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Seed reserve mobilization and seedling morphology of genetically modified soybean treated with glyphosate

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Abstract – The objective of this work was to evaluate the effects of the application of the glyphosate herbicide on seed reserve mobilization and seedling morphology of genetically modified soybean. Two herbicide-tolerant (TMG 1264RR and P98Y11) and two herbicide-sensitive (Emgopa 315 and UFUS 7415) cultivars were selected for the study and subjected to germination, seedling length, and reserve mobilization tests after treatments with glyphosate solutions at the concentrations of 0.00, 0.06, and 0.12%. The hypocotyl/radicle ratio and the efficiency of conversion of reserves to seedlings were also determined. The higher the concentration of glyphosate, the lower the percentage of normal seedlings and the shorter seedling length, mainly in the herbicide-sensitive cultivars. The 'TMG 1264RR' glyphosate-tolerant genotype mobilized more reserves and was more efficient in converting biomass into seedlings. Herbicide application reduced the average length of the seedlings and caused the roots to become shorter than the hypocotyls. During germination, the herbicide changes seedling morphology since the seedling hypocotyl becomes proportionally larger than the radicle. Although, when applied, glyphosate altered the length, weight, and reserve mobilization of the four evaluated genotypes, the most affected were 'Emgopa 315' and 'UFUS 7415', the glyphosate-sensitive ones.

Index terms: *Glycine max*, dynamics of seed reserve, herbicide.

Mobilização de reservas de sementes e morfologia de plântulas de soja geneticamente modificada tratada com glifosato

Resumo – O objetivo deste trabalho foi avaliar os efeitos da aplicação do herbicida glifosato na mobilização de reservas e na morfologia de plântulas de soja geneticamente modificada. Duas cultivares tolerantes (TMG 1264RR e P98Y11) e duas sensíveis ao herbicida (Emgopa 315 e UFUS 7415) foram selecionadas para o estudo e submetidas aos testes de germinação, comprimento de plântulas e mobilização de reservas após tratamentos com soluções de glifosato nas concentrações de 0,00, 0,06 e 0,12%. A relação hipocótilo/radícula e a eficiência da conversão de reservas em plântulas também foram determinadas. Quanto maior a concentração de glifosato, menor a percentagem de plântulas normais e o comprimento das plântulas, principalmente nas cultivares sensíveis ao herbicida. O genótipo 'TMG 1264RR', tolerante ao glifosato, mobilizou mais reservas e foi mais eficiente na conversão de biomassa em mudas. A aplicação do herbicida reduziu o comprimento médio das plântulas e fez com que as raízes ficassem menores que os hipocótilos. Durante a germinação, o herbicida também altera a morfologia da muda uma vez que o hipocótilo fica proporcionalmente maior que a radícula. Embora, quando aplicado, o herbicida glifosato tenha alterado o crescimento, o peso e a mobilização de reservas dos quatro genótipos avaliados, os mais afetados foram 'Emgopa 315' e 'UFUS 7415', que são sensíveis ao herbicida.

Termos para indexação: *Glycine max*, dinâmica de reservas de sementes, herbicida.

Introduction

The development of genetically modified varieties has brought benefits to agriculture, such as the reduced use of pesticides and insecticides and, consequently, lower production costs (Kumar et al., 2020). However, in these crops, the use of herbicides has increased 55.8% (Seixas et al., 2022), which is an indicative of a relationship between the increase in herbicide application and the advent of herbicide-tolerant varieties.

Glyphosate application, for instance, has increased nearly 15-fold since 1996, when Roundup Ready cultivars were first adopted (Benbrook, 2016), which culminated in studies indicating the presence of both glyphosate and its derivative residues in soil samples (Karasali et al., 2019). Considering the increased adoption of herbicide-tolerant cultivars, and the intensified herbicide application that leaves their residue signs in the soil, it is prudent to evaluate the effects of herbicide use on seed germination and seedling development.

Genetically modified seeds may be detected through molecular assays (Fraiture et al., 2015), immunoassays (Pádua et al., 2012), and morphological tests (Melo et al., 2013). Among these, the germination test (Brasil, 2009), which evaluates the germination of seeds and their development in seedlings in the presence of the herbicide, was chosen and adapted to this study. Instead of distilled water, it was used herbicide solutions to moisten the germitest paper (Pereira et al., 2018).

To detect herbicide-tolerant seeds in the adapted germination test, it is necessary to evaluate certain seedling characteristics, such as the inhibition of secondary root development, which is especially evident in conventional cultivars (Pereira et al., 2018). In general, the seedling that germinates in the presence of the herbicide develops more slowly, characterizing loss of vigor. The literature has already shown that adverse environmental conditions, such as water stress, impair the mobilization of seed reserves (Oliveira et al., 2020), which is an indicative that something similar could happen during seed development in the presence of herbicides.

According to Mohammadi et al. (2011), during the heterotrophic growth of seedlings, it is important to determine how and how much of the seed reserves are mobilized under both favorable and unfavorable scenarios, taking into account seed initial weight, the mobilized fraction of reserves, and efficiency in converting reserves into dry matter. More vigorous seeds show an increased capacity to mobilize reserves, and, consequently, a better initial performance (Oliveira et al., 2020), which is why germination and seedling emergence are the stages considered the most critical and potentially sensitive to environmental stresses (Ali et al., 2018). Therefore, it is necessary to verify if a certain herbicide impairs seedling vigor and reserve mobilization when choosing how to control weeds in a crop.

The objective of this work was to evaluate the effects of the glyphosate herbicide on the seed reserve mobilization and seedling morphology of genetically modified soybean.

Materials and Methods

The experiments were carried out at the Laboratory of Plant Cytogenetics and Molecular Genetics of the Department of Biology of Universidade Federal de Lavras, in the state of Minas Gerais, Brazil. Four commercial soybean cultivars were evaluated. Of these, two are sensitive to glyphosate: 'Emgopa 315', which was developed by Agência Goiana de Desenvolvimento Rural e Fundiário; and 'UFUS 7415', from Universidade Federal de Uberlândia. The other two are tolerant to the herbicide: 'P98Y11', developed by Corteva Agriscience do Brasil; and 'TMG 1264RR', from Tropical Melhoramento & Genética.

For the study, seed samples were obtained according to the sampling procedures recommended by Regras para Análise de Sementes (RAS) (Brasil, 2009). Seed germination was evaluated in paper moistened either with water in the control or with glyphosate at 0.06 and 0.12% in the herbicide treatments. The Roundup Original herbicide (Monsanto do Brasil Ltda., São José dos Campos, SP, Brazil), composed mainly of 48.0% g L^{-1} isopropylamine salt of N-(phosphonomethyl) glycine and 35.6% acid equivalent of N-(phosphonomethyl) glycine, was used to prepare the glyphosate solutions for moistening the germitest paper at 2.5 times the weight of dry paper (Melo et al., 2013). To be applied, the formulation was diluted in distilled water at a suitable proportion for the concentrations of 0.06 and 0.12% of the acid equivalent of the herbicide (Pereira et al., 2018).

The germination test was carried out according to the recommendations of RAS (Brasil, 2009), with adaptations (Pereira et al., 2018), to obtain the first and final germination counts, five and seven days after germination, respectively. At the end of this period, the percentages of normal seedlings were computed. The presence or absence of secondary roots in the experimental plot was also evaluated following the recommendations of RAS (Brasil, 2009). The experimental design was completely randomized, in a factorial arrangement with four genotypes x three herbicide rates, with four replicates of 50 seeds each. The data were subjected to the analysis of variance, and means were compared by the Scott-Knott test, at 5% probability.

To measure the water content (WC) of the studied seed lots, three replicates of 50 seeds (W1) were weighed, then heated in oven at 105°C for 24 hours and, then, weighed again (W2) on a scale with four decimal places. The obtained data were applied to the following equation (Pereira et al., 2015): WC = [(W2 - W1) / W1] × 100.

Seedling length was determined according to the test described in Pereira et al. (2009), with the following adaptation: substrate moistening with three solutions of glyphosate at 0.00, 0.06, and 0.12% e.a. instead of with water. The experimental plots were 120, consisting of four soybean cultivars x three herbicide rates x ten replicates. Seed germination paper rolls were prepared, packed in plastic moisture-barrier bags (Coimbra et al., 2007), whose end was kept open for ventilation, and maintained in a biological oxygen demand incubator for seven days at 25°C. At the end of the test, the average lengths of the seedlings (ALS), hypocotyl (ALH), and radicle (ALR) in each experimental plot were measured using a millimeter ruler.

The obtained average lengths were used to calculate the hypocotyl/radicle (HR/RR) ratio in each treatment through the following equations: HR = (ALH / ALS) × 100 and RR = (ALR / ALS) × 100.

To determine if there were reductions (R1 and R2, expressed in percentage) in the HR/RR ratio in the herbicide treatments with glyphosate concentrations from 0.00 to 0.06% (HRR1 and RRR1) and from 0.00 to 0.12% (HRR2 and RRR2), the average hypocotyl and radicle lengths were compared with those of the control (Pereira et al., 2015), using the following equations: HRR1 = [1 - (ALH 0.06% / ALH 0.00%)] × 100, RRR1 = [1 - (ALR 0.06% / ALR 0.00%)] × 100, HRR2 = [1 - (ALH 0.12% / ALH 0.00%)] × 100, and RRR2 = [1 - (ALR 0.12% / ALR 0.00%)] × 100.

Regarding the evaluation of seed reserves, first the weight of ten seeds was obtained, in micrograms, by weighing, on a precision scale, the 120 plots used in the seedling length test. Then, as the WC of each seed lot was obtained, the dry matter reserve weight (W.1) was estimated in each experimental plot or in each seed according to its mobilization from the seeds to the seedlings during germination (Pereira et al., 2015).

After the seedling length was measured, the cotyledons, hypocotyls, and radicles of each experimental plot were separated with a knife and then placed in different envelopes, which were kept in an oven at 80°C for 24 hours. The weight of the envelope contents, also in micrograms, was used to measure the mobilization of seed reserves (Pereira et al., 2015).

The reduction in the seed reserve rate (SRR, expressed in percentage) was obtained from the average W.1 of the hypocotyl (W.1H), radicle (W.1R), seedling (W.1Sd), and pair of cotyledons (W.1PC) of each experimental plot. Considering the prior W.1 of the seed (W.1S) and the W.1PC, the amount of seed reserve mobilized was calculated using the equation: SRR = (W.1S - W.1PC) / W.1S.

Given the W.1H, W.1R, W.1Sd, and the amount of seed reserve mobilized, it was possible to calculate the proportion of reserve mobilized to the hypocotyl (RMH), radicle (RMR), and seedling (RMS), by using the following equations (Pereira et al., 2013): RMH = (W.1H / SRR) × 100, RMR = (W.1R / SRR) × 100, and RMS = (W.1Sd / SRR) × 100.

Additionally, the efficiency of the conversion of reserve to the seedling (ERCS) was obtained by the equation: ECRS = (W.1Sd / W.1S) × 100.

From the lengths and weights of the seedlings, the linear weights of the hypocotyl (LWH), radicle (LWR), and seedling (LWS), in μg cm^{-1}, were obtained by the equations: LWH = W.1H / ALH, LWR = W.1R / ALR, and LWH = W.1Sd / ALS.

All tests were performed in a completely randomized design, in a factorial arrangement composed of four genotypes x three herbicide rates, with ten replicates of ten seeds each. The data were subjected to the analysis of variance, and means were compared by the Scott-Knott test, at 5% probability.

Results and Discussion

Both concentrations of the herbicide solutions (0.06 and 0.12%) inhibited the development of normal seedlings in all evaluated genotypes. The highest herbicide concentration affected the first and the final germination counts of the glyphosate-tolerant genotypes, whose seedlings, however, grew secondary roots, differently from those of the glyphosate-sensitive ones (Table 1).

In a similar research, but with different genotypes, Bervald et al. (2010) and Pereira et al. (2018) also found that the herbicide solution used to moisten the germination paper inhibited the development of normal seedlings and that glyphosate-sensitive seedlings did not grow secondary roots (Bervald et al., 2010; Pádua et al., 2012; Melo et al., 2013). Therefore, the obtained results are not exclusive to specific genotypes, which is an indicative that only glyphosate-tolerant genetically modified cultivars develop normal seedlings.

In the herbicide treatments, there was a reduction in the lengths of the hypocotyl, radicle, and seedlings of all studied genotypes (Table 2). In the case of seedlings, glyphosate affected their development in both herbicide-sensitive and herbicide-tolerant cultivars at different levels of intensity, depending on the applied concentration. This effect was more prominent, however, in seedlings of the sensitive genotypes due to the absence or incipience of secondary roots, as if their development had been blocked by the herbicide. Albrecht et al. (2014), studying other soybean genotypes, also found a decrease in the physiological quality and vigor of seed lots with the used herbicide concentration.

Regarding seedling architecture, radicle length was about 2/3 of seedling length in the control without glyphosate application (Figure 1). However, in the herbicide treatments at the concentrations of 0.06 and 0.12%, there was an inversion, with seedlings presenting a larger proportion of hypocotyls. Likewise, in glyphosate treatments, Funguetto et al. (2004) and Melo et al. (2013), also reported a reduction in the radicle length of other soybean genotypes, whereas Mondal et al. (2017) observed a reduction in the seedling length of peas (*Pisum sativum* L.).

Table 1. Germination of four soybean (*Glycine max*) cultivars subjected to germination test on substrate moistened with glyphosate solutions(1).

Rate (%)	Emgopa 315(2)	UFUS 7415(2)	P98Y11(3)	TMG 1264RR(3)
First germination count (%) - five days				
0.00	76.5Ba	52.0Ca	54.0Ca	91.5Aa
0.06	0.5Cb(4)	0.0Cb(4)	58.0Ba	80.5Ab
0.12	0.0Bb(4)	0.0Bb(4)	5.5Bb	62.0Ac
Mean		37.4		
CV (%)		26.7		
Final germination count (%) - seven days				
0.00	78.0Ba	56.5Ca	59.5Ca	94.0Aa
0.06	1.5Cb(4)	0.1Cb(4)	60.5Ba	94.0Aa
0.12	0.5Cb(4)	0.1Cb(4)	27.5Bb	78.0Ab
Mean		45.4		
CV (%)		20.4		

(1)Means followed by equal letters, uppercase in the lines and lowercase in the columns, do not differ by Scott-Knott text at 5 % probability. (2)Glyphosate-sensitive genotypes. (3)Glyphosate-tolerant genotypes. (4)Absence of secondary roots in all seedlings of the experimental plot.

Table 2. Average length of the hypocotyl, radicle, and seedling of four soybean (*Glycine max*) cultivars treated with glyphosate(1).

Rate (%)	Emgopa 315(2)	UFUS 7415(2)	P98Y11(3)	TMG 1264RR(3)
Average length of the hypocotyl (cm)				
0.00	5.12Ca	7.89Aa	6.79Ba	7.54Aa
0.06	1.66Cb	3.65Bb	5.09Ab	5.67Ab
0.12	1.22Bb	1.42Bc	3.83Ac	3.87Ac
Mean		4.5		
CV (%)		18.8		
Average length of the radicle (cm)				
0.00	13.2Aa	6.48Ca	11.3Ba	13.5Aa
0.06	1.91Bb	1.15Bb	2.28Ab	3.03Ab
0.12	1.74Ab	1.08Ab	1.68Ab	2.33Ab
Mean		4.9		
CV (%)		31.3		
Average length of the seedling (cm)				
0.00	18.3Ba	14.4Ca	18.1Ba	21.0Aa
0.06	3.56Bb	4.80Bb	7.38Ab	8.71Ab
0.12	2.96Bb	2.50Bc	5.51Ac	6.19Ac
Mean		9.4		
CV (%)		17.4		

(1)Means followed by equal letters, uppercase in the lines and lowercase in the columns, do not differ by Scott-Knott text at 5 % probability. (2)Glyphosate-sensitive genotypes. (3)Glyphosate-tolerant genotypes.

In the treatment with glyphosate at 0.06%, the hypocotyl reduction rates were 68, 53, 25, and 25%, respectively, in the genotypes Emgopa 315, UFUS 7415, P98Y11, and TMG 1264RR, increasing to 76, 82, 44, and 49%, at the concentration of 0.12% (Table 2). Therefore, more intense reductions were observed for glyphosate-sensitive cultivars, whose seedling organogenesis was inhibited by the herbicide (Bervald et al., 2010).

Contrastingly, radicle length was similarly affected in all genotypes, under both glyphosate concentrations (Table 2), reinforcing the hypothesis that the development of roots is more likely to be affected by the herbicide than that of the hypocotyl, as also observed for other soybean cultivars by Melo et al. (2013). In another study, the seed lots with contrasting physiological quality only showed differences for the dry matter weight of the radicle and not of the hypocotyl (Oliveira et al., 2020). Therefore, radicles are more affected by the herbicide than the hypocotyls, showing the importance of evaluating the influence of glyphosate on the growth of the aerial part of cultivars in future studies on seedling development under abiotic stress conditions.

In the herbicide treatments, the dry matter of the hypocotyl, radicle, and seedling showed reductions in all four genotypes (Table 3), being less prominent in those tolerant to glyphosate. This is an interesting result, because, since the roots of glyphosate-tolerant seedlings are heavier, it was possible to use the average dry weight of the radicle to differentiate between sensitive and tolerant cultivars, which could not be done through the average length of the radicle.

In the herbicide treatments, the overall mobilized reserve rate was only reduced in the herbicide-sensitive genotypes, specifically at the concentrations of 0.06 and 0.12% in 'Emgopa 315' and of 0.12% in 'UFUS 7415' (Table 4). These results are an indicative that the development of the hypocotyl differs between cultivars that are sensitive and tolerant to glyphosate (Funguetto et al., 2004; Pádua et al., 2012).

The mobilization of reserves in the radicle due to herbicide treatments, however, was reduced regardless of the genotype or the concentration of glyphosate; therefore, the radicles of the four genotypes were affected equally. As highlighted in the literature, the radicle is more affected by treatments with glyphosate than the hypocotyl (Funguetto et al., 2004), meaning that the length, weight, and reserve mobilization averages are not efficient to differentiate between cultivars that are tolerant and sensitive to the herbicide,

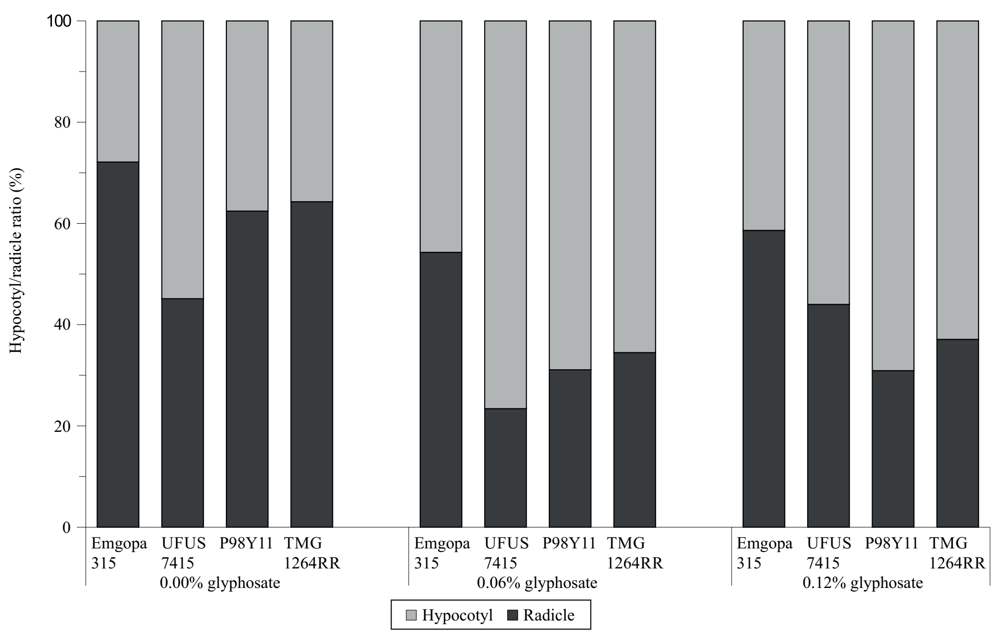

Figure 1. Schematic representation of the ratio of hypocotyl to radicle length for the Emgopa 315, UFUS 7415, P98Y11, and TMG 1264RR soybean (*Glycine max*) cultivars, subjected to germination test in paper moistened with different solutions of glyphosate at the concentrations of 0.00, 0.06 and 0.12%.

although radicle growth, especially of secondary roots, is (Funguetto et al., 2004; Melo et al., 2013).

The effects of glyphosate on the seedlings varied between the tolerant and sensitive genotypes, as well as between the two sensitive ('Emgopa 315' x 'UFUS 7415') and the two tolerant ('P98Y11' and 'TMG 1264RR') ones. The herbicide treatments reduced the reserve mobilized to the seedlings in all genotypes, except in 'TMG 1264RR', possibly due to the better quality of the seed lot. According to Andrade et al. (2019), more vigorous the seeds are, more efficient in using their reserves, producing seedlings with a larger amount of dry matter, longer total length, larger aerial part, and longer roots, regardless of the initial weight of the seed. Silva et al. (2019) added that the accumulation of dry matter is higher in seedlings developed from non-stressed seeds.

The herbicide treatments affected the percentage of mobilized reserves of the hypocotyl in all genotypes at different levels (Table 4). 'TMG 1264RR', with a better physiological quality, was the genotype that most mobilized cotyledon reserves and presented the highest efficiency in mobilized seed reserves to seedlings. However, further studies are necessary to assess whether this is a particularity of the genotype or a matter of initial physiological quality; considering that seed lots with a better quality have resulted in seedlings with more dry matter (Andrade et al., 2019; Oliveira et al., 2020).

The most notable results obtained in the present study were the reduction in the length and thickening of the hypocotyl-radicle axis of the seedlings (Table 5). This

Table 3. Dry matter weight of the hypocotyl, radicle, and seedling of four soybean (*Glycine max*) cultivars treated with glyphosate[(1)].

Rate (%)	Emgopa 315[(2)]	UFUS 7415[(2)]	P98Y11[(3)]	TMG 1264RR[(3)]
	Dry matter weight of the hypocotyl (μg)			
0.00	14.40Ba	25.30Aa	26.7Aa	27.9Aa
0.06	7.23Cb	15.40Bb	21.5Ab	23.1Ab
0.12	5.14Cc	8.85Bc	18.8Ac	17.8Ac
Mean	17.7			
CV (%)	12.4			
	Dry matter weight of the radicle (μg)			
0.00	4.70Ca	10.80Aa	9.56Ba	10.70Aa
0.06	1.95Cb	4.04Bb	5.33Ab	6.16Ab
0.12	1.68Db	3.47Cb	4.82Bb	5.91Ab
Mean	5.8			
CV (%)	20.3			
	Dry matter weight of the seedling (μg)			
0.00	19.10Ba	36.1Aa	36.2Aa	38.6Aa
0.06	9.18Cb	19.4Bb	26.8Ab	29.2Ab
0.12	6.82Cb	12.3Bc	23.6Ac	23.7Ac
Mean	23.4			
CV (%)	11.8			

[(1)]Means followed by equal letters, uppercase in the lines and lowercase in the columns, do not differ by Scott-Knott text at 5 % probability. [(2)]Glyphosate-sensitive genotypes. [(3)]Glyphosate-tolerant genotypes.

Table 4. Mobilization of reserves to the hypocotyl, radicle, and seedling, as well as efficiency in converting mobilized reserves, of soybean (*Glycine max*) cultivars treated with three glyphosate rates[(1)].

Rate (%)	Emgopa 315[(2)]	UFUS 7415[(2)]	P98Y11[(3)]	TMG 1264RR[(3)]
	Mobilized seed reserve (%)			
0.00	38.9Ca	43.6Ba	34.5Da	50.3Aa
0.06	25.9Bb	26.6Bb	29.6Bb	40.1Ab
0.12	22.3Cb	23.1Cb	27.4Bb	33.0Ac
Mean	32.95			
CV (%)	19.01			
	Reserve mobilized to the seedling (%)			
0.00	39.9Ba	60.5Aa	57.1Aa	62.8Aa
0.06	31.3Cb	55.3Aa	49.1Bb	58.1Aa
0.12	27.2Db	37.9Cb	46.1Bb	56.0Aa
Mean	48.44			
CV (%)	19.10			
	Reserve mobilized to the hypocotyl (%)			
0.00	30.0Ba	42.5Aa	42.1Aa	45.4Aa
0.06	25.0Bb	43.7Aa	39.3Aa	45.8Aa
0.12	20.6Cb	27.1Bb	36.7Aa	42.0Aa
Mean	36.69			
CV (%)	20.21			
	Reserve mobilized to the radicle (%)			
0.00	9.88Ca	17.9Aa	15.0Ba	17.4Aa
0.06	6.51Bb	11.6Ab	9.79Ab	12.3Ab
0.12	6.62Cb	10.8Bb	9.41Bb	14.0Ab
Mean	11.76			
CV (%)	20.45			
	Efficiency in converting mobilized reserves (%)			
0.00	14.8Da	26.2Ba	19.5Ca	31.6Aa
0.06	7.59Cb	14.5Bb	14.5Bb	23.3Ab
0.12	5.78Dc	8.61Cc	12.5Bc	18.4Ac
Mean	16.44			
CV (%)	11.90			

[(1)]Means followed by equal letters, uppercase in the lines and lowercase in the columns, do not differ by Scott-Knott text at 5 % probability. [(2)]Glyphosate-sensitive genotypes. [(3)]Glyphosate-tolerant genotypes.

Table 5. Linear weight of the hypocotyl, radicle, and seedling of four soybean (*Glycine max*) cultivars treated with glyphosate[(1)].

Rate (%)	Emgopa 315[(2)]	UFUS 7415[(2)]	P98Y11[(3)]	TMG 1264RR[(3)]
Linear weight of the hypocotyl (μg cm^{-1})				
0.00	2.90Bb	3.24Bc	4.11Ab	3.72Ab
0.06	4.52Aa	4.44Ab	4.31Ab	4.08Ab
0.12	4.20Ba	6.26Aa	4.93Ba	4.64Ba
Mean	4.28			
CV (%)	16.8			
Linear weight of the radicle (μg cm^{-1})				
0.00	0.37Cb	1.72Ab	0.88Bc	0.79Bc
0.06	1.04Ca	3.63Aa	2.34Bb	2.04Bb
0.12	0.96Ca	3.24Aa	2.89Ba	2.56Ba
Mean	1.87			
CV (%)	33.3			
Linear weight of the seedling (μg cm^{-1})				
0.00	1.08Cb	2.55Ac	2.08Bc	1.84Bc
0.06	2.60Ca	4.17Ab	3.67Bb	3.37Bb
0.12	2.30Da	4.92Aa	4.30Ba	3.85Ca
Mean	3.06			
CV (%)	14.5			

[(1)]Means followed by equal letters, uppercase in the lines and lowercase in the columns, do not differ by Scott-Knott text at 5 % probability. [(2)]Glyphosate-sensitive genotypes. [(3)]Glyphosate-tolerant genotypes.

could be explained by the increase in the linear weights of the genotypes with the herbicide treatments because, under these conditions, the seedlings concentrate more reserves, thickening the hypocotyl-radicle axis, as also found by Funguetto et al. (2004). Therefore, the length of the seedlings was more reduced than their weight, since the linear weight increased in all herbicide treatments.

Conclusions

1. Although glyphosate alters the length, weight, and reserve mobilization of the four evaluated soybean (*Glycine max*) genotypes, the most affected are the herbicide-sensitive ones, 'Emgopa 315' and 'UFUS 7415'.

2. During germination, the herbicide changes seedling morphology because it causes the seedling hypocotyl to become proportionally larger than the radicle.

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