DOI: 10.5433/1679-0359.2017v38n6p3897

Harvest season and seed physiological potential of 'dedo-de-moça BRS Mari' hot peppers

Época de colheita dos frutos e potencial fisiológico das sementes de pimenta 'dedo-de-moça BRS Mari'

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Abstract

The cultivation of *chili peppers* (*Capsicum* spp.) plays a key role in the fresh vegetable, condiment, and preserve markets. The determination of the harvest season suitable for seed production is crucial to obtain high-quality seeds and ensure production success. Therefore, this study aimed to determine the harvest season of 'dedo-de-moça BRS Mari' hot peppers that provides the maximum seed physiological potential. The flowers in anthesis were labeled daily and the fruits were harvested 25, 40, 55, 70, 85, and 100 days after anthesis (DAA) and classified as green, yellowish green, orange, red, extreme red, and intense red, respectively. The seed physiological potential was determined by using the water content, dry matter, germination, first germination count, germination rate index, and accelerated aging tests. The seed dry matter increased steadily until 55 DAA (3.95 mg per seed), then increased slightly to 70 DAA (4.05 mg per seed), and stabilized from 85 to 100 DAA. The harvested seeds began to germinate at 55 DAA with approximately 40% germination, which peaked at 70 DAA with 87% germination; this value was maintained until 100 DAA. The highest values of the germination rate index were found at 70, 85, and 100 DAA. An increase in seed vigor was observed, based on the accelerated aging test, which peaked at 85 DAA and subsequently decreased. The peppers were harvested between 70 and 85 DAA and red to extreme red were found to be the most recommended colors to obtain 'dedo-de-moça BRS Mari' hot pepper seeds with high physiological potential.

Key words: *Capsicum baccatum* var. *pendulum*. Germination. Vigor. Physiological maturity.

Resumo

O cultivo de pimentas (*Capsicum* spp.) representa um importante papel no mercado das olerícolas *in natura*, no segmento de condimentos, e conservas. A determinação do ponto ou intervalo adequado de colheita dos frutos para a produção de sementes é fundamental para a obtenção de sementes de qualidade e para garantir o sucesso da produção. Diante disso, objetivou-se determinar o estádio de colheita de

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Received: Apr. 03, 2017 - Approved: Sept. 20, 2017

frutos de pimenta 'dedo-de-moça BRS Mari' que proporcione o máximo potencial fisiológico das sementes. As flores em antese foram etiquetadas diariamente e os frutos foram colhidos aos 25, 40, 55, 70, 85 e 100 dias após a antese (DAA), classificados em verde, verde-amarelado, alaranjado, vermelho, vermelho extremo e intenso, respectivamente. O potencial fisiológico das sementes foi determinado pelos testes de teor de água, massa de matéria seca, germinação, primeira contagem de germinação, índice de velocidade de germinação e envelhecimento acelerado. A massa da matéria seca das sementes aumentou até os 55 DAA (3,95 mg por semente), após este período ocorreu um pequeno aumento até os 70 DAA (4,05 mg por semente) e dos 85 aos 100 DAA estabilizou. As sementes colhidas iniciaram a germinação aos 55 DAA com aproximadamente 40% e aos 70 DAA foi máxima de 87% com valores constantes até os 100 DAA. Os maiores valores de índice de velocidade de germinação foram obtidos aos 70, 85 e 100 DAA. Observou-se haver aumento do vigor pelo envelhecimento acelerado até os 85 DAA, onde o valor foi máximo com posterior redução. A colheita dos frutos a partir dos 70 DAA até os 85 DAA, coloração vermelha a vermelha extrema, é a mais recomendada para obtenção de sementes de pimenta 'dedo-de-moça BRS Mari' de alto potencial fisiológico.
Palavras-chave: *Capsicum baccatum* var. *pendulum*. Germinação. Vigor. Maturidade fisiológica.

The hot peppers 'dedo-de-moça' (*Capsicum baccatum* var. *pendulum*), also known as chifre-de-veado, pimenta-vermelha, and calabresa in Brazil, are widely used in cooking, particularly in the states of Rio Grande do Sul, São Paulo, and Goiás (MOREIRA et al., 2009). Their popularity is mainly attributed to their sensory qualities, such as color, flavor, and pungency, and they are used fresh or processed in the form of liquid or dehydrated sauces (CARVALHO et al., 2009).

The hot pepper market is a segment with great economic and social potential in Brazil (DOMENICO et al., 2012). However, seed companies have little or no interest in the development of new varieties owing to the low yield, difficulty of seed extraction, low seed physiological potential, and lack of production methods (NASCIMENTO et al., 2006). This hot pepper variety is usually grown by smallholder farmers who generally use seeds from peppers harvested in their own farms for sowing.

Hot pepper plants have indeterminate growth and continuous flowering and fruiting that results in fruits at different maturity stages. Thus, as fruits at various maturity stages and seeds at different stages of development and physiological maturity are found within the same plant, it is naturally difficult to determine the optimal harvest season (VIDIGAL et al., 2009a). Furthermore, hot pepper species have fleshy fruits, and the seed maturity process continues even after harvesting. Therefore, the optimal harvest time for the collection of seeds with a high physiological potential must be determined (VIDIGAL et al., 2009b).

Seed maturity results from morphological, physical, and physiological changes, including variations in water content, vigor, and dry matter accumulation (GONÇALVES et al., 2015), in addition to visible changes in the appearance of peppers and seeds, and these changes may be used as harvest indicators (CASTRO et al., 2008). During seed maturity, germination and vigor increase, peaking when seeds reach physiological maturity (MARCOS FILHO, 2005).

Several research studies have reported the harvest season effects on species of the Solanaceae family, including tomato (DIAS et al., 2006; VIDIGAL et al., 2006), hot peppers (VIDIGAL et al., 2009a; QUEIROZ et al., 2011; VIDIGAL et al., 2011; ABUD et al., 2013; RICCI et al., 2013; PEREIRA et al., 2014), and eggplant (MARTINS et al., 2012). Vidigal et al. (2009a) assessed peppers of the Amarela Comprida (*C. annuum* L.) variety harvested on 40, 50, 60, and 70 days after anthesis (DAA) and stored for 3, 6, 9, 12, and 15 days and found the best germination and vigor resulted in seeds from peppers harvested on 60 DAA that were not subjected to postharvest storage. Abud et al. (2013), when assessing peppers of the malagueta

(*C. frutescens*) and biquinho (*C. chinense*) varieties harvested on 25, 40, 55, 70, 85, and 100 DAA, found an increase in seed germination percentage between 40 and 70 DAA. The authors suggested that the optimal harvest season, when seed physiological maturity occurs, is approximately 70 DAA. For the 'dedo-de-moça' variety, Pereira et al. (2014) found that the germination percentage peaked on 45 DAA and that postharvest pepper maturation for 10 days improved the seed physiological potential.

The definition of the optimal harvest season is crucial to minimize the effects of seed deterioration. Thus, this study aimed to determine the harvest season of 'dedo-de-moça BRS Mari' hot peppers that provides the maximum seed physiological potential.

The experiment was conducted at the Center for Agricultural Sciences (Centro de Ciências Agrárias; CCA), Londrina State University (Universidade Estadual de Londrina; UEL), Londrina, Paraná, Brazil (23º23′ South, 51º11′ West; altitude, 560 meters), using seeds of the hot pepper 'dedo-de-moça BRS Mari' (*C. baccatum* var. *pendulum*) variety. The seeds were sowed in expanded polystyrene trays (128 cells) containing Plantmax® hortaliças commercial substrate. Forty days after sowing, seedlings with four to six true leaves were transplanted into pots with 5 L of soil and sand in a 3:1 ratio.

The plants were grown in the protected environment of a greenhouse with a transparent plastic cover and screen that provided 70% shading. During the flowering stage, the flowers were labeled on the day of anthesis (the opening of the flower), sufficient seeds were collected for analysis, approximately 60 hot peppers per treatment. Hot peppers were harvested 25, 40, 55, 70, 85, and 100 days after anthesis (DAA). The hot peppers were sent to the Seed Analysis Laboratory, UEL, and their phenological stage was classified based on the external exocarp color (green, yellowish green, orange, red, extreme red, and intense red).

The seeds were manually extracted from the hot peppers by using a utility knife, washed in running water, and placed on a paper towel at room temperature (25 ºC) for 48 h. Once dry, the seeds were packed in plastic polypropylene bags and stored in a cold room for 7 days at 10 °C and 55% relative humidity. The seeds were subjected to the following assessments:

The water content was assessed in an oven at 105 ± 3º C, for 24 h, according to the Rules for Seed Analysis (BRASIL, 2009), with four 50-seed replicates. The results were expressed as a percentage of the wet weight.

Dry matter was determined together with the seed moisture content (ABUD et al., 2013) consisting of the final average mass of four 50-seed replicates after drying at 105 ± 3 °C for 24 h. The results were expressed as mg seeds^{-1}.

The germination was assessed by using four 50-seed replicates. For seed germination, two blotting paper towels moistened with potassium nitrate solution (0.2% KNO_3), equivalent to 2.5 times mass of the dry paper, were placed in gerbox-type plastic boxes (11.0 × 11.0 × 3.5 cm) to overcome physiological dormancy (BRASIL, 2009). The seeds were maintained in a Mangelsdorf-type germination chamber at 25 °C and exposed to an 8-h photoperiod at the highest temperature (BRASIL, 2009). The assessments were performed on the 10th and 17th day after sowing (VIDIGAL et al., 2009a) and the results were expressed as a percentage of the number of normal seedlings.

First germination count was performed together with the germination test. The percentage of normal seedlings was assessed on the 10th day after sowing (ABUD et al., 2013).

The germination rate index (GRI) was determined based on a daily count of the number of normal seedlings from the start of germination on the third day to the end of the test (the 17th day after sowing). At the end of the test, the germination rate index was determined according to Maguire (1962), GRI

$= (G_1/N_1) + (G_2/N_2) + ... + (G_n/N_n)$, wherein GRI is germination rate index, G_1, G_2, ..., G_n is the number of normal seedlings tallied in the first, second, and final count; and N_1, N_2, ..., N_n is the number of days from sowing to the first, second, and final counts.

For the accelerated aging test, 1.0 g of seeds were evenly spread on the stainless-steel screen attached to gerbox-type plastic boxes with 40 mL distilled water in the bottom. The seeds were kept in an incubator at 42 ºC for 96 h (BHERING et al., 2006). After this period, four 50-seed replicates were subjected to the germination test, according to the method described above. A single assessment was performed on the 14th day, which recorded the percentage of normal seedlings (ABUD et al., 2013).

The experimental design was completely randomized with four 50-seed replicates. The results were subjected to analysis of variance. The treatments were subjected to orthogonal decomposition for the first-, second-, third-, and fourth-degree effects. When observing type I errors, at 5% probability, for some effects, the regression equation was fitted. When the above effects lacked significant fit or a variable showed nonlinear behavior, different nonlinear functions were adjusted. All tests were computed using the software R (https://www.r-project.org).

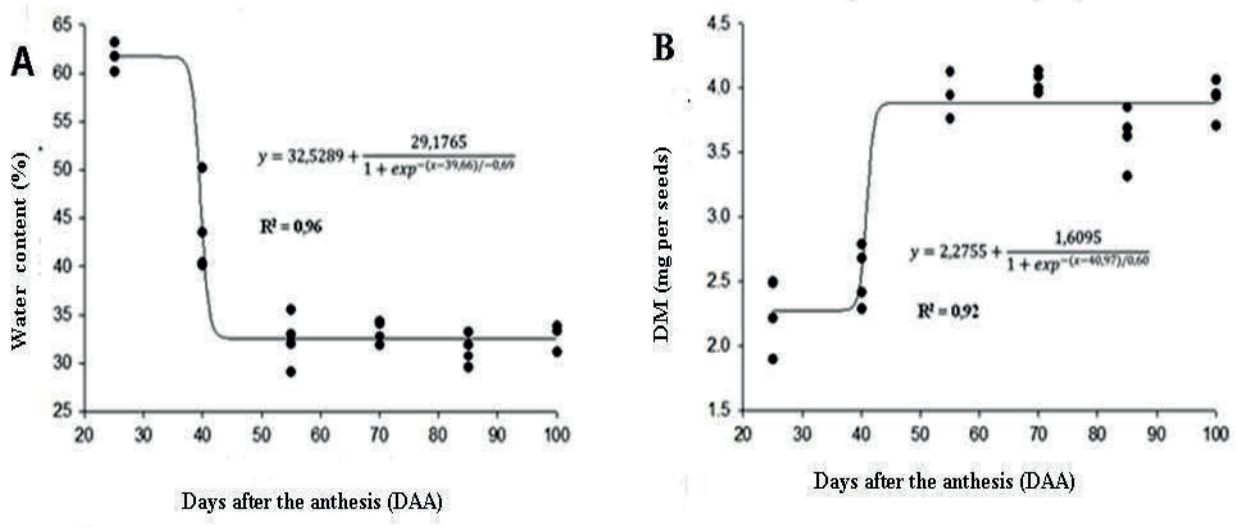
The hot peppers were green, yellowish green, orange, and red on 25, 40, 55, and 70 DAA and extreme red and intense red at 85 and 100 DAA, respectively (Figure 1). In their assessment of the maturity stage of 'dedo-de-moça' hot peppers for seed production, Pereira et al. (2014) found that the hot peppers were intense red on 45 DAA. This occurred because hot peppers have different harvest seasons according to the growing region and season. Crop cycle and harvest season are directly affected by the climatic conditions, cultivation treatments including fertilization and irrigation, pest and disease incidence, and pest control measures (EMBRAPA HORTALIÇAS, 2007).

Figure 1. The appearance of fruits during the maturation process of 'dedo-de-moça BRS Mari' hot peppers (*Capsicum baccatum* var. *pendulum*) on different days after anthesis (DAA).

The initial seed water content, assessed on 25 DAA (green hot peppers), was 63%. At this initial stage of seed development, the water content is naturally higher because embryo formation results from a set of processes of cell expansion and the translocation of metabolites from the plant to the seeds that occurs during this period (BEWLEY et al., 2013). Conversely, the water content decreased to 43% on 40 DAA (yellowish green peppers) and to approximately 34% on 70 DAA (red peppers), but remained constant until the final harvest on 100 DAA (intense red peppers) (Figure 2a). Similar results were reported by Abud et al. (2013), who observed initial water content values higher than 50% in malagueta and biquinho hot pepper seeds on 25 DAA, which decreased during the harvest season. Furthermore, Vidigal et al. (2011) found that sweet peppers of the Amarela Comprida variety were completely immature and that the initial water content of their seeds was higher than 50% on 20 DAA. Conversely, in an evaluation of the physiological potential of 'dedo-de-moça' hot pepper seeds, Justino et al. (2015) observed that the water content decreased during the maturation process.

The accumulation of seed dry matter was minimal in the first stages of development (from 25 to 40 DAA, green and yellowish green peppers), increased after that period, and stabilized on 55 DAA (orange peppers; Figure 2b), which indicated that the plants and seeds interrupted the translocation of assimilates. Abud et al. (2013) observed that the dry matter accumulation of the biquinho and malagueta varieties stabilized at 70 and 80 DAA (red peppers), respectively. According to Piña-Rodrigues and Aguiar (1993), the increased accumulation of seed dry matter is the most reliable physical indicator of the stage of physiological maturity.

Figure 2. Water content (A) and seed dry matter (DM) (B) during the maturation process of 'dedo-de-moça BRS Mari' hot peppers (*Capsicum baccatum* var. *pendulum*)

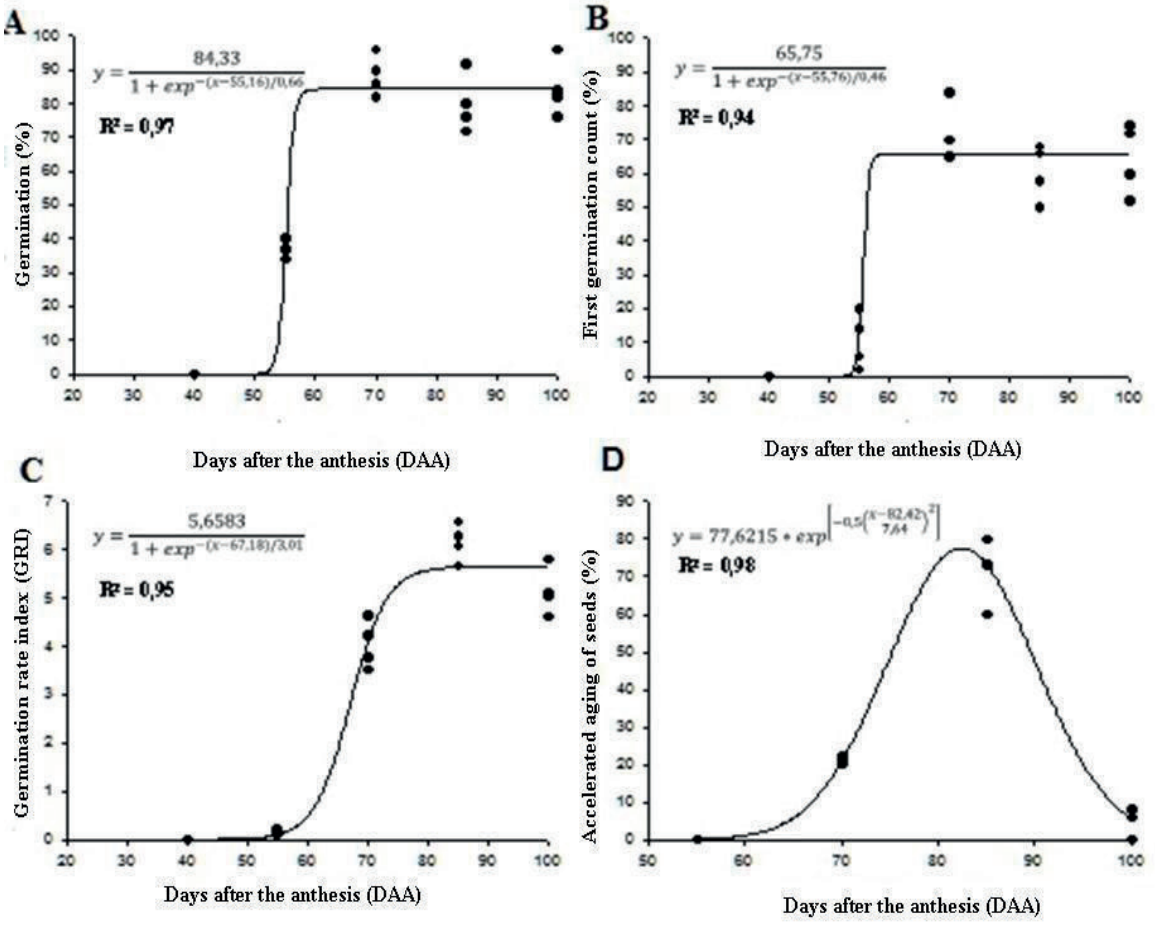


Nascimento et al. (2006) reported that in fleshy fruit species, such as hot peppers, the content of seed dry matter peaks when the hot peppers reach the stage of physiological maturity, which coincides with peak germination and vigor. However, this claim is controversial, because some studies have reported that the peak seed dry matter did not coincide with peak physiological potential. For tomato seeds, Dias et al. (2006) stated that the peak dry matter accumulation occurred on 75 DAA (red fruits) and seed germination peaked slightly before 70 DAA (red fruits). Demir and Ellis (1992b)

reported that bell pepper seed germination peaked on 70 DAA, whereas the dry matter content peaked on 50 DAA.

In the germination test, the seeds collected on 25 and 40 DAA (from green and yellowish green peppers) failed to germinate (Figure 3a). Similar results were found by Abud et al. (2013) in malagueta and biquinho hot pepper seeds, who concluded that the embryo lacked the required maturity for germination in the initial stages of development and that the seeds accumulate reserves for the germination process during this period. Vidigal et al. (2011) also found that no seed germination of hot peppers of the Amarela Comprida variety occurred before 40 DAA. These results corroborated the findings of Queiroz et al. (2011), who stated that the seeds removed from immature hot peppers showed low or no germination.

Figure 3. Germination (A), first germination count (B), germination rate index (C), and accelerated aging of seeds (D) during the maturation process of 'dedo-de-moça BRS Mari' hot peppers (*Capsicum baccatum* var. *pendulum*)



At 55 DAA (yellowish green peppers), the hot pepper seeds started germinating, with 40% normal seedlings obtained (Figure 3a); at 70 DAA (red peppers), the germination increased, averaging 87%, which was sustained until 100 DAA (intense red peppers; Figure 3a). Vidigal et al. (2011) noted an increase in the percentage of germinated seeds during the maturity process, particularly between 40 and 55 DAA for hot pepper seeds of the Amarela Comprida variety. Conversely, Abud et al. (2013)

observed increases in the germination percentage of malagueta hot pepper seeds from 40 to 71 DAA and of biquinho hot pepper seeds between 40 and 79 DAA, which resulted in 86% and 89% germination, respectively. Similarly, Lima and Smiderle (2014) noted that malagueta hot pepper seeds extracted from "red" fruits (between 66 and 70 DAA) resulted in 84% germination. This variation in the number of days until the increase in germination that has been reported in the literature showed that growing environments had strong effects on intraspecific and species-related seed maturity in the *Capsicum* genus, which provided an explanation for the findings of these studies on hot peppers.

The first count showed an increase in vigor with time after anthesis. Germination began from 55 DAA (orange peppers), at an average of 10%, increased until peaking on 70 DAA (red peppers; 65%) and stabilizing over time at that value until 100 DAA (intense red peppers; Figure 3b). Pereira et al. (2014) found a significant increase in the values of germination and first germination count in 'dedo-de-moça' hot pepper seeds extracted from intense red fruits. The first count of Amarela Comprida seeds, at approximately 56% germination, peaked at 60 DAA (VIDIGAL et al., 2011).

The germination rate index (GRI) increased from 40 DAA (yellowish green peppers) to 0.23 on 55 DAA (orange peppers), whereas the GRI on 70 (red peppers), 76 (red peppers), and 85 (extreme red peppers) DAA was 4.30, 6.22, and 5.08 respectively, and slightly decreased on 100 DAA (intense red peppers; Figure 3c). Vieira and Krzyzanowski (1999) stated that higher GRI values resulted in a higher ability of seeds to express their germination potential. Abud et al. (2013) observed GRI values in the range from 1.01–4.07 for malagueta and biquinho hot peppers on 55 DAA.

The accelerated aging test enabled the classification of the stages of maturity into different levels of vigor. The highest vigor was observed on 85 DAA (extreme red fruits), with approximately 80% normal seedlings observed at the end of the test (Figure 3d). Hence, seed physiological maturity most likely occurred at this time because vigor peaks were observed at this maturation point in some species (MARCOS FILHO, 2005).

Thus, in general, the results showed that the seeds had low physiological potential until 55 DAA (orange peppers), in contrast to the results from 70 DAA (red peppers) and when germination and vigor peaked at 85 DAA (extreme red peppers). Seed maturity is a characteristic determined by a set of physical, physiological, and biochemical processes that result in the maximum expression of the seed physiological potential (MARCOS FILHO, 2005). At this time, seeds tend to express the maximum germination and vigor possible, which may or may not coincide with the peak dry matter accumulation. Hence, 'dedo-de-moça BRS Mari' hot pepper seeds reached physiological maturity between 70 and 85 DAA, when the fruits changed from red to extreme red (Figure 1) and the seed water content was approximately 30% (Figure 2a). Furthermore, it should be noted that dry matter accumulation peaks before germination and seed vigor in 'dedo-de-moça BRS Mari' hot pepper seeds, similar to previous observations by Vidigal et al. (2009a, 2009b), Demir and Ellis (1992a, 1992b), and Dias et al. (2006) for hot peppers and other solanaceous fruits. Therefore, the parameter of dry matter accumulation fails to correctly estimate seed maturity. The harvesting of red to extreme red hot peppers between 70 DAA and 85 DAA is the best strategy to obtain 'dedo-de-moça BRS Mari' hot pepper seeds with a high physiological potential.

Acknowledgements

We thank the CAPES, CNPq and Fundação Araucária for their support.

The CNPq or CAPES for granting scholarship to the first author and to the Araucária Foundation for Scholarship Productivity to the second author.

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