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Chemical desiccants for anticipation of harvest and quality improvement of chickpea seeds

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ABSTRACT

Desiccating herbicides can promote uniformity of maturation, and early harvest and provide improvements in the physical, physiological, and sanitary seeds quality. The objective of this work was to evaluate the use of herbicides in early harvest and in the physiological quality of chickpea seeds. The experimental design was of randomized blocks with four replications, considering a complete factorial design with one control (no application) + two factors (four herbicides x three different doses): glufosinate-ammonium (200, 400 and 500 g a.i./ha); diquat (200, 400 and 500 g a.i./ha); carfentrazoneethyl (15, 30 and 37.5 g a.i./ha) and saflufenacil (49, 98 and 122.5 g a.i./ha). Saflufenacil (49 g a.i./ha) showed the lowest harvest anticipation (4 days) and a low percentage of vigor (50.25%). Glufosinate (400 g a.i./ha), was the most promising as it increased germination to 83.75% and vigor to 78.25%, in addition to promoting the anticipation of harvest by up to 17 days, while the normal cycle of the crop, observed in the control, was 154 days.

Keywords: *Cicer arietinum*, Fabaceae, carfentrazone-ethyl, diquat, glufosinate-ammonium, saflufenacil.

RESUMO

Herbicidas dessecantes na antecipação da colheita e melhoria da qualidade de sementes de grão-de-bico

Herbicidas dessecantes podem promover a uniformidade de maturação, antecipar a colheita e proporcionar melhorias na qualidade física, fisiológica e sanitária das sementes. Objetivou-se, com este trabalho, avaliar o uso de herbicidas dessecantes na antecipação da colheita e na qualidade fisiológica de sementes de grão-de-bico. Os tratamentos foram constituídos da dessecação com os herbicidas nas respectivas doses: glufosinate ammonium (200, 400 e 500 g i.a./ha); diquat (200, 400 e 500 g i.a./ha); carfentrazone ethyl (15, 30 e 37,5 g i.a./ha) e saflufenacil (49, 98 e 122,5 g i.a./ha). O arranjo experimental foi em esquema fatorial 4 x 3 + 1 (testemunha como tratamento adicional, sem herbicida), em blocos casualizados, com quatro repetições. O saflufenacil, sob 49 g i.a./ha, foi o que apresentou a menor antecipação da colheita (4 dias) e baixo percentual de vigor (50,25%). O glufosinato, sob 400 g i.a./ha, foi o mais promissor na dessecação, por possibilitar maior germinação (83,75%) e vigor (78,25%), além de promover a antecipação da colheita em até 17 dias, enquanto o ciclo normal da cultura do grão-de-bico, observado na testemunha, foi de 154 dias.

Palavras-chave: *Cicer arietinum*, Fabaceae, carfentrazona-etílica, diquate, glufosinato, saflufenacil.

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Chickpea (*Cicer arietinum*) is the second most consumed legume in the world after soybean and plays an important role in human nutrition, particularly because of the quality of their protein (Megya & Haji, 2019; Swamy *et al*., 2020; Fernandes *et al*., 2022). It is a diploid plant (2n= 16), autogamous (cleistogamous flowers), herbaceous in size, with an annual cycle and wide edaphoclimatic adaptability (Paul *et al*., 2022).

Rainfed cultivation and the intensification of farming activities under irrigated conditions are enabling the diversification of Brazilian production (Cordeiro *et al*., 2015) and the expansion of chickpea crops. The increase in the cropped area exerts an important influence on the seed market as it increases even more the demand regarding physiological and sanitary quality for the crop.

A critical stage in the chickpea production process is the harvest, as the maturation of the pods can show a great unevenness and, consequently, high water content. For plants with indeterminate growth, such as chickpeas, flowering, and maturation are continuous processes, which enable the same plant to present different stages of seed maturation. This makes it difficult to identify the harvest point to have a production that combines high productivity and excellent seed quality

(Trancoso *et al*., 2021). According to Long *et al*. (2019), identifying the maturation stage for harvesting is essential to ensure a good final product and to preserve the seed with high physiological quality.

The use of desiccant herbicides can promote the rapid drying of the plants, the increase in maturation uniformity, reduction in the losses, and anticipation of the harvest, in addition to delaying the deterioration process and resulting in improvements in the physical, physiological, and sanitary quality of the seeds produced (Zuffo *et al*., 2020; Silva *et al*., 2020).

Some factors in the growing environment may promote the action of desiccant herbicides, such as high temperature and low air humidity. However, it is important to consider other aspects of the desiccation process, such as the impact on seed physiology, the quantity of toxic residues in the grain/seed, and the ideal moment for herbicide application.

Considering the need to obtain information about chickpeas in the conditions of the Brazilian Cerrado, the objective of this work was to evaluate desiccant herbicides in early harvest and the physiological quality of chickpeas seeds.

MATERIAL AND METHODS

The experiment was carried out in two stages, the first was conducted in the field and the second in the laboratory. The field phase was implemented at the Center for Innovation in Plant Genetics at Embrapa Cerrados, Sucupira farm (15º54'41''S, 48º02'14''W, 1,260 m altitude) located in the Administrative Region of Riacho Fundo II, Brasilia-DF. According to the Köppen-Geiger climate classification, the climate in the area is the Aw-type with a well-defined rainy and dry season (Cardoso *et al*., 2014). The area of the experiments presents homogeneous soil of the Dystrophic Red Latosol type with the granulometric composition of 300 g/kg clay; 425 g/kg sand and 275 g/kg silt. The soil was corrected (pH 5.9) and had the following nutrient contents in the 0-20 cm layer: P = 14.1 g/kg; Ca = 1.8 cmol/dm^3; Mg = 0.5 cmol/dm^3; K = 0.16 cmol/dm^3; cation exchange capacity (CEC) = 4.9 cmol/kg and organic matter (OM) = 42.5 g/kg.

The chickpea cultivar BRS Toro was used in the experiment, which has a semi-upright plant architecture, 130 days average cycle from emergence to maturation, an 70 cm average plant height, and a yield potential greater than 3,000 kg/ha in irrigated areas and 2,000 kg/ha in the second crop area (rainfed). It is an open-pollinated cultivar suitable for areas with altitudes greater than 600 m (Nascimento *et al*., 2017).

The treatments consisted of desiccation with herbicides at the respective doses: glufosinate ammonium (200, 400, and 500 g a.i./ha); diquat (200, 400, and 500 g a.i./ha); carfentrazone ethyl (15, 30 and 37.5 g a.i./ha) and saflufenacil (49, 98 and 122.5 g a.i./ha). The experimental arrangement was in a 4 x 3 + 1 factorial scheme (control as an additional treatment, without herbicide), in randomized blocks, with four replications. The doses adopted in this work corresponded to 50, 100, and 125% of those recommended for beans (*Phaseolus vulgaris*), which are from the same botanical family as chickpeas and are registered for the products (Brazil, 2023). The plots were formed by four 3-m rows and a distance between rows of 0.5 m, considering the two central rows as useful areas, excluding 0.5 m from the ends of the rows. Seeds were sown on May 15, 2018, with ten seeds per linear meter.

At 130 days after emergence, at desiccant application, chickpea plants had approximately 80% dry pods. The herbicides were applied between 8:00 a.m. and 10:00 a.m., when 87 to 88% relative humidity of the air, 24 to 29ºC air temperature, and mild wind/light breeze were recorded, with 9 km/h speed approximately. A CO_{2}- pressurized backpack sprayer was used at 2.8 kgf/cm^2 constant working pressure, equipped with a bar with four *Turbo TeeJet Induction* flat jet nozzles (TTI 110015), spaced 0.5 m apart, with spray consumption equivalent to 200 L/ha.

Following herbicide application, the water content of the seeds was daily monitored by collecting samples of seeds from the plants present in the borders of the plots, until reaching between 18 and 20%. This was considered the harvest point, which was carried out in the useful area of the plots of each treatment. The plants in the useful area of the plots were cut at ground level, tied, and transported to a drying batch-type, where they remained until the seeds had approximately 13% moisture content (seed water content). The pods of the plants were threshed manually, cleaned using sieves, and stored in a cold chamber until they were sent for laboratory analysis.

The evaluations carried out in the field were as follows: **Crop Cycle (CC)** = number of days of plant development, from sowing to harvest, when the seeds reached a water content between 18 and 20% and; **Grain Yield (GY)** = determined after pods have been threshed and obtained cleaned seeds, with weighing carried out on a precision analytical scale (0.01g) and values expressed in grams.

The evaluations carried out in the laboratory were as follows: **Thousand-Seed Weight (TSW)** = by weighing eight repetitions of 100 seeds, obtained from the portion of pure seeds (Brasil, 2009); **Moisture Content (MC)** = determined from two subsamples of whole seeds using the oven method for 24 hours at 105±3°C temperature (Brasil, 2009); **Paper roll germination (GE)** = carried out using four subsamples of 100 seeds treated with iprodione fungicide (500 g/L, from the dicarboxamide chemical group), distributed in paper rolls, moistened with distilled water in the amount of 2.5 times the weight of dry paper. After this step, the rolls were placed in a germinator (BOD-type germination chamber), at 25°C, for eight days. The count of normal seedlings was performed on the fifth and eighth days after installation of the test (Brasil, 2009), and the results were expressed in percentage; **Accelerated Aging (AA)** = the protocol used in this work was established by the Vigor Committee of the Association of Official Seed Analysis with adaptations by Dias *et al*. (2020). A layer of seeds was placed on a metal screen in a crystal polystyrene gerbox with 40 mL water. After closing, the boxes were taken to the incubator, where they remained for 48 hours at 41+1ºC. Afterwards, four subsamples of 100 seeds were placed to germinate, as described for the germination test; **Electrical Conductivity (EC)** = the protocol used was adapted (ISTA, 2018; Khajeh-Hosseini *et al*., 2019) for four subsamples of 25 seeds per sample. Each subsample was weighed and placed in plastic cups containing 50 mL distilled water and kept at 35ºC for 24 hours of imbibition. The solution was analyzed using a benchtop digital conductivity meter; the obtained values were divided by the weight of the sample (g) and the results were expressed in µS/cm/g, which correspond to the average mass electrical conductivity values, according to the methodology adapted from Vieira (1994); **Potassium leaching (LIXK)** = the adapted protocol (ISTA, 2018; Khajeh-Hosseini *et al*., 2019) was used for four replications of 25 pure seeds, weighed on a 0.01-g precision scale, placed in plastic cups containing 75 mL distilled water and kept at 35°C for 24 hours. After this period, 5 mL of each sample was taken to determine the amount of potassium leached through reading in a Micronal B462 flame photometer. The obtained results were expressed in g/dm^3 of potassium per g of seed (g/dm^3/g).

Data were subjected to analysis of variance and those that showed statistically significant differences were tested for normality, homogeneity of variances, and additivity. To compare means, the Tukey test was used at 5% probability (R Core Team, 2020).

RESULTS AND DISCUSSION

The active ingredients did not influence the results of electrical conductivity (EC) and potassium leaching (LIXK) (Table 1) and there was no influence of herbicide doses on the thousand-seed weight (TSW), electrical conductivity (EC) and potassium leaching (LIXK) (Table 2). Parreira *et al*. (2015) observed that the application of 360 g a.i./ha of glufosinate in common bean pre-harvest, at 74 days after sowing, also did not affect the weight of thousand seeds.

The electrical conductivity (EC) and potassium leaching (LIXK) tests indicate the level of organization of the cell membrane system and, consequently, the level of seed deterioration (Carvalho & Nakagawa, 2000). However, no effect of herbicides, at different doses, was observed on these characteristics (Table 1). Therefore, it can be inferred that there is no relationship between these results and seed quality, but it does with the need to adapt the analysis protocol, especially electrical conductivity, for chickpeas. According to Dias *et al*. (2019), it would be necessary to adjust the electrical conductivity test using subsamples of 75 seeds, a volume of 100 mL water, and permanence for 30 hours at 25ºC. For Castilho *et al*. (2019), the most suitable condition for chickpea seeds consists of using 25 seeds, 50 mL water, and four hours at 30ºC. It should be observed that both tests used in this work can demonstrate, indirectly, the level of the vigor of the seed sample (Silva *et al*., 2014) and are extremely useful and rapid methods to assist in the characterization of the physiological quality (Medeiros *et al.*, 2019).

Crop cycle (CC), grain yield (GY),thousand-seed weight (TSW), germination (GE), and accelerated aging (AA) were influenced by herbicides (Table 1). Anticipating harvest for a longer time was observed with the use of glufosinate, an average of 140.33 cycle days when compared to the other herbicides; for the control, the cycle was 153.50 days, while for diquat and carfentrazone-ethyl, they were 147.17 and 144.75 days, respectively. In all treatments, harvest was anticipated concerning the control, from 4.83 to 13.17 days. In addition, the doses corresponding to 100 and 125% of the recommended amount for beans reduced the crop cycle (Table 2).

Glufosinate also influenced the increase in grain yield (Table 1), with a value of 559.17 g concerning saflufenacil (442.92 g), not differing, however, from carfentrazone-ethyl (525.00 g) and diquat (508.75 g). When no desiccant was used, the grain yield was 432.50 g (Table 1). Unlike the observation in this work, Parreira *et al*. (2015) found no change in common bean grain yield due to the application of 360 g a.i./ha of glufosinate in the pre-harvest, at 74 days after sowing. The authors explain that, even at an advanced vegetative stage, the rapid desiccation generated by some herbicides can paralyze the accumulation of dry mass that was still being transferred to the seeds.

Seed germination was less affected by diquat, with a value of 91.08% when compared to glufosinate (82.92%);

Table 1. Crop cycle (CC), grain yield (GY), 1000-seed weight (TSW), germination (GE), accelerated aging test (AA), electrical conductivity (EC), and potassium leaching (LIXK) of chemical desiccants. Brasília, Embrapa Cerrados, 2021.

Herbicides	CC (days)	GY (g)	TSW (g)	GE (%)	AA (%)	EC (µS/cm/g)	LIXK (dm^3/g)
Glufosinate	140.33c[1]	559.17a	351.87ab	82.92 b	68.75ab	184.26a	10.82a
Diquat	147.17ab	508.75ab	334.97b	91.08 a	74.33a	198.81a	10.99a
Carfentrazone-ethyl	144.75b	525.00ab	359.58a	85.75 ab	63.08b	190.33a	10.93a
Saflufenacil	148.67a	442.92b	349.29ab	89.00 ab	66.17ab	221.70a	10.59a
Control	153.50	432.50	359.22	62.00	48.00	202.83	11.45
LSD	2.78	94.01	23.63	6.22	9.96	48.13	1.01

[1]Means followed by same lowercase letters in the column do not differ from each other by the Tukey test (5%).

Table 2. Crop cycle (CC), grain yield (GY), 1000-seed weight (TSW), germination (GE), accelerated aging test (AA), electrical conductivity (EC), and potassium leaching (LIXK) according to the doses of chemical desiccants. Brasília, Embrapa Cerrados, 2021.

Doses (%)	CC (days)	GY (g)	TSW (g)	GE (%)	AA (%)	EC (µS/cm/g)	LIXK (dm^3/g)
50	148.00a[1]	505.31a	350.68a	81.94b	59.25b	195.51a	10.84a
100	144.00b	521.88a	351.21a	87.69a	75.75a	191.45a	10.79a
125	143.69b	499.69a	344.89a	91.94a	69.25a	209.35a	10.86a
Control	153.50	432.50	359.22	62.00		202.83	11.45
LSD	2.18	73.89	18.58	4.89	48>00	37.83	0.80

[1]Means followed by same lowercase letters in the column do not differ from each other by the Tukey test (5%).

nevertheless, the use of diquat did not differ from saflufenacil (89.00%) and carfentrazone-ethyl (85.75%) (Tables 1 and 3). Comparing to the applied doses, 50, 100, and 125% of the recommended ones for beans, the percentage of germination increased significantly with the concentration of herbicides (Tables 2 and 3). In addition, an increase was observed in the germination with the use of herbicides and doses used in relation to the control, whose mean value was 62.00% (Tables 1 to 3).

Similarly, the highest value for accelerated aging, 74.33%, was found in seeds from desiccation by diquat (Table 1) in comparison to the use of carfentrazone-ethyl herbicide (63.08%); however, it did not differ from the other treatments, with values of 68.75 and 66.17%, for glufosinate and saflufenacil, respectively (Table 1). The increase in the applied doses, similarly to germination, increased or maintained the percentage of accelerated aging, except for carfentrazone-ethyl (Tables 2 and 3). For accelerated aging, due to different herbicides and doses, all values found in this work were higher than the control, 48.00% (Tables 1 to 3).

Thus, the use of herbicides diquat, at 400 and 500 g a.i./ha, carfentrazone-ethyl, at 30 and 37.50 g a.i./ha, and saflufenacil, at 122.50 g a.i./ha, positively influenced chickpea seed germination (Table 3). Glufosinate (400 and 500 g a.i./ha), diquat (400 and 500 g a.i./ha), carfentrazone-ethyl (30 and 37.50 g a.i./ha), and saflufenacil (98.00 and 122.50 g a.i./ha) provided an increase in seed vigor, according to the accelerated aging test (Table 3). It should be observed that germination showed a positive correlation with the results of accelerated aging at a level of 0.9 or 90% ($p \leq 0.05$), showing that the initial quality of the chickpea cultivar seed lot is fundamental in maintaining the physiological quality and occurred regardless of treatment and dose used.

The four assessed herbicides (glufosinate, diquat, carfentrazone-ethyl, and saflufenacil), applied at the recommended concentration for common bean, provided results that indicated similarity with the chickpea crop. According to Silva *et al*. (2017), in the common bean crop, harvest anticipation of 29 and 22 days was observed with the use of active ingredients diquat (450 g a.i./ha) and glufosinate (550 g a.i./ha), respectively.

The use of desiccants with a dose higher than that recommended for beans (125%) did not influence early harvest (CC), germination (GE), or vigor (SV) (Table 2). Penckowski *et al*. (2005) also observed that the application of the desiccants diquat (300 and 600 g a.i./ha) and glufosinate (300 g a.i./ha) in the pre-harvest period did not affect the germination and vigor of common bean seeds. According to Santos *et al*. (2004), the use of doses between 10 and 30 g a.i./ha of carfentrazone-ethyl in beans did not negatively affect the seeds, as long as the application of the desiccant occurred 30 days after flowering. Conversely, the application of glufosinate at 200 and 400 g a.i./ha during the grain-filling period of ryegrass (*Lolium multiflorum*) reduced germination and seed vigor and increased the percentage of dead seeds (Schaeffer *et al*., 2020).

Attempts at savings arising from the reduction in the concentration of

Table 3. Germination (GE) and accelerated aging test (AA) according to the chemical desiccants and doses. Brasília, Embrapa Cerrados, 2021.

Tests	Herbicides	Doses (%)		
		50	100	125
GE (%)	Glufosinate	82.75 abA[1]	83.75 bA	82.25 bA
	Diquat	83.75 aB	94.75 aA	94.75 aA
	Carfentrazone-ethyl	72.25 bB	90.00 abA	95.00 aA
	Saflufenacil	89.00 aAB	82.25 bB	95.75 aA
Control			62.00	
CV (%)			6.66%	
AA (%)	Glufosinate	53.00 aB	78.25 aA	75.00 aA
	Diquat	67.00 aA	81.00 aA	75.00 aA
	Carfentrazone-ethyl	66.75 aA	74.25 aA	48.25 bB
	Saflufenacil	50.25 aB	69.50 aA	78.75 aA
Control			48.00	
CV (%)			13.66	

[1]Means followed by same lowercase letters in the column do not differ from each other by the Tukey test (5%).

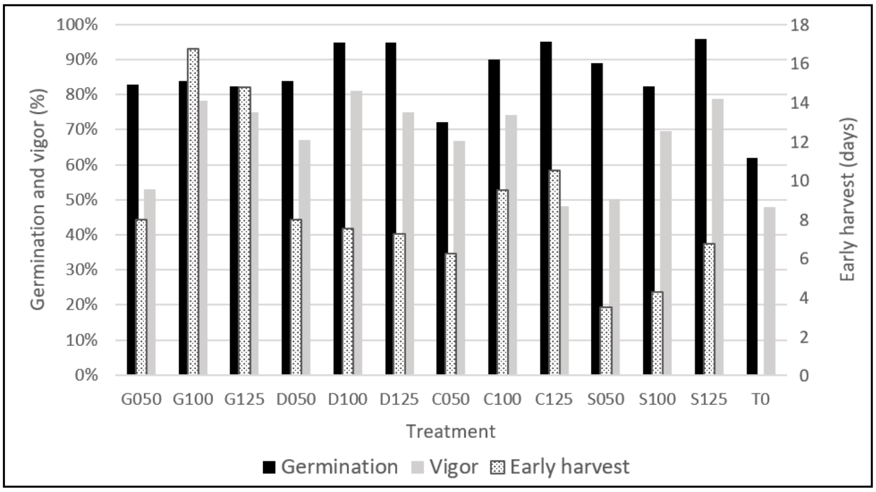

Figure 1. Germination (%), vigor (%), and early harvest (days) according to herbicide treatments. G050 = glufosinate 200 g a.i./ha; G100 = glufosinate 400 a.i./ha; G125 = glufosinate 500 g a.i./ha; D050 = diquat 200 g a.i./ha; D100 = diquat 400 g a.i./ha; D125 = diquat 500 g a.i./ha; C050 = carfentrazone-ethyl 15 g a.i./ha; C100 = carfentrazone-ethyl 30 g a.i./ha; C125 = carfentrazone-ethyl 37.5 g a.i./ha; S050 = saflufenacil 49 g a.i./ha; S100 = saflufenacil 98 g a.i./ha; S125 = saflufenacil 122.5 g a.i./ha; T0 = control (germination, vigor and early harvest according to herbicide treatments). Brasília, Embrapa Cerrados, 2021.

active ingredients caused a loss in the effectiveness of the application for harvest anticipation (CC), germination (GE), and vigor (EA) (Table 2). On the other hand, the use of an excessive dose, whether intentional or accidental, in addition to causing economic losses, can also pose a risk of environmental impact and increase the residual effect of the chemical substance in the grain, which can be rendered unusable for human or animal consumption.

The use of glufosinate at 400 and 500 g a.i./ha provided a reduction in the number of days in the crop cycle, in addition to yielding higher seed quality (Figure 1). The application of 400 g a.i./ha of glufosinate would enable the reduction of costs to the farmer and similar results, both related to the physiological quality of the seed and the anticipation of the harvest. Another herbicide with a recommended dose for beans and that provided high physiological quality (90.00% germination and 74.25% vigor) to the seed and anticipation with intermediate results was carfentrazone-ethyl, at 30 g a.i./ha (Table 3 and Figure 1).

Unsuccessful desiccation and use of saflufenacil at 49 g a.i./ha were those that presented seeds with the lowest average percentages related to germination, vigor, and harvest anticipation (Figure 1). The decline in germination percentage and vigor of chickpea seeds, after storage or delay in harvesting, were also found by Wood & Scott (2021).

The use of the desiccant herbicide glufosinate at 400 g a.i./ha was more efficient than the others, providing high physiological quality of the seeds, with values of 83.75% germination and 78.25% vigor, and promoting a greater anticipation of the harvest (up to 17 days) than the other evaluated treatments. Germination showed a positive correlation with accelerated aging.

It should be observed that the use of these herbicides for chickpeas is not recommended until being registered on the Ministry of Agriculture, Livestock and Supply (MAPA). Nevertheless, it is expected, based on the results obtained with the development of this work, to subsidize and motivate the chemical industries to carry out registrations and/or extensions of use of some of these products under MAPA's recommendation for use in these production areas.

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