# Yield and quality of wheat seeds as a function of desiccation stages and herbicides[1]

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ABSTRACT - This study aimed to evaluate the yield and seed quality of wheat, cultivar 'Quartzo', harvested after desiccation with two desiccants (glyphosate and paraquat) at two reproductive stages (11.2 and 11.3). The study used a randomized block experimental design in a 3 x 2 factorial arrangement (two desiccants and a control) and two growth stages of wheat, with four replications. The following were assessed: seed yield, thousand seed weight and seed quality (germination, first germination count, root and shoot weight, seedling dry and fresh weight, accelerated aging, electrical conductivity, cold germination, potassium leaching). Based on the results, it can be concluded that the use of desiccants on wheat at the two stages of development have not affected yield, but they have negatively influenced physiological seed quality. Generally, the herbicide glyphosate showed the lowest phytotoxic effect on seeds, and desiccant application at stage 11.2 resulted in higher physiological seed quality compared with application at stage 11.3.

Index terms: *Triticum aestivum*, glyphosate, paraquat, growth stage, vigor.

## Produtividade e qualidade de sementes de trigo em função de estádios de dessecação e herbicidas

RESUMO – Objetivou-se nesse trabalho avaliar a produtividade e qualidade fisiológica de sementes de trigo, cultivar 'Quartzo', colhidas após a dessecação com dois dessecantes (glyphosate e paraquat) em dois estádios reprodutivos (11.2 e 11.3). O delineamento experimental utilizado foi em blocos casualizados, em esquema fatorial 3 x 2 (dois dessecantes e uma testemunha) e dois estádios fenológicos do trigo, com quatro repetições. Foram avaliados a produtividade de sementes, a massa de mil sementes e a qualidade das sementes (germinação, primeira contagem de germinação, comprimento de parte aérea e radicular, massa fresca e seca de plântulas, envelhecimento acelerado, condutividade elétrica, frio sem solo e lixiviação de potássio). Diante dos resultados obtidos, pode-se concluir que o uso de dessecantes na cultura do trigo nos dois estádios de desenvolvimento não interferiu na produtividade, mas influenciou negativamente na qualidade fisiológica de sementes. De forma geral, o glyphosate foi o que proporcionou menor efeito fitotóxico sobre as sementes, e as sementes obtidas com aplicação de dessecantes no estádio 11.2 foram de qualidade fisiológica superior às obtidas com aplicação no estádio 11.3.

Termos para indexação: *Triticum aestivum*, glyphosate, paraquat, estádio fenológico, vigor.

## Introduction

Seed production technology recommends that harvest should be made as close as possible to physiological maturity. However, at this stage, seed water content is higher than 30% in crops such as corn, soy, oat, bean and wheat, thus not compatible with the technology available for mechanical harvesting (Lacerda et al., 2003; Marcos-Filho, 2005). Furthermore, the later the harvest after seeds have matured, the more likely they are to deteriorate, because they are subject to adverse conditions, which leads to significant reduction in quality and amount of seed yield (Marcos-Filho, 2005). An alternative used by farmers to minimize seed deterioration in the field is to apply selective herbicides. These desiccants are applied when most seeds are mature so that the crop can reach maturity more thoroughly, and harvest can be made a few days earlier, thereby enabling better physiological and sanitary seed quality (Lacerda et al., 2005).

Glyphosate and paraquat are the main desiccants used as herbicides, but only paraquat is registered with Brazil's

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Ministry of Agriculture, Livestock and Supply for use as a desiccant in crops such as potatoes, sugar cane, corn and soybeans, but not wheat crops, though (Agrofit, 2013). Paraquat is a post-emergence, non-selective, contact herbicide used as an electron acceptor in photosystem I. It forms free radicals that lead to lipid peroxidation and membrane disruption, causing desiccation of plants within a short time period (Vargas and Roman, 2006). Glyphosate is a systemic, total action herbicide that belongs to the group of glycines and it is used at post-emergence. Glyphosate inhibits plant enzyme 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS), responsible for the synthesis of essential aromatic amino acids (phenylalanine, tyrosine and tryptophan), which are precursors of essential plant products such as lignin, alkaloids, flavonoids, benzoic acids and vitamin K (Toni et al., 2006). Glyphosate is widely adopted in areas where no-till farming is used.

There have been several positive results as to the effectiveness of desiccants in reducing the moisture content and preserving the quality of seeds of soybean (Daltro et al., 2010; Guimarães et al., 2012), bean (Santos et al., 2004) and canola (Silva et al., 2011). The use of glyphosate desiccation for earlier harvest is becoming frequent, mainly because glyphosate offers low cost and product versatility. However, several studies have reported negative effects of this herbicide, when it is used for desiccation of soybeans between stages R6 and R7.2, on physiological seed quality and early seedling performance, especially on the seedling root system (Daltro et al., 2010; Guimarães et al., 2012). Penckowski et al. (2005), while assessing the effect of pre-harvest desiccation on bean seed quality, observed that treatments with glufosinate-ammonium + etephon, diquat and glufosinate-ammonium were efficient in desiccating the crop and did not affect germination and vigor, but paraquat (240 g a.i.ha$^{-1}$) and glyphosate (720 g a.i.ha$^{-1}$) were not as efficient as the other treatments, and negatively affected germination. Glyphosate also reduced seed vigor.

In a study on times for desiccant application on wheat and their effect on seed yield, Santos and Vicente (2009) observed that herbicide application at pre-harvest did not affect yield. However, it affected seed germination: the application of glufosinate-ammonium on wheat at pre-harvest, 40 days after flowering (DAF), gave the best result for germination while the treatment with paraquat at 26 and 33 days after flowering gave the lowest germination rate.

Because of the situation above mentioned and the growing production demand, a greater number of agricultural cycles is required in the same area, which results in the reduction of the crop cycle. The use of desiccants for early harvest of wheat has increased steadily although there are not enough experimental data on desiccation, particularly on wheat seed quality. Based on this assumption, the present study aimed to evaluate the effect of using two herbicides as desiccants, at two reproductive stages, on the yield and physiological seed quality of wheat.

## Material and Methods

The experiment was conducted under field conditions in the municipality of Boa Vista das Missões, located in the north of the state of Rio Grande do Sul. Geographical coordinates are 27º 20' 26'' (S) and 69º 36' 56'' (W). Soil in the area is typically a red Latosol, with the following physical and chemical properties: clay = 67%, water pH = 5.6, SMP index = 6.5, organic matter = 3.1%, phosphorus = 10.9 mg.dm$^{-3}$; potassium mg.dm$^{-3}$ = 84; calcium cmolc.dm$^{-3}$ = 5.3; magnesium cmolc.dm$^{-3}$ = 5.0 and sulfur = 10 cmolc.dm$^{-3}$.

Wheat was sown on July 10, 2011, among soybean crop residues in no-tillage system and with row spacing of 0.17 m. The cultivar used was 'Quartzo', with a seeding density rate of 165 kg.ha$^{-1}$.

The experiment used a randomized block design with four replications. Each plot was 5 m$^2$ (2.0 x 3.0 m), with 11 rows and 300 seeds per m². The treatments were arranged in a 3 x 2 factorial design, whose factors were the herbicides glyphosate (720 g a.i.ha$^{-1}$) and paraquat (240 g a.i.ha$^{-1}$) applied alone and the control without herbicide at two application times: physiological stage 11.2 (99 days after sowing - DAS) and stage 11.3 (105 DAS), and control (111 DAS). Stage 11.2 is characterized by having plants at physiological maturity with soft and moist seeds, while the stage 11.3 corresponds to hard seeds (Large, 1954).

The herbicide treatments were applied using a $CO_2$ pressurized backpack sprayer (200 kPa pressure) outfitted with four XR 110.02 flat fan tips, spaced at 0.5 m, with a spray volume of 200 L.ha$^{-1}$. Figure 1 shows the daily mean values of temperature, relative air humidity and rainfall that occurred during the crop cycle.

The harvest of the plots was performed ten days after treatment (DAT). The seeds harvested in the field were analyzed for yield and quality in the Seed Technology Laboratory of Universidade Federal de Santa Maria, Frederico Westphalen Campus, Rio Grande do Sul. The following analyses were performed:

*Seed yield*: the six central rows were collected from each plot, and 0.50 m was discarded at each end for evaluation of seed yield, totaling a target study area of 2.04 m$^2$.

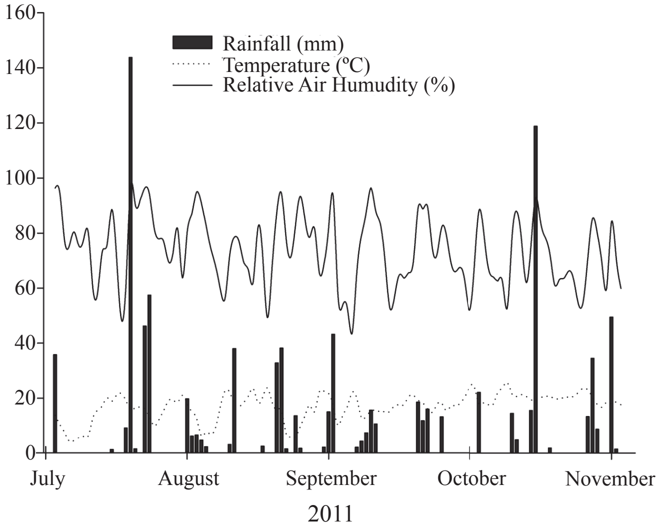


Figure 1. Average daily temperature (°C), relative humidity (%) and daily rainfall (mm) during the field experiment.

*Thousand seed mass*: the analysis was performed by weighing eight replicates of 100 seeds from the main sample (Brasil, 2009).

*Germination test*: four replications were used with four subsamples of 50 seeds for each treatment, with germitest paper rolls as the substrate, moistened with distilled water in a volume equivalent to 2.5 times the dry weight of the substrate. After preparation of the rolls, they were placed in plastic bags and kept in a BOD (Biochemical Oxygen Demand) incubator at a constant temperature of 20 °C. The seeds were counted after four and eight days after experimental setup, and the results were expressed as the percentage of normal seedlings (Brasil, 2009).

*First germination count:* performed together with the germination test by evaluating the number of normal seedlings on the fourth day after the start of the test. The results were expressed as the percentage of normal seedlings.

*Accelerated aging test*: conducted with four subsamples of 50 seeds for each treatment, in transparent plastic boxes (gerboxes), measuring 11 x 11 x 3 cm, fitted with minicameras. 40 mL of distilled water were added to the boxes. A mesh was placed above the water, and the seeds were placed on the mesh in each box. Then the plastic boxes were taken to the BOD incubator at 42 ºC, where they remained for 48 hours (Marcos-Filho, 1999). After this period, the seeds were germinated as described in the germination test, and the number of normal seedlings was counted on the fourth day after the experimental setup. The results were expressed as the percentage of normal seedlings.

*Electrical conductivity test*: electrical conductivity was determined by using four replicates of 50 seeds for each treatment. The samples were weighed on a precision balance, soaked in water in a plastic container with 75 mL of distilled water, and then stored at 25 °C for 24 h (Krzyzanowski et al., 1999). After that period, electrical conductivity was measured in the soaking solution with a CD-4303 digital conductivity meter, and the results were expressed as $\mu S.cm^{-1}.g^{-1}$.

*Cold germination test*: performed using the methodology described by Krzyzanowski et al. (1999) adapted for wheat crops. Four replicates of 50 seeds were used for each treatment. They were placed on moist germitest paper with an amount of water equivalent to 2.5 times the weight of the paper. After sowing, the rolls were placed inside plastic bags, sealed with adhesive tape, and kept in an incubator at 5 °C for seven days. After that time, the rolls inside the plastic bags were transferred to a BOD incubator at 20 °C, where they remained for four days. The results were analyzed by considering the percentage of normal seedlings.

*Potassium leaching test*: four replicates of 50 seeds were placed in 200 mL plastic cups, where 75 mL of distilled water were added, and kept at 25 °C for 120 min. Leached potassium values were determined by using the method of flame photometry, and the results were expressed as grams of $K^+.kg^{-1}$ seed.

*Seedling shoot and root length*: data were collected together with the germination test at eight days by measuring eight subsamples of 15 seedlings for each treatment. The average shoot and root lengths of normal seedlings were obtained by dividing the sum of the measures of the subsamples by the number of normal seedlings measured, and the results were expressed as $mm.seedling^{-1.}$

*Seedling fresh and dry weight*: measured for the seedlings previously used in the germination test for length determination. Each replicate was weighed on a balance with 0.001 g precision, placed in paper bags and taken to a forced air circulation oven at 55 ºC for 72 hours. After that, each replicate was weighed on a precision balance. The results were expressed as $mg.seedling^{-1.}$

Data underwent analysis of variance and, if significant, multiple comparison of means was performed by Tukey's test at 5% probability.

## Results and Discussion

The results for yield, thousand seed weight, germination, first germination count, potassium leaching, electrical conductivity, accelerated aging, cold test, shoot length and root length, showed significant interaction between application times x herbicides (Table 1).

Table 1. Summary of analysis of variance for the evaluated parameters, for wheat cultivar Quartzo, under two desiccation times and desiccants: Yield (Y) and thousand seed weight (TSW), Germination (G), First Germination Count (FGC), Potassium Leaching (PL), Electrical Conductivity (EC), Accelerated Aging (AA) Cold Test (CT), Seedling Fresh Weight (FW) and Seedling Dry Weight (DW), Shoot Length (SL) and Root Length (RL).

| VF | DF | Mean squares | | | | | |
|---|---|---|---|---|---|---|---|
| | | Y | TSW | G | FGC | PL | EC |
| Blocks | 3 | 63,676.5 $^{ns}$ | 2.6166 $^{ns}$ | 6.81* | 55.26* | 0.0477* | 0.50* |
| Desiccants (D) | 2 | 12,343.6 $^{ns}$ | 0.5072 $^{ns}$ | 434.29* | 1116.29* | 6.5066* | 383.74* |
| Times (T) | 1 | 256,994.6 $^{ns}$ | 10.5603 $^{ns}$ | 70.04* | 117.04* | 1.3066* | 11.62* |
| D X T | 2 | 74,325.0 $^{ns}$ | 3.0541 $^{ns}$ | 22.79* | 30.04* | 0.4516* | 38.81* |
| Residual | 15 | 182,307.4 | 7.4913 | 1.35 | 4.83 | 0.0164 | 6.81 |
| CV (%) | - | 7.75 | 6.03 | 1.40 | 3.03 | 3.91 | 9.46 |
| Mean | | 5512.78 | 35.33 | 83.04 | 72.45 | 3.28 | 27.58 |
| VF | DF | Mean squares | | | | | |
| | | AA | CT | FW | DW | SL | RL |
| Blocks | 3 | 10.77* | 9.61* | 0.00385* | 0.00098* | 42.87* | 0.00529 $^{ns}$ |
| Desiccants (D | 2 | 1818.87* | 378.29* | 2.70131* | 0.10822* | 3941.89* | 2873.79* |
| Times (T) | 1 | 216.00* | 96.00* | 0.00015 $^{ns}$ | 0.00093 $^{ns}$ | 3.03 $^{ns}$ | 44.44* |
| D X T | 2 | 190.12* | 25.12* | 0.00215* | 0.00188* | 201.30* | 29.68* |
| Residual | 15 | 6.51 | 2.67 | 0.00291 | 0.00091 | 12.2300 | 2.81 |
| CV (%) | - | 3.31 | 1.93 | 1.61 | 2.67 | 3.01 | 2.55 |
| Mean | | 77.00 | 84.91 | 3.34 | 1.13 | 116.25 | 65.91 |

* Significant at 5% probability by the F-test. $^{ns}$: Not significant. VF = variation factors; DF = degree of freedom, CV = coefficient of variation.

According to the results (Table 2), no statistical significance was observed, which is indicative that neither desiccation times nor herbicides significantly influenced seed mass accumulation or wheat seed yield, for that matter. Similar results were found by Marchiori Jr. et al. (2002), who observed no negative interference of desiccants on the results for yield and thousand seed weight when using desiccants diquat, paraquat, glufosinate and carfentrazone-ethyl in canola, and soybean (Inoue et al., 2002). Santos and Vicente (2009) observed no effect on seed yield when they evaluated the effect of paraquat on pre-harvest wheat.

Table 2. Yield (Y) and thousand seed weight (TSW) of wheat, cultivar Quartzo, under two desiccation times and desiccants.

| Desiccants | Y (kg/ha) | | TSW (g) | |
|---|---|---|---|---|
| | Desiccation time | | | |
| | Stage 11.2** | Stage 11.3** | Stage 11.2 | Stage 11.3 |
| Glyphosate | 5,662.80 $^{ns*}$ | 5,581.38 $^{ns}$ | 36.30 $^{ns}$ | 35.55 $^{ns}$ |
| Paraquat | 5,635.50 | 5,506.04 | 35.79 | 34.98 |
| Control | 5,550.48 | 5,602.03 | 35.58 | 35.29 |
| Mean | 5,616.26 | 5,593.15 | 35.89 | 35.27 |
| CV (%) | 7.75 | | 6.03 | |

* *non-significant.*

** The physiological stage 11.2 for wheat development shows plants at physiological maturity with soft and moist seeds, while stage 11.3 corresponds to hard seeds, according to the scale proposed by Feekes (Large, 1954).

For the germination variable, as well as for the first germination count, significant interactions were observed for the factors herbicides and desiccation times (Table 3). Regardless of application times, both herbicides negatively affected seed germination of wheat compared to the control. However, a more pronounced effect on the results of this variable was observed when using paraquat, while glyphosate caused less detrimental effect. Similar results were found by Santos and Vicente (2009), who found that the application of the herbicide paraquat at pre-harvest at 26 and 33 days after wheat flowering reduced seed germination, a lower result when compared with the treatment with glufosinate-ammonium.

However, Caierão and Acosta (2007), when using paraquat and glyphosate on barley crops, observed no negative interference of the desiccants on seed vigor. It should be emphasized that the values obtained in the germination test, in the present study, allow the seeds obtained - only where the treatment was desiccated with glyphosate at stage 11.2 – to be rated as suitable for sale because according to Normative Instruction No. 45 of 2013 (Brasil, 2013), 80% is the minimum percentage required as a standard for wheat seeds.

Table 3. Germination (G) and First Germination Count (FGC) of wheat seeds, cultivar Quartzo, under two desiccation times and desiccants.

| Desiccants | G (%) | | FGC (%) | |
|---|---|---|---|---|
| | Desiccation time | | | |
| | Stage 11.2** | Stage 11.3** | Stage 11.2 | Stage 11.3 |
| Glyphosate | 84.25 Ba* | 77.50 Bb | 75.50 Ba | 69.50 Bb |
| Paraquat | 78.75 Ca | 75.25 Cb | 64.25 Ca | 57.00 Cb |
| Control | 91.25 Aa | 90.30 Aa | 84.25 Aa | 82.29 Aa |
| Mean | 84.75 | 81.02 | 74.67 | 69.60 |
| CV (%) | 1.40 | | 3.03 | |

* For each characteristic, similar uppercase letters in the column and lowercase letters on the line, do not differ by Tukey's test at 5%.
** The physiological stage 11.2 for wheat development shows plants at physiological maturity with soft and moist seeds, while stage 11.3 corresponds to hard seeds, according to the scale proposed by Feekes (Large, 1954).

The analysis of seed germination by first germination count (Table 3) shows that the desiccant negatively affected the seeds from less vigorous desiccated plants when compared with the treatment without desiccation (control). When comparing the two desiccants, glyphosate showed a minor influence on this variable.

For the factor desiccation time, germination and first germination count increased the germination potential for treatments with early herbicide application (stage 11.2), a behavior that occurred for both herbicides. The decrease in germination potential between the first and second application is possibly a result of the increased exposure of seeds to adverse weather conditions between the two growth stages (Figure 1). This behavior is explained by greater exposure to humidity and sudden temperature fluctuations.

In Table 4, the results of the potassium leaching and electrical conductivity tests show that desiccation negatively affects vigor of wheat seeds, regardless of herbicide and application time. The potassium leaching test (PL), which accounts for cell membrane integrity, according to Miguel and Marcos-Filho (2002), showed that seeds from treatments with desiccants paraquat and glyphosate released higher amounts of potassium compared to the control (Table 4). This is probably due to the action of the desiccants, associated with lipid peroxidation caused by secondary lipid metabolites, which react with membrane lipids and, thus, disrupt and change their structure (Duke et al., 2003; Bervald et al., 2010). Consequences of such disruption include lower control of selective permeability, loss of cellular compartmentalization, disruption of cellular metabolism, inefficient mechanisms for repair and synthesis. These events directly affect seed performance (Marcos-Filho, 2005). These results corroborate the findings of Bervald et al. (2010), i.e., increasing rates of glyphosate affected the membrane permeability of soybean seeds, increasing the exchange of solutes between seeds and the medium, thus reducing seedling vigor. However, Marchiori Jr. et al. (2002) emphasized that the herbicide paraquat used at early harvest did not affect the membrane permeability of canola seeds (*Brassica napus*). Thus, different behaviors can be inferred for each species.

As previously mentioned, the results for the electrical conductivity (EC) test showed increases in electrolyte leaching in seeds from plants where desiccants had been applied, compared with the control. This loss of elements directly influences the potential for germination and seed vigor. Sá and Lazarini (1995), when working with soybeans, found that electrical conductivity values below 60 $\mu S.cm^{-1}.g^{-1}$ are associated with a high percentage of emergence in the soil, germination and vigor, while Marcandalli et al. (2011) obtained high germination percentage even with electrical conductivity values around 100 $\mu S.cm^{-1}.g^{-1}$. However, in this study, the values of electrical conductivity below 34 $\mu S.cm^{-1}.g^{-1}$ significantly compromised the germination percentage of wheat, and revealed a particular feature of this crop. Considering application time (Table 4), the herbicides had different behaviors: the best application time, i.e., the one that interfered the least with vigor of wheat seeds, was stage 11.3 for glyphosate and stage 11.2 for paraquat. This difference in behavior may occur due to the mobility of the product along the sprayed plants. Glyphosate is a systemic product and, thus, it causes major damage to seeds when applied before they reach physiological maturity (Daltro et al., 2010).

Table 4. Potassium leaching (PL) and Electrical Conductivity (EC) of wheat seeds, cultivar Quartzo, under two desiccation times and desiccants.

| Desiccants | PL (g.kg$^{-1}$) | | EC (µS.cm$^{-1}$.g$^{-1}$) | |
|---|---|---|---|---|
| | Application time | | | |
| | Stage 11.2** | Stage 11.3** | Stage 11.2 | Stage 11.3 |
| Glyphosate | 3.35 Bb* | 3.67 Ba | 33.70 Aa | 27.37 Bb |
| Paraquat | 4.15 Ab | 4.62 Aa | 31.47 Ab | 33.62 Aa |
| Control | 2.35 Ca | 2.00 Cb | 19.67 Ba | 18.69 Ca |
| Mean | 3.28 | 3.43 | 28.28 | 26.56 |
| CV (%) | 3.91 | | 9.46 | |

* For each characteristic, similar uppercase letters in the column and lowercase letters on the line, do not differ by Tukey's test at 5%.
** The physiological stage 11.2 for wheat development shows plants at physiological maturity with soft and moist seeds, while stage 11.3 corresponds to hard seeds, according to the scale proposed by Feekes (Large, 1954).

The results for accelerated aging and cold tests confirm the trend already evident in other tests, i.e., the non-desiccated control has better performance compared with treatments with herbicides, which is justified by probable toxic effects of desiccants, which reduce seed vigor (Table 5). However, among the products used, paraquat makes seeds less viable for possible storage, since it affects the germination of seeds after they have been exposed to stresses. It was found that the best application time for both desiccants is at stage 11.2. The accelerated aging and cold tests showed that application at stage 11.3 decreased seed vigor. This phenomenon may be associated with the fact that when the application was made, the seeds had already reached physiological maturity and were under environmental conditions such as humidity and temperature fluctuations, which account for the decline of seed vigor (Marcos-Filho, 2005).

Table 5. Accelerated Aging (AA) and Cold Test (CT) of wheat seeds, cultivar Quartzo, under two desiccation times and desiccants.

| Desiccants | AA (%) | | CT (%) | |
|---|---|---|---|---|
| | Application time | | | |
| | Stage 11.2** | Stage 11.3** | Stage 11.2 | Stage 11.3 |
| Glyphosate | 79.75 Ba* | 79.00 Ba | 85.50 Ba | 78.75 Bb |
| Paraquat | 69.50 Ca | 52.25 Cb | 82.50 Ba | 77.25 Bb |
| Control | 90.75 Aa | 89.45 Aa | 92.75 Aa | 91.68 Aa |
| Mean | 80.00 | 73.57 | 86.92 | 82.56 |
| CV (%) | 3.31 | | 1.93 | |

* For each characteristic, similar uppercase letters in the column and lowercase letters on the line, do not differ by Tukey's test at 5%.
** The physiological stage 11.2 for wheat development shows plants at physiological maturity with soft and moist seeds, while stage 11.3 corresponds to hard seeds, according to the scale proposed by Feekes (Large, 1954).

For shoot fresh and dry weight of wheat, the results show that there are injuries resulting from desiccation of the crop (Table 6). In this case, the two desiccants behaved in a similar manner on the variables analyzed, and they caused significant damage at both times of application to the non-desiccated control, i.e., they reduced seed vigor. These data are in line with the reports of Tillmann and West (2004), who found a reduction of dry weight of soybean seedlings desiccated with glyphosate compared with the control.

The results for shoot and root length (Table 7) confirmed the negative influence of desiccation of wheat on seed quality. For these two variables, the treatments with desiccants led to losses in shoot and root development of wheat, compared with the non-desiccated control. Again, the herbicide paraquat was the most damaging, as it produced the most drastic effect on the second application time. This difference was not observed for glyphosate, whose effect remained constant at both desiccation times. These results differ from the study of Marcandalli et al. (2011) with soybean. They observed that glyphosate negatively influences physiological seed quality, especially when it is assessed by the root length test, and that paraquat does not change the physiological potential of seeds.

Table 6. Shoot fresh weight (FW) and shoot dry weight (DW) of seedlings from seeds of wheat, cultivar Quartzo, under two desiccation times and desiccants.

| Desiccants | FW (mg) | | DW (mg) | |
|---|---|---|---|---|
| | Application time | | | |
| | Stage 11.2** | Stage 11.3** | Stage 11.2 | Stage 11.3 |
| Glyphosate | 3.11 Ba* | 3.08 Ba | 1.11 Ba | 1.12 Ba |
| Paraquat | 2.90 Ba | 2.94 Ba | 1.05 Ba | 1.00 Ba |
| Control | 4.00 Aa | 4.10 Aa | 1.26 Aa | 1.29 Aa |
| Mean | 3.34 | 3.37 | 1.14 | 1.14 |
| CV (%) | 1.61 | | 2.67 | |

* For each characteristic, similar uppercase letters in the column and lowercase letters on the line, do not differ by Tukey's test at 5%.
** The physiological stage 11.2 for wheat development shows plants at physiological maturity with soft and moist seeds, while stage 11.3 corresponds to hard seeds, according to the scale proposed by Feekes (Large, 1954).

Table 7. Shoot length (SL) and Root Length (RL) of seedlings from seeds of wheat cultivar Quartzo under two desiccation times and desiccants.

| Desiccants | SL (mm) | | RL (mm) | |
|---|---|---|---|---|
| | Application time | | | |
| | Stage 11.2** | Stage 11.3** | Stage 11.2 | Stage 11.3 |
| Glyphosate | 113.9 Bb* | 122.9 Ba | 70.0 Ba | 68.9 Ba |
| Paraquat | 98.6 Ca | 87.5 Cb | 48.9 Ca | 41.8 Cb |
| Control | 137.3 Aa | 135.4 Aa | 82.8 Aa | 81.0 Aa |
| Mean | 116.6 | 115.3 | 67.2 | 63.9 |
| CV (%) | 3.01 | | 2.55 | |

* For each characteristic, similar uppercase and lowercase letters in the column on the line, do not differ by Tukey's test at 5%.
** The physiological stage 11.2 for wheat development shows plants at physiological maturity with soft and moist seeds, while stage 11.3 corresponds to hard seeds, according to the scale proposed by Feekes (Large, 1954).

## Conclusions

The use of desiccants paraquat and glyphosate does not affect yield of wheat crops, but it negatively influences physiological seed quality, regardless of application time.

The herbicide glyphosate has lower phytotoxic effect on seeds compared with paraquat.

Wheat seeds obtained with desiccant application at the stage of soft and moist seeds (11.2) have higher physiological quality than those obtained with application at the stage of hard kernel seeds (11.3).

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