOGAKI, H. **Seed maturation and germination**. Reference module in life sciences. Netherlands: Elsevier, 2017. p. 1-9.

CARVALHO, N.M.; NAKAGAWA, J. **Sementes**: ciência, tecnologia e produção. 5.ed. Jaboticabal: FUNEP, 2012. 590 p.

DEMIR, I.; MAVI, K.; OZCOBAN, M. Seed development and maturation in Aubergine (*Solanum melongena* L.). **Gartenbauwissenschaft**, Stuttgart, v.67, n.4, p.148-154, 2002.

DINIZ, F.O.; NOVEMBRE, A.D.L.C. Maturation of *Physalis peruviana* L. seeds according to flowering and age of the fruit. **Revista Ciência Agronômica**, Fortaleza, v.50, n.3, p.447-457, 2019.

EMBRAPA. **Sistema brasileiro de classificação de solos**. 5.ed. Brasília: Embrapa Solos, 2018.

FIGUEIREDO, J.C.; DAVID, A.M.S.S.; SILVA, C.D.; AMARO, H.T.R.; ALVES. D.D. Maturação de sementes de pimenta em função de épocas de colheita dos frutos. **Revista Scientia Agraria**, Cutritiba, v.18, n.3, p.1-7, 2017.

FISCHER, G.; EBERT, G.; LÜIDDERS, P. Production, seeds and carbohydrate contents of cape gooseberry (*Physalis peruviana* L.) fruits grown at two contrasting Colombian altitudes. **Journal of Applied Botany and Food Quality**, Göttingen, v.81, n.1, p.29-35, 2007.

HORVITZ, S.; CHANAGUANO, D.; AROZARENA, I. Andean blackberries (*Rubus glaucus* Benth) quality as affected by harvest maturity and storage conditions. **Scientia Horticulturae**, New York, v.226, p.293-301, 2017.

HEGAZY, E.M.; ALI, A.O.; EL-SAYED, H.S.; KASSEM, J.M. Quality properties of husk tomato juice and its impact in stirred probiotic yogurt. **Asian Food Science Journal**, London, v.7, n.2, p.1-10, 2019.

HSIEH, K.Y.; TSAI, J.Y.; LIN, Y.H.; CHANG, F.R.; WANG, H.C.; WU, C.C. Golden berry 4β hydroxywithanolide E prevents tumor necrosis factor α induced procoagulant activity with enhanced cytotoxicity against human lung cancer cells. **Scientific Reports**, New Delhi, v.11, n.4610, p.1-12, 2021.

ICONTEC. **Frutas frescas: uchuva, especificaciones.** Bogotá: Instituto Colombiano de Normas Técnicas, 1999 15 p. (NTC, 4580).

ISTA - International Seed Testig Association. **International rules seed testing**. Rome, 2019.

KÖPPEN, W.; GEIGER, R. **Klimate der Erde**. Gotha: Verlag Justus Perthes, 1928.

LAN, Y.- H.; CHANG, F.-R.; PAN, M.-J.; WU, C.-C.; WU, S.-J.; CHEN, S.-L.; WANG, S.-S.; WU, M.J.; WU, Y.-C. New cytotoxic withanolides from *Physalis peruviana*. **Food Chemistry**, London, v.116, n.2, p.462–469, 2009.

MAJCHER, M.A.; SCHEIBE, M.; JELE, H.H. Identification of odor active compounds in *Physalis peruviana* L. **Molecules**, Basel, v.25, n.2, p.1-9, 2020.

MARCHIORETTO, L.R.; ROSSI, A.; CONTE, E.D. Chemical root pruning improves quality and nutrient uptake of Cape Gooseberry (*Physalis peruviana*) seedlings. **Scientia Horticulturae**, New York, v.261, n.1, p.1-8, 2020.

MEDEIROS, A.D.; ZAVALA-LEÓN, M.J.; SILVA, L.J.; OLIVEIRA, A.M.S.; DIAS, D.C.F.S. Relationship between internal morphology and physiological quality of pepper seeds during fruit maturation and storage. **Agronomy Journal**, Madison, v.112, n.1, p.25-35, 2020.

MIER-GIRALDO, H., DÍAZ-BARRERA, L.E., DELGADO-MURCIA, L.G., VALERO-VALDIVIESO, M.F., CÁEZ-RAMÍREZ, G. Cytotoxic and immunomodulatory potential activity of *Physalis peruviana* fruit extracts on cervical cancer (HeLa) and fibroblast (L929) cells. **Journal of Evidence-Based Complementary and Alternative Medicine**, Oxford, v.22, n.4, p.777-787, 2017.

MILANEZ, J.T.; NEVES, L.C.; SILVA, P.M.C.; BASTOS, V.J.; SHAHAB, M.; COLOMBO, R.C.; ROBERTO, S.R. Pre-harvest studies of buriti (*Mauritia flexuosa* L.F.), a Brazilian native fruit, for the characterization of ideal harvest point and ripening stages. **Scientia Horticulturae**, New York, v.202, n.1, p.77-82, 2016.

MUNIZ, J.; KRETZSCHMAR, A.A.; RUFATO, L.; PELIZZA, T.R.; MARCHI, T.; DUARTE, A.E.; LIMA, A.P.F.; GARANHANI, F. Sistemas de condução para o cultivo de *Physalis* no planalto catarinense. **Revista Brasileira de Fruticultura**, Jaboticabal, v.33, n.3, p.830-838, 2011.

NUNES, A.L.; SOSSMEIER, S.; GOTZ, A.P.; BISPO, N.B. Germination eco-physiology and emergence of *Physalis peruviana* seedlings. **Journal of Agricultural Science and Technology B**, Libertyville, v.8, n.1, p.352-359, 2018.

PUENTE, L.; NOCETTI, D.; ESPINOSA, A. *Physalis peruviana* Linnaeus, an update on its functional properties and beneficial effects in human health. *In:* MARIOD, A.A. **Wild fruits:** composition, nutritional value and products. 2.ed. Cham: Springer International Publishing, 2019. p. 447-463.

PÉREZ-HERRERA, A.; MARTÍNEZ-GUTIÉRREZ, G.A.; MORALES, I.; SÁNCHEZ-MEDINA, M.A.; ESCAMIROSA-TINOCO, C. Physicochemical characterization and antioxidant activity of wild *Physalis* spp. genotypes. **Emirates Journal of Food and Agriculture**, Abu Dhabi, v.33, n.6, p.458-464, 2021.

PUENTE, L.; NOCETTI, D.; ESPINOSA, A. Effects of drying methods on the characterization of fatty acids, bioactive compounds and antioxidant capacity in a thin layer of physalis (*Physalis peruviana* L.) pulp. **Journal of Food Science and Technology**, Mysore, v.58, n.4, p.1470–1479, 2021.

R DEVELOPMENT CORE TEAM. **R**: a language and environment for statistical computing. Vienna: R Foundation for Statistical Computing, 2021.

RAMOS, C.A.S.; SOARES, T.L.; BARROSO, N.S.; PELACANI, C.R. Influence of maturity stage on physical and chemical characteristics of fruit and physiological quality of seeds of *Physalis angulata* L. **Scientia Horticulturae**, New York, v.284, n.1, p.1-10, 2021.

RANAL, M.A.; SANTANA, D.G. How and why to measure the germination process?. **Brazilian Journal of Botany**, São Paulo, v.29, n.1, p.1-11, 2006.

RHS. **Colour chart**. 4th ed. London: Royal Horticultural Society, 2001.

RODRIGUES, F.A.; PENONI, E.S.; SOARES, J.D.R.; PASQUAL, M. Caracterização do ponto de colheita de *Physalis peruviana* L. na região de Lavras-MG. **Bioscience Journal**, Uberlandia, v.28, n.6, p.862-867, 2012.

RODRIGUES, F.A.; PENONI, E.S.; SOARES, J.D.R.; SILVA, R.A.L.; PASQUAL, M. Caracterização física, química e físico-química de *Physalis* cultivada em casa de vegetação. **Ciência Rural**, Santa Maria, v.44, n.8, p.1411-1414, 2014.

RODRIGUES, M.H.B.S.; Penoni, E.S.; Soares, J.D.R.; Pasqual, M. Characterization of physiological maturity of *Physalis peruviana* L. fruits. **Semina**: Ciencias Agrarias, Londrina, v.42, n.1, p.929-948, 2021.

SANTOS, C.F.; DIAS, G.C.; PINTO, S.I.C.; LEITE, P.C.; SILVA, K.P. Adubação de plantio com NPK para a cultura do *Physalis* (*Physalis peruviana* L.). **Revista Agroambiental**, Pouso Alegre, v.11, n.2, p.179-192, 2019.

SANTIAGO, W.R.; GAMA, J.S.N.; TORRES, S.B.; BACCHETTA, G. Physiological maturity of *Physalis angulata* L. seeds. **Revista Ciência Agronômica**, Fortaleza, v.50, n.3, p.431-438, 2019.

SATHASIVAM, R.; RADHAKRISHNAN, R.; KIM, J.K.; PARK, S.U. An update on biosynthesis and regulation of carotenoids in plants. **South African Journal of Botany**, Amsrterdam, v.140, p.290-302, 2020.

SBRUSSI, C.A.G.; ZUCARELI, C.; PRANDO, A.M.; SILVA, B.V.A.B. Maturation stages of fruit development and physiological seed quality in *Physalis peruviana*. **Revista Ciência Agronômica**, Fortaleza, v.45, n.3, p.543-549, 2014.

TANAN, T.T.; SILVA, A.L.; LEITE, R.S.; ARRIERO, S.S.; NASCIMENTO, M.N. *Physalis* growth, development and yield at different sowing seasons in the brazilian northeastern semiarid. **Colloquium Agrariae**, Presidente Prudente, v.17, n.1, p.36-43, 2021.

THOMÉ, M.; OSAKI, F. Adubação de nitrogênio, fósforo e potássio no rendimento de *Physalis* spp. **Revista Acadêmica Ciência Animal**, Curitiba, v.8, n.1, p.11-18, 2010.

TORO, R.M.; ARAGÓN, D.M.; OSPINA, L.F.; RAMOS, F.A.; CASTELLANOS, L. Phytochemical analysis, antioxidant and anti-inflammatory activity of calyces from *Physalis peruviana*. **Natural Product Communications**, Westerville, v.9, n.11, p.1-3, 2014.

TREVISANI, N.N.; SCHMIT, R.; BECK. M.; GUIDOLIN, A.F.; COIMBRA, J.L.M. Selection of fisális populations for hibridizations, based on fruit traits. **Revista Brasileira de Fruticultura**, Jaboticabal, v.38, n.2, p.1-7, 2016.

VAILLANT, F.; CORRALES-AGUDELO, V.; MORENO-CASTELLANOS. N.; ÁNGEL-MARTÍN, A.; HENAO-ROJAS, J.C.; MUÑOZ-DURANGO, K.; POUCHERET, P. Plasma metabolome profiling by high-performance chemical isotope-labelling LC-MS after acute and medium-term intervention with golden berry fruit (*Physalis peruviana* L.), confirming its impact on insulin-associated signaling pathways. **Nutrients**, Basel, v.13, n.3125, p.1-16, 2021.

YANG, W.-J.; CHEN, X.-M.; WANG, S.-Q.; HU, H.-X.; CHENG, X.-P.; XU, L.-T.; REN, D.-M.; WANG, X.-N.; ZHAO, B.-B.; LOU, H.-X.; SHEN, T. 4β-Hydroxywithanolide E from goldenberry (whole fruits of *Physalis peruviana* L.) as a promising agent against chronic obstructive pulmonary disease. **Journal of Natural Products**, Columbus, v.83, n.4, p.1217−1228, 2020.

YU, T.J; CHENG, Y.B.; LIN, L.C.; TSAI, Y.H.; YAO, B.Y.; TANG, J.Y.; CHANG, F.R.; YEN, C.H.; YANG, F.O.; CHANG, H.W. *Physalis peruviana*-derived Physapruin A (PHA) inhibits breast cancer cell proliferation and induces oxidative-stress-mediated apoptosis and dna damage. **Antioxidants,** Basel, v.10, n.393, p.1-14, 2021.

WEN, X.; HELLER, A.; WANG, K.; HAN, Q.; NI, Y.; CARLE, R.; SCHWEIGGERT, R. Carotenogenesis and chromoplast development during ripening of yellow, orange and red colored *Physalis* fruit. **Planta**, Berlin, v.251, n.95, p.1-16, 2020.