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Production and quality of cowpea seeds desiccated with saflufenacil and flumioxazin[1]

Produção e qualidade de sementes de feijão-caupi dessecadas com saflufenacil e flumioxazina

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HIGHLIGHTS:
Prolonged storage of cowpea seeds decreases seed quality.
The anticipation of cowpea harvest is favored when the crop is treated with flumioxazin as a desiccant.
The physiological quality of the seeds is maintained when the cowpea crop is dried with flumioxazin.

ABSTRACT: The use of desiccants allows to anticipate cowpea harvest at a time closer to physiological maturity. The desiccants saflufenacil and flumioxazin promote the drying and falling of leaves and loss of water from seeds. This study aimed to evaluate the effects of saflufenacil and flumioxazin doses applied to the cowpea crop on the production and quality of seeds at harvest and after storage for six months. Two experiments were carried out in a split-plot design (5 × 2). In the first experiment, the main factor consisted of saflufenacil doses (0, 25, 50, 100, and 150 g ai ha^{-1}), while the second factor consisted of evaluation periods (after harvest and six months after harvest). In the second experiment, the main factor consisted of flumioxazin doses (0, 10, 20, 30, and 40 g ai ha^{-1}) and the second factor consisted of the same evaluation periods. The treatments were designed in randomized blocks, with four replications. Saflufenacil application from 25 g ha^{-1} compromised the yield components and technological quality, while flumioxazin doses did not affect the yield components. Storage at 20 °C for six months decreased the physiological quality of seeds. Flumioxazin application at cowpea harvest promoted uniformity of maturity and harvest anticipation, without compromising the physiological quality after harvest.

Key words: *Vigna unguiculata* L., storage, yield components, desiccant

RESUMO: O uso de dessecantes permite antecipar a colheita do feijão-caupi em época mais próxima à maturidade fisiológica. Os dessecantes saflufenacil e flumioxazina promovem a secagem e queda das folhas e a perda de água das sementes. Objetivou-se nesta pesquisa avaliar os efeitos de doses de saflufenacil e flumioxazina aplicadas na cultura do feijão-caupi sobre a produção e qualidade das sementes por ocasião da colheita e após o armazenamento por seis meses. No primeiro experimento, os tratamentos foram arranjados em parcelas subdivididas (5 x 2), em que o fator principal foi constituído das doses de saflufenacil (0, 25, 50, 100 e 150 g i.a ha^{-1}) e o fator secundário das épocas de avaliação: após a colheita e seis meses após a colheita. No mesmo arranjo, no segundo ensaio o fator principal constou das doses do herbicida flumioxazina (0, 10, 20, 30 e 40 g i.a ha^{-1}) e o fator secundário das mesmas épocas de avaliação. Os tratamentos foram delineados em blocos ao acaso, com quatro repetições. A aplicação de saflufenacil a partir de 25 g ha^{-1} comprometeu os componentes de produção e qualidade tecnológica, enquanto as doses de flumioxazina não comprometeram os componentes de produção. O armazenamento a 20 ºC por seis meses diminuiu a qualidade fisiológica de sementes. A aplicação de flumioxazina na colheita do feijão-caupi promoveu a uniformidade da maturidade e a antecipação de colheita, sem comprometer a qualidade fisiológica após a colheita.

Palavras-chave: *Vigna unguiculata* L., armazenamento, componentes de rendimento, dessecante

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Introduction

Cowpea (*Vigna unguiculata* L.) has great importance for semi-arid regions and regions where off-season cultivation is possible. This crop adapts well to the off-season cultivation in the southwest of Goiás, with sowing in February or March, and its exploitation has increased among producers who aim to cultivate drought-tolerant crops (CONAB, 2019). However, the yield has not been satisfactory, requiring the adaptation of management strategies that maximize production (Almeida et al., 2013; CONAB, 2019).

Desiccant herbicides have been used right after the plants reach physiological maturity to provide the anticipation of common bean harvest, aiming to improve the performance of mechanized harvesting (Franco et al., 2013). However, research on chemical desiccation of plants is necessary to guarantee, among other advantages, the physiological and health quality of cowpea seeds, in which most varieties show indeterminate growth and uneven maturation (Lindemann et al., 2017).

Few studies have been carried out in the cowpea crop, which has no registered herbicides for its desiccation, with the need for information on the safe use of chemicals (Cruz et al., 2018; Assis et al., 2019).

Possible alternatives for desiccation aiming at the anticipation of cowpea harvest consist of the use of the herbicides saflufenacil and flumioxazin. Saflufenacil belongs to the chemical group of pyrimidinedione, which acts by inhibiting the protoporphyrinogen oxidase (PROTOX) enzyme (Grossmann et al., 2011). It is registered as a desiccant for the anticipation of cotton, potato, bean, sunflower, and soybean harvest. Flumioxazin is recommended for pre-emergence, incorporated pre-planting, or post-emergence applications in various crops, also presenting a desiccant action for promoting harvest anticipation and uniform maturation (Ataide et al., 2015; Carvalho et al., 2017).

Considering the little knowledge on the action of these herbicides in the cowpea desiccation, this study aimed to evaluate the effects of saflufenacil and flumioxazin doses applied to the cowpea crop on the production and quality of seeds at harvest and after six months of storage.

Material and Methods

The experiments with cowpea were conducted in Rio Verde, GO, Brazil, at the geographic coordinates 17° 48' 67" S and 50° 54' 18" W, with an altitude of 754 m. The soil in the area, classified as Oxisol, presented the following physicochemical composition at a depth of 0-20 cm: pH (SMP) = 6.2, Ca^{2+} = 4.64 $cmol_c\ dm^{-3}$, Mg^{2+} = 2.50 $cmol_c\ dm^{-3}$, Al^{3+} = 0.04 $cmol_c\ dm^{-3}$, $H^+ + Al^{3+}$ = 4.5 $cmol_c\ dm^{-3}$, CEC = 12.1 $cmol_c\ dm^{-3}$, K = 0.46 $cmol_c\ dm^{-3}$, P (Mehlich) = 13.1 mg dm^{-3}, organic matter = 3.62 mg dm^{-3}, Zn^{2+} = 4.5 mg dm^{-3}, base saturation of 62.8%, aluminum saturation = 0.5%, clay = 645 dag kg^{-1}, silt = 100 dag kg^{-1}, and sand = 255 dag kg^{-1}.

The experimental design was randomized blocks with four replications. Two experiments were carried out in a split-plot design (5 × 2). In the first experiment, the main factor consisted of saflufenacil doses (0, 25, 50, 100, and 150 g ai ha^{-1}), while the second factor consisted of evaluation periods of seed quality (after harvest and six months after harvest). In the second experiment, the main factor consisted of flumioxazin doses (0, 10, 20, 30, and 40 g ai ha^{-1}) and the second factor consisted of the same evaluation periods as the first experiment. Each experimental unit consisted of 24.5 m^2, with four rows of 7 m in length spaced 0.5 m from each other and a useful area consisting of the two central rows of 5 m in length.

Cowpea of the variety BRS Guariba was sown on March 17, 2018. The seeds were treated with 100 g of pyraclostrobin + thiophanate-methyl + fipronil 100 kg^{-1} seeds and inoculated with 300 mL of *Bradyrhizobium* spp. Sowing was carried out at 3 cm depth, with a population of 12 plants per linear meter. Fertilization at sowing consisted of 300 kg ha^{-1} of the formulation 04-14-08 (N-P_2O_5-K_2O).

Weed control was performed using the mixture bentazone + imazamox (Amplo®) at a dose of 1.0 L commercial product (cp) ha^{-1} at 13 days after emergence (DAE) and haloxyfop-p-methyl (Verdict R®) at a dose of 0.4 L cp ha^{-1} at 17 DAE. The insecticide lambda-cyhalothrin + chlorantraniliprole (Ampligo®) was applied during the crop cycle at a dose of 0.16 L cp ha^{-1} to control *Spodoptera eridania* (Cramer). The fungicide fluxapyroxad + pyraclostrobin (Orkestra SC®) was applied at a dose of 0.3 L cp ha^{-1} to control *Erysiphe polygoni*. Wind speed, temperature, and air relative humidity were 2 m s^{-1}, 26 °C, and 50%, respectively, at the application time. The accumulated precipitation during the crop cycle was 260 mm.

Saflufenacil and flumioxazin doses were applied at 78 days after sowing (DAS), at stage R5, when pods were at physiological maturity and plants showed a pod with straw brown color and seeds presented 70% moisture (Carvalho & Nakagawa, 2012). The treatments were sprayed with a CO_2-pressurized knapsack with four spray tips model TT110° 03 and set to a constant pressure of 250 kPa and a spray solution volume of 200 L ha^{-1}.

Seed moisture content in each plot was monitored, and the harvest point was established when they had values of 13-15% moisture. The plants were cut close to the soil when these values were reached, the pods were removed manually, threshed, and placed to dry in an oven at 35 °C until reaching 11% moisture. The seeds were cleaned on sieves and classified to determine the proportion of seeds per sieve. Total samples from each plot were weighed, passed through a set of metallic sieves with mesh sizes/shapes of 7.5 mm/oval, 4.5 mm/oblong, 3.5 mm/oblong, 3.5 mm/oval, and bottom. The samples were packed in plastic bags and taken to a BOD incubator set at 20 °C, where they remained during the evaluation period.

The number of days of harvest anticipation was determined by counting the days elapsed from desiccation until the plants were fully defoliated and the grains in the range of 13-15% moisture relative to the day when the control not treated with herbicides was harvested (Brasil, 2009; Krzyzanowski et al., 2015). The thousand-grain weight was determined, as recommended by the Rules for Seed Testing (Brasil, 2009), using eight replications of 100 seeds, and the values were extrapolated to 1000 seeds. At the same time, the yield was determined in bags ha^{-1} by weighing all seeds obtained from the observation area.

The facilities of the laboratories of weeds, seeds, and drying and storage of grains of the Instituto Federal Goiano (IF Goiano) were used during the seed analysis stages.

Seed quality was verified after harvest and six months after storage using the following tests: germination, seedling dry mass, first and second germination counts, root and shoot length, accelerated aging, emergence in sand, emergence rate index, electrical conductivity, hydration coefficient, and grain color. The evaluations were performed as described below using duplicates of 50 seeds for each replication.

Germination (G): Initially, the seeds were treated with carbendazim + thiram at doses of 0.3 and 0.7 g ai kg^{-1} seed. Subsequently, the seeds were sown on germitest papers moistened with distilled water in the amount of 2.5 times the paper weight. The rolls were placed separately per replication from the field in plastic bags and maintained at 25 °C in a germination chamber for eight days when the percentage of normal seedlings was evaluated (Brasil, 2009).

The first germination count (FGC) was performed together with the germination tests, with a count performed on the fifth day after the germination test was set up, according to Brasil (2009).

The accelerated aging test was carried out using 200 seeds placed in a germination box with an aluminum screen inside. The seeds were evenly distributed under the screen. An aliquot of 40 mL of distilled water was added to each germination box and the seeds were placed on the screen. The boxes were covered and taken to the germinator chamber at 41 °C for 48 hours. The seeds were subjected to the germination test after the aging period, as previously described, and the percentage of normal seedlings were obtained at five days after sowing on the germitest paper (Brasil, 2009).

The emergence test was conducted in a greenhouse using four replications of 50 seeds, with sowing carried out in sand at a depth of 3 cm. The environment was irrigated by automatic sprinkler four times a day. Daily counts were performed until the eighth day after sowing, considering the emergence of seedlings with cotyledons that had an angle of 90° relative to the substrate. The emergence rate index (ERI) was calculated using the formulas proposed by Maguire (1962):

$$ERI = \left(\frac{G1}{N1}\right) + \left(\frac{G2}{N2}\right) + \ldots + \left(\frac{Gn}{Nn}\right) \quad (1)$$

where:
ERI - emergence rate index;
G - number of normal seedlings computed in the counts; and,
N - number of days from sowing to 1^{st}, 2^{nd}, ..., 8^{th} evaluation.

The electrical conductivity test was carried out with eight replications of 50 seeds from each treatment, previously weighed on a 0.01-g precision scale and placed in plastic cups with 75 mL of distilled and deionized water, remaining under soaking in a BOD at 25 °C. The electrical conductivity reading was carried out after 24 hours, using a Technal TEC-4MP digital conductivity meter. The results were expressed in μS cm^{-1} g^{-1} seed (Vieira & Krzyzanowski, 1999).

The hydration coefficient was determined using 15 g of seeds soaked in 60 mL of distilled water (1:4 ratio) at room temperature (25 °C). Maceration water was removed after 12 hours, followed by free water removal. Each sample was placed on absorbent paper for 2 min before weighing. Weight gain was obtained by the hydration coefficient (HC), calculated by Eq. 2.

$$HC = \frac{MW}{DW} 100 \quad (2)$$

where:
HC - hydration coefficient;
MW - weight of grains after hydration; and,
DW - weight of grains before hydration, adapted from El-Refai et al. (1988) and Nasar-Abbas et al. (2008).

The color of the integument of whole and uniform grains was determined using a ColorFlex EZ colorimeter with the Hunter color system, which indicates the colors in a three-dimensional system. The vertical axis L* indicates the lightness of the sample from white to black, axis a* corresponds to the component from red to green, and axis b* corresponds to the value from yellow to blue, according to Afonso Júnior & Corrêa (2003). For better characterization, the seeds were evaluated in the resting position at two different points, and the average of each seed was subsequently calculated. The color difference (ΔE*) was obtained using Eq. 3.

$$\Delta E^* = \left[\left(\Delta L^*\right)^2 + \left(\Delta a^*\right)^2 \right]^{0.5} \quad (3)$$

where:
ΔE* - value for the color difference;
ΔL* - difference between L* of the initial and stored samples; and,
Δa* - difference between a* of the initial and stored samples.

The data were submitted to the Shapiro-Wilk normality test and transformed into the square root (x+0.5) for analysis when significant ($p \leq 0.05$). Subsequently, the means of the evaluation periods were subjected to analysis of variance and compared by the Tukey test ($p \leq 0.05$), while the doses were subjected to polynomial regression analysis.

Results and Discussion

The days of harvest anticipation (DHA), seed yield (SY), thousand-seed weight (TSW), and seed classification in the mesh sieves of 7.5 mm/oval (P7.5), 4.5 mm/oblong (P4.5), 3.5 mm/oblong (P3.5ob) were affected by saflufenacil doses applied to cowpea in pre-harvest (Table 1). The increase in doses led to linear anticipation in cowpea harvest, reaching eight days at the highest dose compared to the control treatment. On the other hand, a linear reduction was found for SY and TSW (Table 1). Each gram of saflufenacil used in the desiccation led to a reduction of 2.05 kg ha^{-1} in cowpea SY, which represents 52.15% of losses at the highest dose compared to the plots not treated with the herbicide.

Table 1. Days of harvest anticipation (DHA), seed yield (SY), thousand-seed weight (TSW), and seed weight on mesh sieves of 7.5 mm (P7.5), 4.5 mm (P4.5), 3.5 mm with an oblong shape (P3.5ob), 3.5 mm with an oval shape (P3.5oval), and bottom of the cowpea crop as a function of saflufenacil doses applied in pre-harvest

Variable	Dose (g ha^{-1})					Regression	R^2 (%)
	0	25	50	100	150		
DHA	0	0	1.00	5.25	8.00	$\hat{Y} = -0.95 + 0.058^*x$	97.79
SY (bags ha^{-1})	12.95	9.98	9.35	8.88	6.75	$\hat{Y} = 708.37 - 2.05^*x$	92.06
TSW (g)	199.34	190.20	192.07	178.66	180.55	$\hat{Y} = 196.44 - 0.12^*x$	89.64
P7.5 (g)	8.27	7.32	2.25	1.70	0.40	$\hat{Y} = 7.44 - 0.05^*x$	89.99
P4.5 (g)	578.45	400.85	366.57	340.12	280.77	$\hat{Y} = 498.07 - 1.61^*x$	86.30
P3.5ob (g)	46.37	74.77	78.67	88.15	61.17	$\hat{Y} = 48.303 + 0.9956^*x - 0.0061^*x^2$	95.16
P3.5oval (g)	4.75	8.40	9.32	6.12	3.75	$\hat{Y} = 5.63 + 0.091^*x - 0.0007^*x^2$	88.22
Bottom (g)	2.77	0.57	0.20	0.70	0.72	$\hat{Y} = 2.28 + 0.0501^*x + 0.0003^*x^2$	84.01

* - Significant by the F-test ($p \le 0.05$)

Changes in yield components in common bean and cowpea cultivars due to desiccants applied at different times in pre-harvest were reported by Franco et al. (2013) and Assis et al. (2019), respectively, even with harvest anticipation. The desiccants paraquat, ammonium glufosinate, and paraquat + diuron applied to cowpea when 50% of the pods had green colored seeds (season I) or when 70% of the pods were purple (season II) anticipated harvest by up to 13 and 9 days, respectively, but the seed size and yield were affected (Assis et al., 2019).

The increase in saflufenacil doses caused a linear reduction in TSW, and its addition at a dose of 1 g ha^{-1} in desiccation reduced 0.120 g of TSW. According to Franco et al. (2013), the reduction in TSW of beans is related to the desiccation period and genotype, which may be lower the closer the physiological maturity.

Seed size is a variable widely used in processing (Oliveira & Morais, 2017), but it does not influence the germinative performance of cowpea (Araujo Neto et al., 2014). In this sense, higher seed retention was observed in oblong mesh sieves, with opening diameters of 4.5 and 3.5 mm (Table 1). Each saflufenacil gram applied per hectare caused a reduction in the retention of 0.05 and 1.61 g in mesh sieves with opening diameters of 7.5 and 4.5 mm, respectively. The highest TSW of treatments without saflufenacil application is possibly associated with the maximum seed dry matter accumulation at the physiological maturity of plants (Pereira et al., 2015).

The variables SY, TSW, and the classification of seeds on mesh sieves of 7.5 mm with an oval shape (P7.5), 4.5 mm with an oblong shape (P4.5), 3.5 mm with an oblong shape (P3.5ob), and bottom were not influenced by flumioxazin doses applied to cowpea in pre-harvest (Table 2). The use of the highest dose anticipated harvest by three days and did not reduce SY. Thus, the increase in flumioxazin doses provided higher seed retention only on the sieve with a circular mesh opening of 3.5 mm in diameter (Table 2), which had a small fraction of the total seeds. According to Soltani et al. (2013), one of the advantages associated with the use of the herbicides saflufenacil and flumioxazin in the pre-harvest of *Phaseolus vulgaris* is its uniform desiccation. Saflufenacil, unlike flumioxazin and other PPO enzyme inhibiting herbicides, has physicochemical properties that allow its mobility via the phloem (Ashigh & Hall, 2010). Although the translocated amount is similar to other PPO-inhibiting herbicides, the saflufenacil application to only one leaf of American black nightshade (*Solanum americanum*) caused the plant to die, evidencing its translocation, which did not occur with flumioxazin (Grossmann et al., 2011).

Water absorption rate (HC), emergence rate index (ERI), germination (G), abnormal seedlings (AS), shoot (SL) and root length (RL), and seedling dry mass (DM) showed no effects for the interaction between saflufenacil doses and evaluation periods (Table 3).

Likewise, no interaction effects were observed for normal seedlings from accelerated aging (NSAA), moisture (M), electrical conductivity (EC), chroma (C), hue angle (°h), and L coordinate of cowpea seeds as a function of saflufenacil doses and evaluation period at harvest and six months of storage (Table 4).

The increase in saflufenacil doses linearly increased seed HC, which may be associated with the selective membrane permeability. The normal water absorption by seeds occurs when all the interconnected processes occur normally. In this context, a signaling cascade leads to biochemical reactions, which are determinant for the whole process, and the seeds affected by herbicides can change the biochemical reaction speed, impairing water absorption and, hence, the subsequent processes (Carvalho & Nakagawa, 2012).

Table 2. Days of harvest anticipation (DHA), seed yield (SY), thousand-seed weight (TSW), and seed weight on mesh sieves of 7.5 mm (P7.5), 4.5 mm (P4.5), 3.5 mm with an oblong shape (P3.5ob), 3.5 mm with an oval shape (P3.5oval), and bottom of the cowpea crop as a function of flumioxazin doses applied in pre-harvest

Variable	Dose (g ha^{-1})					Regression	R^2 (%)
	0	10	20	30	40		
DHA	0.00	0.00	1.00	2.00	3.00	$\hat{Y} = -0.40 + 0.08^*x$	97.01
SY (bags ha^{-1})	13.72	11.14	11.93	11.04	12.19	$\hat{Y} = \bar{Y} = 12.00$	--
TSW (g)	197.80	197.19	194.72	191.55	192.36	$\hat{Y} = \bar{Y} = 194.72$	--
P7.5 (g)	6.10	4.65	3.82	3.26	4.80	$\hat{Y} = \bar{Y} = 4.52$	--
P4.5 (g)	622.85	491.15	525.88	491.02	513.25	$\hat{Y} = \bar{Y} = 528.83$	--
P3.5ob (g)	44.00	47.65	52.02	42.50	66.85	$\hat{Y} = \bar{Y} = 50.60$	--
P3.5oval (g)	4.40	6.20	6.90	7.32	9.35	$\hat{Y} = 4.63 + 0.11^*x$	97.04
Bottom (g)	0.55	1.05	0.92	1.12	1.17	$\hat{Y} = \bar{Y} = 0.96$	--

* - Significant by the F-test ($p \le 0.05$)

Table 3. Water absorption rate (HC), emergence rate index (ERI), germination (G), abnormal seedlings (AS), seedling shoot length (SL), seedling root length (RL), and seedlings dry mass (DM) of cowpea seeds as a function of saflufenacil doses and evaluation periods at harvest and six months of storage (6MS)

Dose (g ha⁻¹)	HC (%)	ERI	G (%)	AS (%)	SL (cm)	RL (cm)	DM (g)
0	228.72[2/]	84.33[ns]	95.00[ns]	3.75[ns]	9.71[ns]	5.78[ns]	0.65[ns]
25	230.98	82.80	98.00	1.75	10.07	5.95	0.57
50	230.90	84.05	89.25	6.25	9.89	6.90	0.54
100	233.60	80.20	93.50	5.00	10.23	6.56	0.64
150	234.79	82.02	97.00	2.75	10.45	6.05	0.55
Evaluation period							
Harvest	229.60 b	78.78 b[1/]	95.90 a	3.00 a	11.44 a	6.53 a	0.39 b
6MS	234.00 a	86.58 a	93.20 a	4.80 a	8.70 b	5.96 a	0.79 a
CVa (%)	1.08	5.68	7.81	58.25	18.49	28.05	35.36
CVb (%)	1.75	10.90	8.24	65.29	33.35	33.46	29.07

[1/]Means followed by the same letter in the column do not differ from each other by the Tukey test at $p \leq 0.05$; [2/]Effect explained by the model $\hat{Y} = 229.27 + 0.039x$, $R^2 = 98.07$; ns - Not significant by the F-test ($p > 0.05$)

Table 4. Normal seedlings from accelerated aging (NSAA), moisture (M), electrical conductivity (EC), chroma (C), hue angle (°h), and L coordinate of cowpea seeds as a function of saflufenacil doses and evaluation periods at harvest and six months of storage (6MS)

Dose (g ha⁻¹)	NSAA (%)	M (%)	EC (μS cm⁻¹ g⁻¹)	C	°h	L
0	64.65[ns]	10.47[ns]	140.02[ns]	11.08[ns]	1.37[ns]	38.11[ns]
25	67.12	10.67	134.38	10.92	1.37	36.68
50	63.75	10.85	147.05	12.66	1.34	37.33
100	62.75	11.09	135.51	12.19	1.36	36.75
150	67.00	10.38	128.71	11.95	1.36	36.19
Evaluation period						
Harvest	88.50 a[1/]	10.87 a	119.85 b	19.35 a	1.32 b	46.24 a
6MS	41.60 b	10.51 b	154.42 a	4.17 b	1.40 a	27.78 b
CVa (%)	8.06	5.60	8.04	11.17	3.15	4.04
CVb (%)	9.13	4.22	9.97	8.44	1.53	5.06

[1/]Means followed by the same letter in the columns do not differ from each other by the Tukey test at $p \leq 0.05$; ns - Not significant by the F-test ($p > 0.05$)

The variables ERI, SL, DM, HC, NSAA, M, EC, and grain color (Tables 3 and 4) were lower at six months of storage. Thus, the tests need to be carried out and the moisture of the storage site maintained below 20 °C to preserve the physiological quality of seeds, preventing deterioration (Carvalho et al., 2017). Other effects, such as functional properties due to many phenolic compounds, specifically flavonoids, which have antioxidant capabilities, might also be involved, confirming the correlations found after storage (Barros et al., 2017).

The effect of various desiccants has been studied in several crops, with contrasting results for evaluating the physiological quality of soybean seeds. Desiccation of soybean seeds using ammonium glufosinate, paraquat, and carfentrazone applied at the R7.1 stage showed no reduction in germination (Pereira et al., 2015). Lima et al. (2018) used ammonium glufosinate and diquat to desiccate cowpea plants found no differences in germination and vigor right after harvest when desiccation was carried out between 50 and 100% of brown-colored pods.

The physiological quality of bean seeds was reduced with storage, mainly in an environment where the temperature remains above 20 °C (Zucareli et al., 2015). Thus, in general, seeds of the variety BRS Guariba may show reduced germination after 90 days of storage (Boiago et al., 2013).

No effects of the interaction between flumioxazin doses and evaluation periods were observed for HC, ERI, G, AS, SL, RL, and DMS (Table 5). However, AS, SL, and RL presented the lowest values regardless of the flumioxazin doses (Table 5), while storage influenced EC and grain color (Table 6) at six months of storage.

Treatments showed no differences regarding HC at harvest and after storage (Table 5). Cowpea has a characteristic of water absorption capacity, probably related to the high cell

Table 5. Water absorption rate (HC), emergence rate index (ERI), germination (G), abnormal seedlings (AS), shoot (SL) and root length (RL), and seedling dry mass (DM) of cowpea seeds as a function of flumioxazin doses and evaluation periods at harvest and six months of storage (6MS)

Dose (g ha⁻¹)	HC (%)	ERI	G (%)	AS (%)	SL (cm)	RL (cm)	DM (g)
0	225.92[ns]	82.22[ns]	97.75[ns]	1.43[ns]	8.28[ns]	6.47[ns]	0.52[ns]
10	226.14	81.80	92.50	2.17	8.16	6.17	0.57
20	225.07	82.19	94.75	2.00	9.19	7.36	0.55
30	227.10	84.29	95.25	1.67	7.88	5.81	0.65
40	224.88	84.57	88.75	2.50	8.09	4.86	0.64
Evaluation period							
Harvest	223.42 a	81.58 a	96.50 a	1.69 a	11.06 a	8.70 a	0.58[ns]
6MS	228.22 a	84.46 a	91.10 a	1.16 b	5.58 b	3.57 b	0.59
CVa (%)	1.34	4.69	9.26	53.51	19.35	34.38	26.74
CVb (%)	1.37	13.48	9.54	49.29	28.40	24.33	34.66

[1/]Means followed by the same letter in the columns do not differ from each other by the F-test ($p \leq 0.05$); ns - Not significant by the F-test ($p > 0.05$)

Table 6. Normal seedlings from accelerated aging (NSAA), moisture (M), electrical conductivity (EC), chroma (C), hue angle (°h), and L coordinate of cowpea seeds as a function of flumioxazin doses and evaluation periods at harvest and six months of storage (6MS)

Dose (g ha⁻¹)	NSAA (%)	M (%)	EC (μS cm⁻¹ g⁻¹)	C	°h	L
0	86.25^ns	12.46^ns	144.89^ns	11.07^ns	1.37^ns	37.56^ns
10	79.50	12.63	136.73	11.26	1.37	37.30
20	88.00	12.98	132.30	11.36	1.38	37.41
30	88.62	13.08	143.84	13.14	1.34	37.73
40	90.50	13.36	146.97	12.63	1.35	36.82
Evaluation period						
Harvest	87.45^ns	11.01 a	118.69 b	20.06 a	1.31 b	46.88 a
6MS	85.70	14.79 a	163.19 a	3.84 b	1.41 a	27.85 b
CVa (%)	5.89	8.99	16.52	16.11	3.80	4.21
CVb (%)	7.79	12.06	14.01	12.99	1.15	3.65

1/Means followed by the same letter in the columns do not differ from each other by the Tukey test at p ≤ 0.05; ns - Not significant by the F-test (p > 0.05)

wall lignification, reducing the water absorption of its seeds (Sarmento et al., 2016).

Changes were observed in the EC of seeds after six months of storage. It is explained by the disorganization of cell membranes, which is a natural process (Tables 4 and 6). Seeds stored for six months showed changes at all desiccant doses, including the treatment that did not receive the herbicide. Thus, these characteristics were compromised regardless of the use of the herbicide. The EC values after storage were higher than those found at harvest time.

Seed color (C, °h, and L) was altered with the course of storage (Tables 4 and 6). The highest chroma and ΔL values were observed for not stored grains. However, the values decreased after storage regardless of the desiccant application. Color is the primary basis on which the consumer selects grains for consumption, as lighter integuments are associated with freshly harvested and fast-cooking grains (Siqueira et al., 2016; Ojwang et al., 2013). Darkening is related to a decrease in tannin content due to oxidation, with a modification of its structures, causing the extracted content to be lower after storage (Cavalcante et al., 2017).

This information is economically important, as desiccation with flumioxazin allows to anticipate harvest in a few days, without compromising seed quality since it increases the management options for desiccation with the choice of an appropriate dose.

Conclusions

1. Saflufenacil application at the dose of 150 g ha⁻¹ allowed to anticipate harvest by eight days, but decreased yield by about 360 kg ha⁻¹ and reduced seed weight classified on mesh-sieve openings of 7.5, 4.5, and 3.5 mm.

2. Flumioxazin application at the dose of 40 g ha⁻¹ anticipated harvest by three days and showed no effect on the produced seed yield and quality.

3. The storage of cowpea seeds free of herbicides for six months at 20 °C reduced their germination and vigor, decreasing their quality.

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