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PRE-HARVEST DESICCATION FOR PRODUCING HIGH QUALITY COWPEA SEEDS

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ABSTRACT

Pre-harvest desiccation of indeterminate growth habit plants such as cowpea may improve harvest efficiency, uniform maturation and seed quality. This research aimed to determine the effects of pre-harvest desiccation and harvesting time on the yield and quality of cowpea seeds. Two experiments were carried out in Dourados, State of Mato Grosso do Sul, Brazil, in the 2015 and 2017 growing seasons. The experimental design was a split-plot, with main plots arranged as a randomized complete block design, with four replications. Main plots corresponded to the application or no application of paraquat at physiological maturity and subplots to harvesting times: 0, 3, 6. 9, 12 and 15 days after that stage. Moisture content, weight and yield were assessed for each treatment. Physiological quality was evaluated by germination and vigor tests. Means of desiccation conditions were compared by the Tukey test (p≤0.05) and harvest times by regression analysis, arranged as a 2x6 factorial. Seed yield and weight were negatively influenced by pre-harvest desiccation with paraquat and delayed harvest. Isolated and interactive responses for desiccation treatments and harvesting time on seed quality varied depending on the growing season. Seed germination and vigor were decreased by late harvest, while desiccation effects varied depending on harvest time.

Keywords: *Vigna unguiculata*; physiological quality; harvesting time; germination.

INTRODUCTION

Innovations to enhance seed production and quality have been developed to improve the cultivation of many species. High-quality seedlots directly affect the establishment of seedlings and guarantee a vigorous population of plants; therefore, seeds may be considered as the main input to assure effective implementation of a technology in the field (Wimalasekera, 2015).

Seed quality is one of the main challenges to increase the production of cowpea (*Vigna unguiculata* (L.) Walp.), which is an important food source in tropical and subtropical regions (Torres et al., 2015). The crop has a great contribution to food security and environmental sustainability, being cropped in rotation and integrated production systems. Africa is the largest producer of cowpea, but this legume is widely adapted and grown throughout the world. In fact, this species can be successfully cultivated under different environmental conditions (Freire Filho, 2011), and it has great potential to be cultivated in large areas due to advances in breeding and technologies that enhance yield. However, uneven maturation is often a major obstacle for

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cowpea harvest. For instance, plants do not show clear senescence signs and exhibit dry pods, green pods and flower buds simultaneously, with variations even within the same cultivar (Menezes Junior et al., 2017). Although manual harvest can be conveniently used in small areas, the possibility of mechanizing this procedure requires more uniform populations to increase efficiency and reduce losses.

Theoretically, harvesting seeds at physiological maturity would provide higher quality as a consequence to extremely low deterioration levels (Marcos-Filho, 2016). However, cowpea seeds show approximately 54% moisture at this stage (Nogueira et al., 2014). In this case, waiting for the plants to dry in the field may cause grains and seeds to be exposed to environmental adversities, leading to a rapid decrease in quality. Peske et al. (2012) stated that high temperatures, relative humidity, and excessive rainfall at pre-harvest stages contribute to accelerate deterioration processes in seeds. In this sense, using herbicide desiccants is a viable alternative for producers to anticipate harvest and minimize seed deterioration in the field (Assis et al., 2019). Moreover, cowpea desiccation plays an important role in overcoming heterogeneous maturation, which is inherent to indeterminate growth habit species with additional stay-green traits (Menezes Junior et al., 2017). Many studies have focused on pre-harvest desiccation of different crops (Jaskulski and Jaskulska, 2014; He et al., 2015; McNaughton et al., 2015; Tavares et al., 2016; Rosa et al., 2019), mostly soybeans (Delgado et al., 2015; Pereira et al., 2015; Zuffo et al., 2019, 2020). In cowpea, Assis et al. (2019) harvested seeds at 12 days by applying paraquat, glufosinate ammonium and paraquat + diuron when plants showed 90% of brown pods, with no effects on yield and physiological quality. Similarly, Raisse et al. (2020) found that paraquat and diquat were the most efficient herbicides for the anticipation of harvest (9 days) of cowpea, resulting in the production of high quality seeds.

Paraquat (1,1′-dimethyl-4,4′-bipyridinium dichloride) has been widely used due to its broad postemergence spectrum of weed control, non-selectivity and soil-inactivity (Hawkes, 2014), causing desiccation and defoliation. Although it has currently been discontinued in some countries, is one of the most widely used herbicides in the United States and other locations, being vital to establish the non-till system in agriculture, one of the primary conservation grain production systems (Albrecht et al., 2022).

The phenological scales currently published for cowpea do not describe physiological maturity with precision. Moura et al. (2012) presented a scale for cowpea, being R5 (pods with fully developed grains) and R6 (maturity of 50% of the pods) the final development stages.

Plant architecture influences cropping practices and supports decisions such as the best time to harvest and desiccate (Menezes Junior et al., 2017). Therefore, it is mandatory to assess cultivar response to the active ingredient applied for desiccation at different plant development stages (Pereira et al., 2015), particularly considering that it is difficult to determine the ideal period for plant desiccation in species with indeterminate growth habit. Upon desiccating soybeans and harvesting at different times, Toledo et al. (2014) observed that high quality seeds can be obtained from desiccated and non-desiccated plants harvested 9 and 12 days after the physiological maturity stage, respectively.

In this context, this research aimed to determine the effects of pre-harvest desiccation and harvesting time on the yield and quality of cowpea seeds.

MATERIALS AND METHODS

Two experiments were carried out in Dourados, State of Mato Grosso do Sul, Brazil (54°48′23″ W, 22º13′18″ S; 430 m asl) in the 2015 and 2017 seasons. An additional season was sown in 2016 but production was lost due to frost. Soil in the experimental area is a Rhodic Ferralsol (Santos et al., 2018). According to Köppen-Geiger's classification, climate is a tropical monsoon (Alvares et al., 2013), with and average temperature of 22.7 ºC and rainfall of 1,428 mm. Fig. 1 shows climate data recorded in the area during the experiments.

The experimental design was a split-plot, with main plots arranged as a randomized complete block design, with four replications. Main plots corresponded to pre-harvest desiccation and subplots to harvesting times. Each experimental unit consisted of five 5-m plant rows, being considered for analyses the three central rows, except 0.5 m in each border.

Cowpeas, cv. BRS Guariba, were mechanically sown on March 19 of 2015 and March 13 of 2017 over soybean residues. BRS Guariba shows indeterminate and semi-erect growth habit and biological cycle of approximately 70 days. Seeds were previously treated with fungicides (carboxin + thiram, 300 mL 100 kg^{-1} of seeds) and sown at 0.45 m row spacing, aiming a population of 250,000 plants ha^{-1}. Soil fertilization consisted of 280 kg ha^{-1} of 4-14-8 NPK formula applied at sowing, plus 30 kg ha^{-1} of side dressing nitrogen applied as urea 30 days later.

Desiccation treatments consisted of paraquat

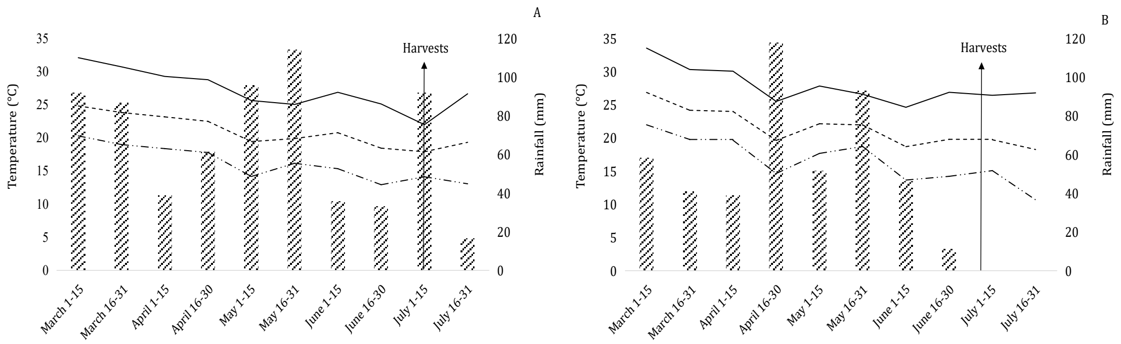

Fig. 1. Rainfall (columns) and temperatures (lines) during cowpea production in the 2015 (A) and 2017 (B) seasons.

(Gramoxone 200®) applied at the dose of 2 L ha^{-1} at R6 stage, and a control treatment (without desiccation), considering the phenological scale presented by Moura et al. (2012). The application was carried out with a boom-type sprayer with water volume equivalent to 200 L ha^{-1}. Harvest took place 0, 3, 6, 9, 12, 15 and 18 days after desiccation. For the 2015 season, harvest dates were July 2, 5, 8, 11, 14 and 17. For the 2017 season, harvest dates were July 4, 7, 10, 13, 16 and 19.

At each harvest time, plants were cut close to soil surface and seeds were threshed manually. Seeds were weighted to calculate yield on a 13% moisture content basis. Initial moisture was determined using two subsamples of 20 seeds per replication and an oven at 105 ± 3 °C for 24 h (MAPA, 2009).

Seeds were then stored in paper bags under environmental conditions for assessing physical and physiological quality.

Weight of 100 seeds was determined over four subsamples of 100 seeds per replication, according to MAPA (2009). In order to evaluate percentage of germination and first count, four subsamples of 50 seeds were distributed on paper towels moistened with water equivalent to 2.5 the weight of the dry paper. Paper rolls were kept at 25°C for 8 days, with a previous count on the 5th day for vigor assessment (MAPA, 2009). To assess vigor by the electrical conductivity test, four subsamples of 50 seeds per replication were weighed and soaked into 200-mL plastic cups containing 100 mL of distilled water for 24 h at 25ºC (Vieira and Marcos-Filho, 2020); the conductivity of the solution was read with an electrical conductivity meter and expressed as µS cm^{-1} g^{-1}. For seeding length measurement, four subsamples of 10 seeds per replication were sown over a straight line drawn on paper towels moistened with water equivalent to 2.5 times the weight of the dry paper. Rolls were placed in plastic bags in upright position and left to germinate at 25 °C for 5 days (Krzyzanowski et al., 2020) for the subsequent measurement of normal seedlings. Afterwards, these were placed in paper bags and dried at 80 °C for 24 h (Krzyzanowski et al., 2020).

Data was submitted to analysis of variance to identify interaction between treatments. When significant, slicing was performed to compare desiccation conditions using the Tukey test ($p \leq 0.05$) and quantitative treatments of harvest times using regression analysis.

RESULTS AND DISCUSSION

Seed production was influenced by pre-harvest desiccation in both seasons (Table 1). Grain yield was significantly higher under non-desiccated conditions, confirming that identifying the appropriate stage for pre-harvest desiccation is crucial to guarantee production of crops with indeterminate growth habit. According to Pereira et al. (2015), an effective response to desiccation is often influenced by the growth stage of plants, which directly affects quality and yield. In addition, Assis et al. (2019) reported that cowpea yield was higher when paraquat was applied on plants showing a minimum of 90% of brown pods, with no significant differences with respect to non-desiccated plants.

Seed yield was also influenced by harvest time in the 2015 season. There was a gradual initial increase with time, followed by a reduction within the last harvest period (Fig. 2A). Yield variations are expected to be observed in indeterminate growth habit species once pod and grain formation is continuous, which favors parceled harvest. Additionally, yield is deeply influenced by environmental conditions, especially during seed maturation. Although water supply was not limited in any season or stages, rainfall excess

Table 1. Mean comparison for seed yield and mass as affected by cowpea pre-harvest desiccation and harvesting time in the 2015 and 2017 growing seasons.

Source of variation	Seed yield (kg ha^{-1})		Mass of 100 seeds (g)	
	2015	2017	2015	2017
Desiccation				
With	882.31 b [1]	886.46 b	14.70 b	14.56
Without	1026.70 a	1006.72 a	14.93 a	14.51
Harvest time (days after physiological maturity)				
0	908.64 [2]	1014.57	14.79 [3]	14.57
3	865.78	830,24	14.81	14.49
6	881.17	920.81	14.90	14.41
9	959.05	1008.06	14.91	14.61
12	1427.26	884.42	14.86	14.56
15	685.15	1021.44	14.62	14.58
Desiccation (D)	*	*	**	ns
Harvest time (HT)	**	ns	*	ns
D x HT	ns	ns	ns	ns
C.V. (D) (%)	33.63	27.44	5.06	5.53
C.V. (D x HT) (%)	22.66	14.40	2.31	4.49

[1] Means followed by different letters significantly differ as for desiccation conditions.
[2] $y = -1.8379x^3 + 38.01x^2 – 170.32x + 957.02$, $R^2 = 0.64$; [3] $y = -0.0037x^2 + 0.0488x + 14.754$; $R^2 = 0.84$.
* and ** significant at 5 and 1% probability levels, respectively; ns: not significant.

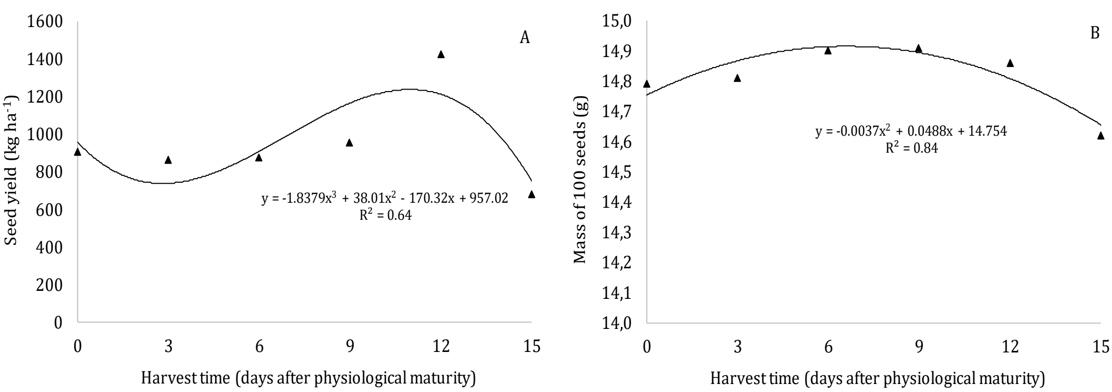

Fig. 2. Seed yield (A) and mass (B) affected by cowpea harvesting time in the 2015 season.

was recorded in the first half of July by the time seeds were harvested (Fig. 1A). With respect to moisture content, it was found that the higher the moisture at each harvest the lower the yield. In soybean, Tsukahara et al. (2016) confirmed that moisture is directly related to grain weight and yield. Despite the values of all treatments were calculated on a 13% moisture basis, it is known that moisture content is involved in seed deterioration processes, as related to sequential size expansion and retraction. Additionally, rainfall influences harvest efficiency, especially associated with the stay-green condition in cowpea.

Seed mass was also influenced by both desiccation and harvest time in the 2015 season (Table 1). Although seed mass can show high heritability (Silva et al., 2014), it can be influenced by cropping practices such as pre-harvest desiccation, which may cease photo-assimilated compounds to seeds. In accordance to yield results, desiccated plants produced lighter seeds, similar as those from early harvests, which can be an effect of an incomplete filling stage. In this latter case, the heaviest seeds were harvested approximately 6 days after physiological maturity (Figure 2B). After that period, mass was decreased possibly due to the exposition of seeds to environmental conditions. Similarly, Toledo et al. (2014) found soybean seeds from non-desiccated treatments to show increased mass with time, up to 9 days after physiological maturity, decreasing thereafter.

Germination percentage and first count were influenced by harvesting time in the 2015 season and by its interaction with paraquat desiccation in the 2017 season (Table 2). Those attributes were drastically reduced as harvest was delayed (Fig. 3), confirming that deterioration processes advance naturally as seeds dry in the field under natural environmental conditions. In soybeans, Zuffo et al. (2017a, 2017b) found that the delay in seed harvest at ten days after the R8 stage already impaired seed vigor, while germination was decreased after 15 days.

In the 2017 season, seed germination was influenced by harvest time as well as desiccation treatments (Figs. 3C and 3D). Seeds from desiccated plants showed a sharp decrease in germination and vigor, whereas seed vigor was reduced within the first 6 to 9 days after physiological maturity followed by an increase under non-desiccated conditions. As opposed to yield, pre-harvest desiccation provided seeds with higher germination and vigor at any harvest times compared to non-desiccation. It is important to establish that desiccation leads to plant senescence, which in turn prevents plants from producing new branches, flowers and pods. However, a slight increase in germination was observed under non-desiccated conditions, possibly due to the formation of new seeds.

The accentuated difference observed among seeds from the studied desiccation conditions in the 2017 season may have occurred due to the greater environmental variations to which seeds are submitted in the field. In this sense, Assis et al. (2019) reported negative effects of paraquat desiccation, but this occurred when plants showed less than 70% of purple pods. However, other authors have reported positive effects of pre-harvest desiccation on physiological quality (Pereira et a., 2015; Zuffo et al., 2019). It is also important to point out that the effects of pre-harvest desiccation on seed quality closely depend on environmental conditions by the time plants are sprayed. According to Peske et al. (2012), high temperatures and relative humidity as well as excessive rainfall in pre-harvest stages

Table 2. Mean comparison for seed germination percentage, first count and electrical conductivity as affected by cowpea pre-harvest desiccation and harvesting time in the 2015 and 2017 growing seasons.

Source of variation	Germination (%)		Germination first count (%)		Electrical conductivity (µS cm^{-1} g^{-1})	
	2015	2017	2015	2017	2015	2017
Desiccation						
With	47	75	46	68	205.52	161.99
Without	46	53	44	17	199.95	164.71
Harvest time (days after physiological maturity)						
0	84 (1)	69	82 (2)	46	212.58 (3)	156.80
3	52	67	49	43	248.65	157.50
6	51	61	49	42	225.36	149.76
9	42	64	41	44	261.79	153.40
12	40	59	39	37	268.04	189.72
15	8	66	8	41	0.00 (4)	172.93
Desiccation (D)	ns	**	ns	**	ns	ns
Harvest time (HT)	**	**	**	**	**	**
D x HT	ns	**	ns	**	ns	**
C.V. (D) (%)	15.01	14.45	19.04	13.61	20.23	14.85
C.V. (D x HT) (%)	24.24	15.45	25.21	19.61	12.43	14.40

(1) $y = -4.0476x + 76.52$; $R^2 = 0.86$; (2) $y = -3.8857x + 73.81$; $R^2 = 0.84$; (3) $y = 4.1353x + 218.47$; $R^2 = 0.68$. (4) Above maximum readings by the equipment.
** significant at 1% probability level; ns: not significant.

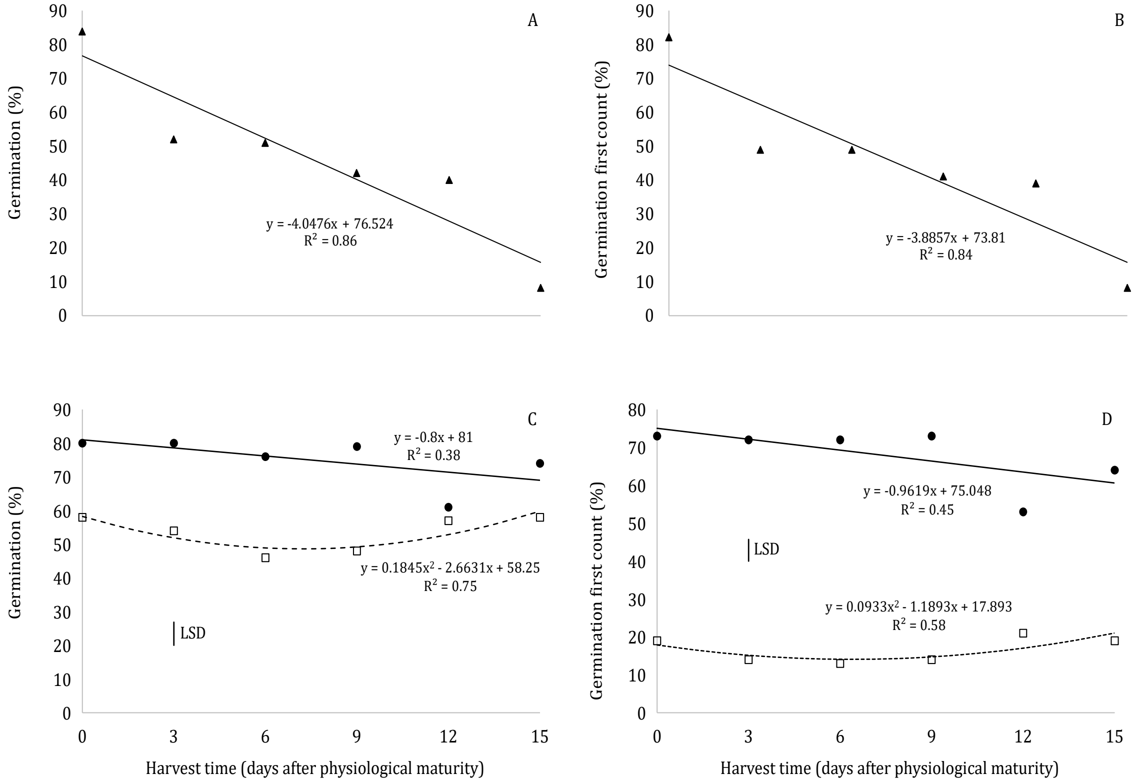

Fig. 3. Seed germination (A, C) and first count (B, D) affected by cowpea pre-harvest desiccation in the 2015 season (A, B) and interacting with harvesting time in the 2017 season (C, D) (◆ mean values of desiccation conditions; ● with pre-harvest desiccation; □ without pre-harvest desiccation). LSD: Least Significant Difference.

contribute to accelerate deterioration processes in seeds.

Germination decreased mainly due to higher percentage of dead seeds in the 2015 season (linear correlation coefficient -0.89) as a consequence of unfavorable conditions during harvest. Distinctly, there was a higher percentage of abnormal seedlings in the 2017 season, which caused germination to reduce (linear correlation coefficient -0.91).

Same as observed in the germination tests, seed electrical conductivity was also influenced by harvesting time in the 2015 season and in the interaction with paraquat desiccation in the 2017 season (Table 2). Late harvest decreased seed vigor as conductivity values were higher along time in both growing seasons (Figs. 4A and 4B). Such increase in conductivity may be caused by changes in membrane permeability of deteriorated tissues. Pinto et al. (2014) also found differences in seed vigor when desiccating bean plants. The authors observed that seeds harvested in the upper position of the plant showed higher vigor in combination with desiccant applications at 44 and 49 days after flowering.

Seedling growth varied depending on the use of paraquat as desiccant and harvest time combined, except for seedling dry matter in the 2017 season (Table 3). Delayed harvest caused seedling length and dry matter to decrease, more intensely under non-desiccation conditions in the 2015 season (Figs. 5A and 5B), while seedlings were significantly larger compared to the desiccated treatments but only for the earliest harvest, with no reflections in dry matter. In the 2017 season, desiccated plants produced seeds with decreased vigor as harvest was delayed (Figure 5C). Additionally, differences in length between desiccated and non-desiccated conditions were significant within the late harvest events, favoring high vigour of seeds from control plants. Dry matter also decreased as harvest was delayed regardless of desiccation treatments (Figure 5D).

In general, the results obtained in the present study confirms the urgency of establishing appropriate recommendations for cowpea desiccation practices. Given the stay-green

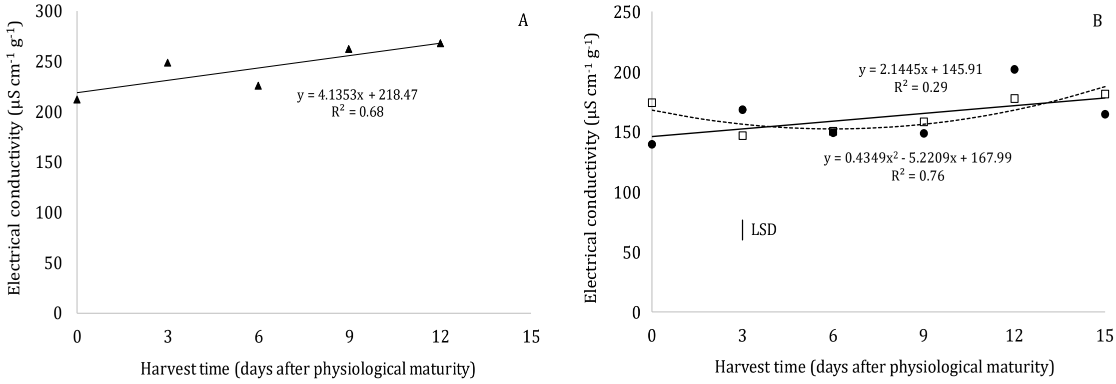

Fig. 4. Seed electrical conductivity affected by cowpea pre-harvest desiccation in the 2015 season (A) and interacting with harvesting time in the 2017 season (B) (◆ mean values of desiccation conditions; ● with pre-harvest desiccation; □ without pre-harvest desiccation). LSD: Least Significant Difference.

Table 3. Mean comparison for seedling length and dry matter as affected by cowpea pre-harvest desiccation and harvesting time in the 2015 and 2017 growing seasons.

Source of variation	Seedling length (cm)		Dry matter (mg seedling^{-1})	
	2015	2017	2015	2017
Desiccation				
With	8.04	10.56	32.02	73.80
Without	8.60	11.48	25.96	77.99
Harvest time (days after physiological maturity)				
0	15.04	12.79	40.24	86.40
3	6.33	11.48	32.06	82.83
6	12.06	10.95	36.24	74.90
9	8.41	13.08	32.45	72.40
12	7.17	8.52	29.70	65.63
15	0.90	9.31	3.27	73.23
Desiccation (D)	ns	ns	**	ns
Harvest time (HT)	**	**	**	**
D x HT	**	**	**	ns
C.V. (D) (%)	159.98	33.90	44.11	23.40
C.V. (D x HT) (%)	55.54	35.24	46.83	24.78

** significant at 1% probability level; ns: not significant.

traits associated with *Vigna* species, desiccation practices may favor mechanical harvest. Stay-green refers to the heritable delayed foliar senescence character in model and crop plant species (Thomas and Ougham, 2014).

Notwithstanding, there are no herbicides registered and recommended for cowpea desiccation. Therefore, knowledge about the appropriate stages for pre-harvest application may prevent yield and quality losses, and serve as basis for future studies on this matter. In the present study, cowpea yield and weight were negatively influenced by pre-harvest desiccation with paraquat and decreased with harvest delay. Those fluctuations reflect cowpea natural traits of irregular maturation and a heterogeneous cycle of seed formation and deterioration.

Harvesting seeds at or close to physiological maturity would ensure higher germination and vigor due to extremely low deterioration levels

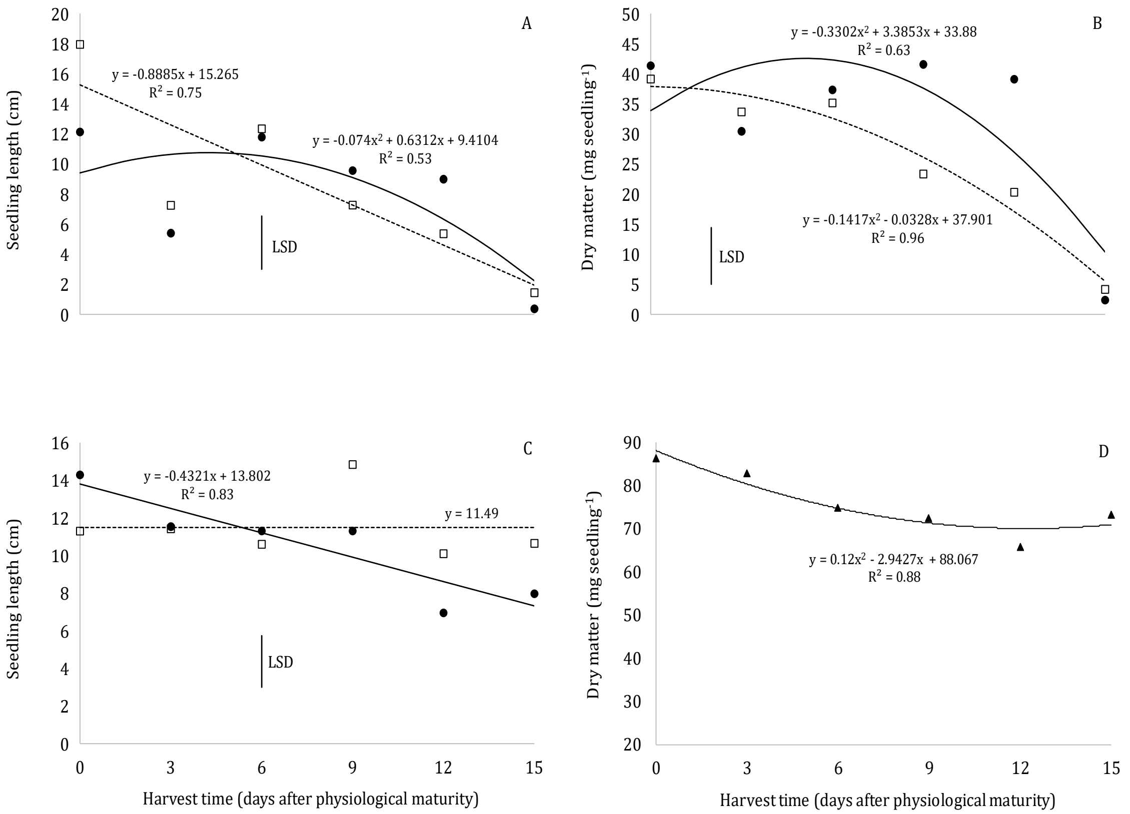

Fig. 5. Seedling length (A, C) and dry matter (B, D) affected by cowpea pre-harvest desiccation and harvesting time in the 2015 season (A, B) 2017 (C), and by harvesting time alone in the 2017 season (D) (◆ mean values of desiccation conditions; ● with pre-harvest desiccation; □ without pre-harvest desiccation). LSD: Least Significant Difference.

(Marcos-Filho, 2015). As harvest is delayed in order for seeds to dry, natural aging progresses and quality is reduced, especially under unfavorable weather conditions. This study confirms that delayed harvest decreases seed physical and physiological quality regardless of the desiccation management, but with differences depending on the treatment used. This may be an effect of a stay-green condition of cowpea plants, which may disturb harvest efficiency and require desiccation treatments (Menezes Junior et al., 2017).

CONCLUSIONS

The results obtained in this study confirm that cowpea seed yield and weight are negatively influenced by pre-harvest desiccation with paraquat and delayed harvest due to indeterminate growth habit characteristics and deterioration processes. Additionally, the effect of isolated and interactive responses for desiccation treatments and harvest time on seed quality varied in the two seasons under study, particulalry due to rainfall conditions during harvest. Late harvest resulted in reduced seed germination and vigor, while desiccation effects varied depending on harvest time after physiological maturity.

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Author's contribution

All of the authors contributed in all stages of this research (literature review, definition of methods, discussion of results and approving final version of the manuscript).

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