http://journal.unoeste.br/index.php/ca/index
DOI: 10.5747/ca.2024.v20.h524
ISSN on-line 1809-8215

Colloquium Agrariae

Submetido: 27/07/2022 Revisado: 07/06/2023 Aceito: 31/01/2024

PHENOLOGY AND HARVEST POINTS OF SNAP BEAN VARIETIES RELATED TO DEGREE DAYS ACCUMULATION

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Abstract

The objective of this study was to characterize the phenology and determine the harvest points of snap bean varieties related to degree-day accumulation. The experiments were conducted in the Teaching Garden of the Federal University of Ceará, evaluating five bean genotypes. A randomized block design with three and five replications was used for experiments 1 and 2, respectively. Each experimental unit consisted of a 9.6 m seedbed. In the first experiment, the spacing adopted was 0.1 x 0.4 m (24 plants per plot). For the second experiment, the spacing adopted was 0.1 x 0.3 m (32 plants per plot). Phenological characterization was carried out, estimating the thermal requirement and the pod growth curve. The evaluated genotypes presented thermal requirements ranging between 1,282 and 2,111 °C per day. The Habichuela genotype presented shorter cycle length, lower degree-day accumulation and higher initial pod growth compared to the others. It is recommended to harvest Feijão Vagem do Panamá (FVP), Habichuela and De Metro between the 10^{th} and 15^{th} day after fruiting. For Pronto Alívio and Quiura Bejuco, the harvest should be conducted at the 20^{th} day after fruiting.

Keywords: phenological characterization; growth curve; thermal requirement.

FENOLOGIA E PONTOS DE COLHEITA DE VARIEDADES DE FEIJÃO-VAGEM RELACIONADOS COM O ACÚMULO DE GRAUS-DIA

Resumo

Objetivou-se com este estudo caracterizar a fenologia e determinar os pontos de colheita de variedades de feijão-vagem relacionados com o acúmulo de graus-dia. Os experimentos foram realizados na Horta Didática da Universidade Federal do Ceará, avaliando-se cinco genótipos de feijão-vagem. Utilizou-se o delineamento em blocos casualizados com três e cinco repetições para

os experimentos 1 e 2, respectivamente. Cada unidade experimental foi constituída por um canteiro com 9,6 m de comprimento. No primeiro experimento, adotou-se o espaçamento de 0,1 x 0,4 m (24 plantas parcela^{-1}). Para o segundo experimento, o espaçamento adotado foi de 0,1 x 0,3 m (32 plantas parcela^{-1}). Realizou-se a caracterização fenológica, estimando-se a exigência térmica e a curva de crescimento das vagens. Os genótipos avaliados apresentaram exigência térmica variando entre 1.282 e 2.111 °C dia^{-1}. O genótipo Habichuela apresentou menor duração de ciclo, menor acúmulo de graus-dia e maior crescimento inicial de vagens em comparação aos demais. Recomenda-se a colheita do Feijão Vagem do Panamá, Habichuela e De Metro entre o 10º e 15º dia após a frutificação. Para Pronto Alívio e Quiura Bejuco, a colheita deve ser realizada aos 20 dias após a frutificação.
Palavras-chave: caracterização fenológica; curva de crescimento; exigência térmica.

Introduction

Common bean (*Phaseolus vulgaris* L.) and cowpea bean (*Vigna unguiculata* L. Walp.) are leguminous plants that have great commercial importance around the world, being cultivated in more than 100 countries, mainly in the humid and semi-arid tropics of Africa, Asia and the Americas (Silva *et al.*, 2018). In Brazil, the cultivation of common beans predominates in the Midwest, Southeast, and South regions, mainly due to climatic factors. In turn, the cowpea bean prevails in the North and Northeast regions, especially for its wide adaptability, low production cost and high nutritional value (Vale; Bertini; Borém, 2017).

In Brazil, the production of fresh pods is basically intended for consumption *in natura*, being directed to the industry in small quantities. Among the aforementioned species, the most widely cultivated for pod production and consumption is *P. vulgaris* L. (snap bean); however, the production of *V. unguiculata* ssp. *sesquipedalis* (yardlong bean) has been growing in the last decade (Gomes *et al.*, 2016). This growth has been motivated mainly by its better adaptation, better aspect, fruit length and exotic flavor, being traditional in Eastern cuisine and present in regional foods from the Midwest and North of Brazil (Carnib, 2017). In addition, both species have important nutritional properties, representing excellent sources of iron, proteins, carbohydrates, vitamins and minerals (Mullins; Arjmandi, 2021; Kotue *et al.*, 2018).

For commercialization, the pods must be harvested while they are still green (immature), tender and with little developed seeds, and the ideal harvest point is when the pods reach maximum development, but before they become fibrous and with protruding seeds. At this stage, the pods are easily cooked, which favors their form of consumption (Vale; Bertini; Borém, 2017; Peixoto; Cardoso, 2016). This market segment is attractive and presents potential for expansion; however, the scarcity of information in the literature regarding the phenological characterization of cultivars with pod aptitude makes it difficult to exploit the species (Lazaridi *et al.*, 2017).

Phenology refers to the part of botany that studies the different phases of growth and development of plants, both vegetative and reproductive, marking the times of occurrence and their respective characteristics (Oliveira *et al.*, 2018). Accordingly, the phenological characterization of bean accessions is relevant for supporting the work of producers and breeders, thus providing information both for the choice of genotypes suitable for the growing conditions, as well as for their genetic improvement (Santana *et al.*, 2019). In addition, the knowledge about phenology helps in the assertive management of the crop, facilitating the adoption of good cultivation strategies, providing higher yields and profitability (Lopes Sobrinho *et al.*, 2019).

In combination with phenology, the determination of degree days is relevant because it allows the evaluation of the duration of the cycle, thus considering not only the duration in days, but also its variation in relation to temperature (Saffariha *et al.*, 2021; Sarker *et al.*, 2020). This information can be used to indicate the climatic potential of a region in relation to the production of varieties of the species under study, and can also contribute to the planning of activities and implementation of crops (Khouzani, 2021). In several plant species such as maize (Hamid *et al.*, 2020), soybean (Akyuz *et al.*, 2017), cotton (Ban *et al.*, 2015) and grape (Pires; Lima, 2018), a close relationship between cycle length and thermal accumulation has been identified.

In view of the above, the objective of this work was to characterize and relate the phenology of snap bean varieties with degree-day accumulation.

Material and Methods

Five bean genotypes were evaluated in this survey, one belonging to the species named *P. vulgaris* L. and four to the species named *Vigna unguiculata*, all with potential for pod production (Table 1).

Table 1. Evaluated genotypes and their respective origins.

Genotype	Scientific name	Origin
Habichuela	*Vigna unguiculata ssp. sesquipedalis*	Panama
Feijão Vagem do Panamá	*Vigna unguiculata ssp. sesquipedalis*	Panama
Pronto Alívio	*Vigna unguiculata* L.	Panama
Quiura Bejuco	*Phaseolus vulgaris* L.	Panama
Feijão de Metro	*Vigna unguiculata ssp. sesquipedalis*	Brazil

In 2019, two trials were conducted in the Teaching Garden of the Federal University of Ceará (UFC), in Fortaleza, Ceará. The experimental area used presented the following geographical coordinates: 3º44'25" South latitude, 38º34'35" West longitude and altitude of 19.5 meters. According to the Köppen classification, the climate of the region is Aw, rainy tropical type. During the conduction of the trials, daily information on temperature and rainfall was collected from the database of the agrometeorological station of the UFC (Table 2).

Table 2. Period of conduction of the trials and their respective average temperatures and rainfall.

Essay	Realization period	Duration	Maximum average temperature	Minimum average temperature	Accumulated precipitation
1	Feb 27 - Jun 24	117 days	32.7 ºC	25.1 ºC	1647.3 mm
2	Aug 19 - Nov 27	101 days	31.5 ºC	25.3 ºC	20.8 mm

This study used an experimental design containing randomized blocks with three and five replications for the first and second trials, respectively. In both experiments, sowing was carried out using three seeds per hole, and thinning was performed seven days after sowing (DAS), leaving one plant in each hole. Each experimental unit consisted of a 9.6 m seedbed. In the first experiment, the spacing adopted was 0.1 x 0.4 m, totaling 24 plants per plot. For the second experiment, the spacing adopted was 0.1 x 0.3 m, resulting in 32 plants per plot.

In both experiments, the localized micro-sprinkler irrigation system was used, being performed twice a day, early in the morning and late in the afternoon. In order to perform the staking, bamboo stakes were used to be driven into the soil, which were placed every three meters within the cultivation lines. The stakes had their apexes joined by a piece of galvanized wire, 20 gauge, at an estimated height of 2.20 m.

For foundation fertilization, 1.2 kg of nitrogen fertilizer (urea with 45% N) was applied per seedbed, distributed manually along the planting line. At 20 and 40 DAS, top dressings were applied with the same proportion of urea. The control of pests and weeds was carried out according to the need observed in the field.

For phenological characterization of the genotypes, the description of Laing, Jones and Davis (1984) was used, who consider the bean development stages in two phases: vegetative and reproductive. The degree days required for the development of each stage were calculated based on equation 1:

$$ADD = [(Tmax + Tmin) / 2] - Tba$$

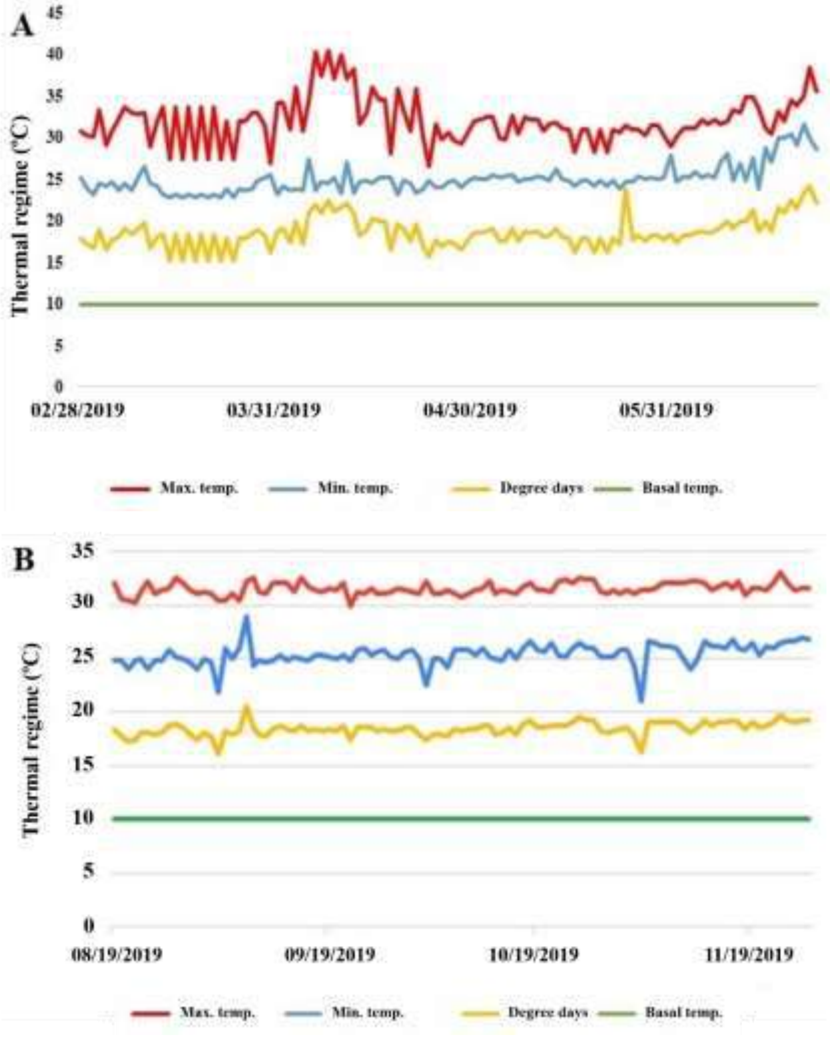
where: ADD: accumulated degree days; Tmax: maximum daily air temperature (°C); Tmin: minimum daily air temperature (°C); Tba: lower base temperature (°C).

A total of 30 pods were selected from each variety, ten from each plot, and evaluated from the beginning of the R7 phase (fruit set) until the end of R9 (pod drying). The length and diameter of the selected pods were measured daily using a graduated ruler (cm) and a digital pachymeter (mm), respectively.

Results and Discussion

During the period of the first experiment, the average temperatures ranged between 25 and 35 °C (Figure 1). The ideal temperature range for the development of common bean is between 15 and 29 °C (Fancelli, 2009); while, for cowpea bean, it is between 22 and 34 °C (Vale; Bertini; Borém, 2017). The knowledge of these temperature ranges is important, because prolonged exposure of these species to temperatures above 35 °C can cause serious metabolic stresses, thus damaging their development and production.

Figure 1. Thermal regimes recorded over the course of two snap bean experiments. Experiment 1 (A) and Experiment 2 (B).

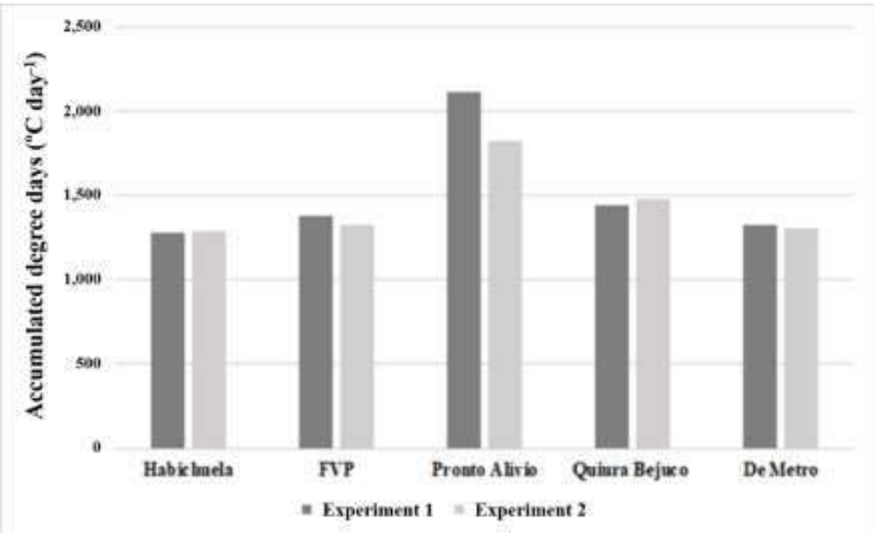


The thermal regime of the second experiment showed more stability, with less variation between the extreme temperatures, with averages of 25.3 and 31.5 °C for the minimum and maximum temperatures, respectively.

The temperatures may have influenced the photosynthetic activity of the plants and, consequently, their phenological cycle. For both studied bean species, temperatures around 25 °C provided greater photosynthetic activity and higher production (Fancelli, 2009; Vale; Bertini; Borém, 2017).

The overall average accumulated degree days (ADD) of the genotypes during the first trial was 1496 ºC per day, with the cycles lasting an average of approximately 82 days; while, in the second experiment, conducted in the August to November subperiod, the overall average was 1444ºC per day, with an average cycle of 79 days, thus indicating that, in the second half of the year, there was less thermal requirement of the genotypes for completion of their cycles (Figure 2). According to Khouzani (2021), the increase in ambient temperature causes a reduction in ADD's to complement each phenological stage, which may result in shorter cycles. The information on the duration of the phenological stages is relevant since it allows the producer to schedule himself to carry out the managements to be carried out in the culture since both already have a defined correlation.

Figure 2. Accumulated degree days for the five snap bean genotypes evaluated in two experiments.

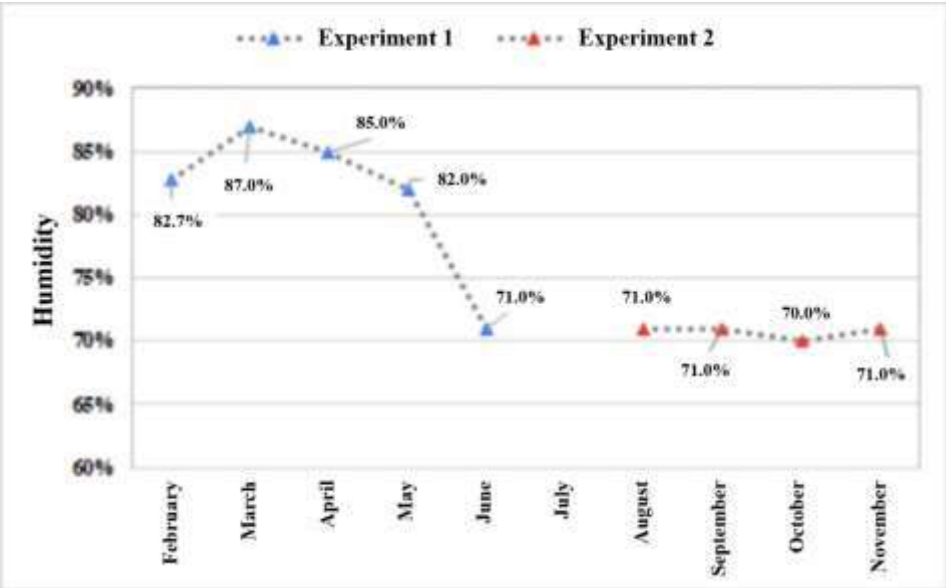


The varieties presented little variation in accumulation of ADD in relation to the experiments, except for the variety named Pronto Alívio, for which it was observed the need for a greater thermal accumulation for the total accomplishment of its cultivation cycle (Figure 2). This small variation in ADD presented by the genotypes may have been due to the small variation in temperature between the trials (Figure 1).

In both experiments, the variety named Habichuela presented the least variation in thermal need, with a total of 1282 °C per day accumulated over 70 days in the first experiment, and 1288 °C per day accumulated over 71 days in the second trial (Figure 2). With the exception of the Pronto Alívio genotype, the average thermal accumulation rates observed for the other genotypes were similar to those observed by Khouzani (2021) who, under the cultivation conditions of Ahwaz, localized in Iran, found thermal requirements ranging from 1150 to 1430 degree days for the cowpea bean variety named Baghdadi.

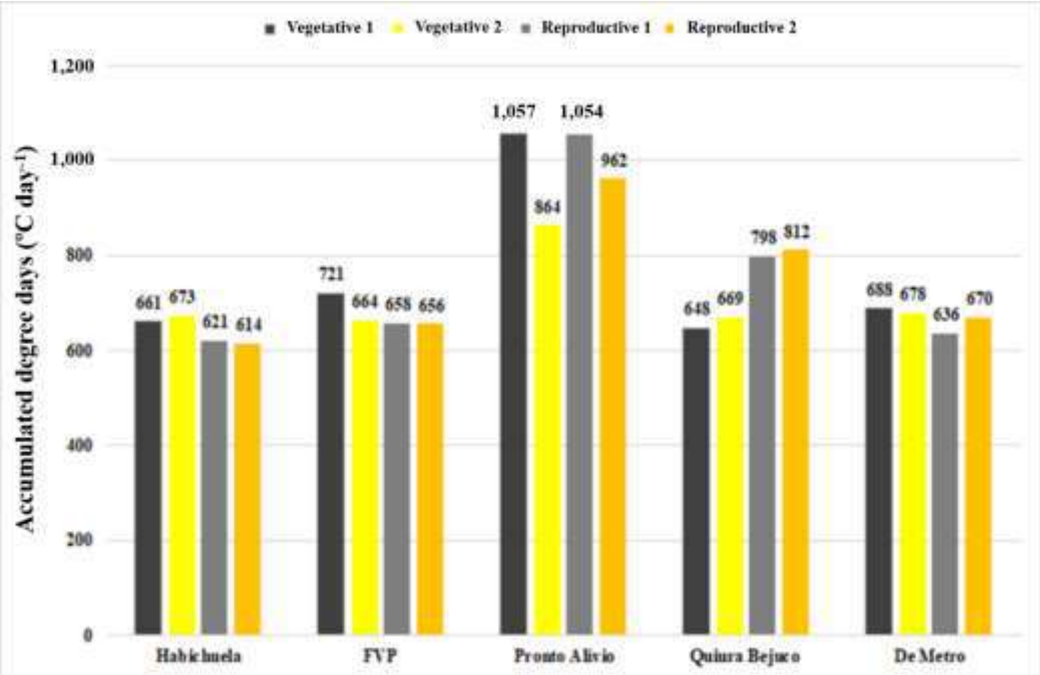
Based on the ADD results, the Pronto Alívio variety was considered the later variety, because it had a greater thermal need to accomplish its cycle compared to the others (Figure 2). The above average prolongation verified for its vegetative phenophases, mainly in the V3 and V4 stages, with consequent increase in the production of vegetative branches, especially in the first experiment, may be due to the strong influence of climatic conditions on the phenological behavior of the crop. This is because the high levels of relative air humidity (Figure 3) observed in the first experiment, coupled with high temperatures (Figure 1), may have influenced metabolic activities in this genotype, potentiating its indeterminate growth habit, resulting in the prolongation of its vegetative stage (Qaderi; Martel; Dixon, 2019).

Figure 3. Humidity variation recorded over two snap bean experiments.



In order to better understand the thermal requirement of snap bean varieties, it is important to analyze the ADD requirement for accomplishment of the vegetative and reproductive phases, separately (Figure 4), although both occur concomitantly in the plants. During the vegetative phase, the Quiura Bejuco genotype presented thermal accumulation like that recorded by the Habichuela, Feijão Vagem do Panamá (FVP) and De Metro varieties. Nonetheless, during the reproductive phase, it required the second highest thermal sum, behind only to the Pronto Alívio variety.

Figure 4. Accumulated degree days in the vegetative and reproductive phases for the five evaluated bean genotypes.

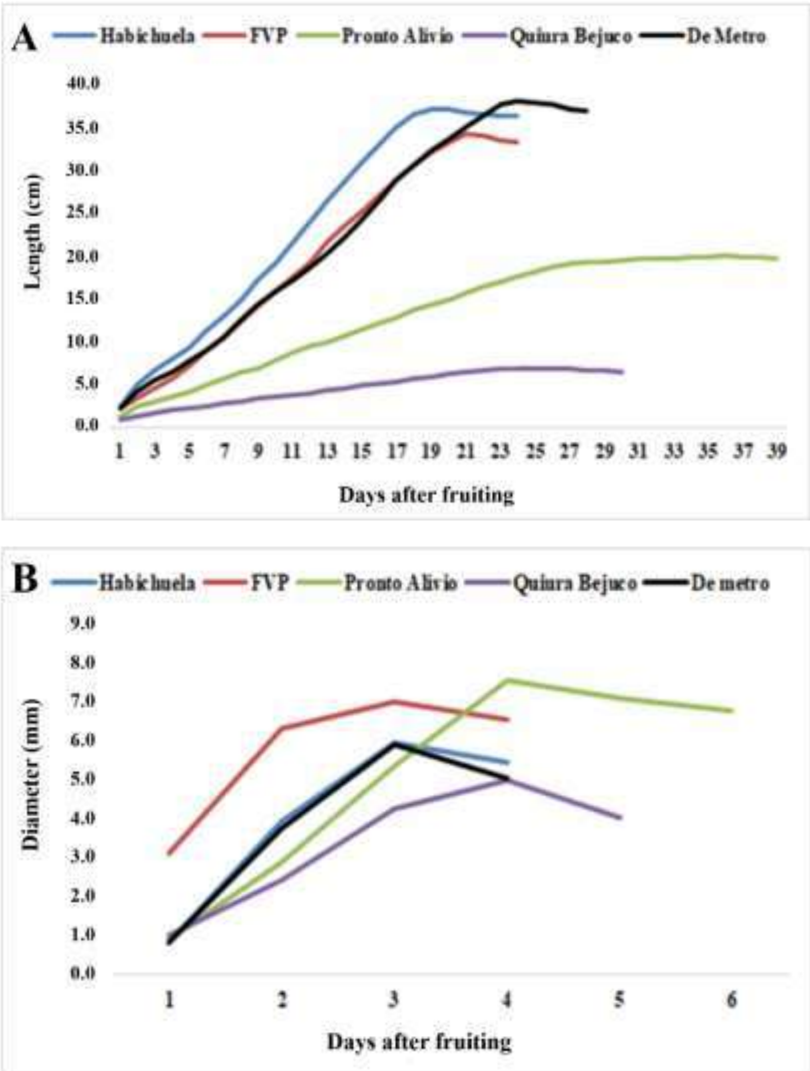


The phase of greatest thermal requirement in the bean plant is a matter of controversy among authors. According to Moura *et al.* (2012), the vegetative phase requires higher levels of ADD because the most complex processes are carried out precisely at this stage. Therefore, in the reproductive phase, the plant would already be fully structured to develop the other processes related to the accomplishment of the cycle. For Silva *et al.* (2017), the reproductive stage requires a greater number of degree days compared to the vegetative stage due to the metabolic intensity required for grain formation. Disagreeing reports in the literature may be explained by the genetic differences between the evaluated varieties and the different environmental conditions to which they were subjected.

In the current study, the varieties named Pronto Alívio and Quiura Bejuco presented behaviors in agreement with the statement of Silva *et al.* (2017). On the other hand, the varieties named Habichuela, Feijão Vagem do Panamá (FVP) and De Metro presented similar behaviors to those found by Moura *et al.* (2012), presenting higher thermal requirements in the vegetative phase than in the reproductive phase (Figure 4). This result indicates that the three aforementioned genotypes present slower metabolic activity and/or greater needs in the vegetative phase. From a practical point of view, the ideal is that the reproductive phase is accomplished as quickly as possible, because it is in this phase that the crop is more vulnerable to losses in quality of grains and pods due to the attack of pests and diseases. Therefore, it is advantageous to cultivate genotypes that present lower thermal requirement during the reproductive phases.

The pod growth curves as a function of time, for the different evaluated genotypes, are presented in Figure 5. All curves presented sigmoid behavior, but the genotypes named Habichuela, Feijão Vagem do Panamá (FVP) and De Metro presented well-defined curves.

Figure 5. Pod growth curves of five bean genotypes evaluated in two experiments. Length (A) and Diameter (B).



It was found that the varieties named Habichuela, Feijão Vagem do Panamá (FVP) and De Metro presented growth curves with similar shapes, thus indicating similar behavior in relation to pod formation (Figure 5). However, the Habichuela genotype stood out from the others regarding initial growth, recording the highest average daily growth (2 cm per day). This variety presented a duration of 24 days for the fruiting-harvesting subperiod and its pods reached the maximum length

19 days after the R7 stage, with an average of 36.3 cm. The highest growth rates were observed between the 11th and 15th day after fruiting, which is the most appropriate time to harvest the pods of this variety. After the 20th day, there was a regression in pod length due to the natural drying process.

The variety named Feijão Vagem do Panamá (FVP) presented its physiological maturity 24 days after the beginning of fruiting, with its pods reaching their maximum length on the 22nd day, with an average of 33.5 cm (Figure 5). The genotype De Metro presented pods with a maximum length of 37.3 cm on the 28th day after the beginning of fruiting. The genotypes named Quiura Bejuco and Pronto Alívio presented similar phenological behavior, expressing slower average pod growth compared to the other varieties. The aforementioned genotypes presented daily growth rates of 0.3 and 0.5 cm per day, respectively, resulting in later cycles. The Pronto Alívio variety even presented the longest number of days for pod production (39 days), reaching a maximum length of 19.6 cm only on the 36th day after fruiting.

With respect to pod diameter, it was found that the genotypes named Habichuela, Feijão Vagem do Panamá (FVP) and De Metro presented the highest growth rates in the first seven days after fruiting. The varieties named Quiura Bejuco and Pronto Alívio, on the other hand, showed the highest growth rates in the period between the 8th and 14th day after fruiting (Figure 5). In turn, the genotypes Feijão Vagem do Panamá (FVP), Habichuela and De Metro presented the largest pod diameters at the beginning of week 3 (7.09, 6.02 and 5.98 mm, respectively), between 10 and 15 days after fruiting, which is the ideal time to harvest them. The Pronto Alívio and Quiura Bejuco varieties presented maximum values for this parameter only in the fourth week after fruiting, with 7.64 and 5.06 mm, respectively, and could be harvested 20 days after fruiting.

The right moment of harvesting to maximize the yield of commercial pods still raises some doubts and probably differs between bean cultivars. It is generally accepted that the ideal pod harvest time is before physiological maturity, when the seeds are still underdeveloped (beginning of grain filling), that is, when the pods reach maximum development, but before they become fibrous and with protruding seeds (Peixoto; Cardoso, 2016). In agreement with the statement of the aforementioned authors, in the current work, the maximum growth of pods in terms of length and diameter was verified between the second and third weeks after fruiting (Figure 5), approximately 50-60 days after sowing the plants, being, therefore, defined as the ideal period for harvesting the pods of the tested genotypes.

In general, the simultaneous predominance of high temperatures, low rainfall and low relative humidity, climatic characteristics recorded in the second experiment, caused a reduction in the thermal requirements of the evaluated genotypes. The knowledge of this result is important because it allows the prediction of the behavior of cultivated genotypes, thus helping producers in the management of snap beans.

Conclusions

The evaluated genotypes presented thermal requirements ranging between 1,282 and 2,111ºC per day. The Habichuela genotype presented shorter cycle length, lower degree-day accumulation and higher initial pod growth compared to the others. It is recommended to harvest Feijão Vagem do Panamá (FVP), Habichuela and De Metro between the 10th and 15th day after fruiting. For Pronto Alívio and Quiura Bejuco, the harvest should be conducted at the 20th day after fruiting.

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