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ARTICLE

Outcomes of water deficit stress on the physiological quality of soybean seeds

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ABSTRACT: This study aimed to compare the physiological seed quality of soybean cultivars produced under or without water deficit stress. Seed samples of three soybean cultivars produced in the 2019/2020 crop season were collected in a rural property and in a company that obtains the cultivars. In the rural property, the seeds were produced under water deficit stress and high temperatures during the crop's and were characterized by the presence of greenish seeds. In the company that obtains the cultivars, the sample consisted of a certified seed lot produced under normal rainfall and temperature conditions, without greenish seeds. Germination, average germination time, germination speed index, average germination speed, the number of normal and abnormal seedlings, the seedling height and dry weight, the root evaluations (length, surface area, volume, average diameter and dry mass) and the total seedling dry mass were also evaluated. Soybean seeds produced under water deficit stress showed a reduction in physiological quality directly proportional to the percentage of greenish seeds present in each seed lot. The occurrence of water deficit stress on the soybean in the reproductive and maturation stages negatively impacts the soybean crop installation in the subsequent season due to the low physiological seed quality.

Index Terms: germination, *Glycine max* (L.) Merrill, greenish seeds, vigor.

RESUMO: Este trabalho teve como objetivo comparar a qualidade fisiológica de sementes de cultivares de soja produzidas com ou sem déficit hídrico. Amostras de sementes de três cultivares de soja produzidas na safra 2019/2020 foram coletadas em propriedade rural e em empresa obtentora das cultivares. Na propriedade rural, as sementes foram produzidas sob estresse hídrico e altas temperaturas durante a safra e caracterizaram-se pela presença de sementes esverdeadas. Na empresa obtentora das cultivares, a amostra foi constituída por um lote de sementes certificadas produzidas em condições normais de chuva e temperatura, sem sementes esverdeadas. Germinação, tempo médio de germinação, índice de velocidade de germinação, velocidade média de germinação, número de plântulas normais e anormais, a altura e peso seco da plântula, o comprimento da raiz, área superficial, volume, diâmetro médio e massa seca, a massa seca de plântulas foram avaliados. Sementes de soja produzidas sob estresse hídrico apresentaram redução na qualidade fisiológica diretamente proporcional à porcentagem de sementes esverdeadas presentes em cada lote de sementes. A ocorrência de estresse hídrico na soja nas fases reprodutiva e maturação impacta negativamente a instalação da cultura da soja na safra subsequente devido à baixa qualidade fisiológica da semente.

Termos de indexação: germinação, *Glycine max* (L.) Merrill, sementes esverdeadas, vigor.

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INTRODUCTION

Soybean stands out among the main crops produced in Brazil. A determining factor to obtain high crop yields is the uniform establishment of the plant stand, so good quality seeds are essential. Nutritional, environmental, and climatic conditions to which the plants are exposed, time of harvest, means of transport, and seed storage can directly influence the seed quality.

The physiological seed quality is characterized by germination and vigor, which can be defined as the sum of attributes that give the seed the potential to germinate, emerge and quickly result in normal seedlings under a wide variety of environmental conditions (Tunes et al., 2011). Such quality can be affected by several factors, including deterioration in the field and bed bug damage, weathering damage, and mechanical damage by harvesting combine (Krzyzanowski et al., 2018).

Water stresses due to deficit or excess of water are harmful to the soybean crop, mainly in the most sensitive phases such as germination/emergence and flowering/filling of the seeds. The exposure of soybean crop to water deficit stress during reproductive stages results in losses in grain yield and seed quality. The cotyledons exhibit traces of green pigment, originating greenish seeds. Consequently, these seeds have reduced vigor and viability (Pardo et al., 2015) and disuniformity in seedling size and root system formation (Zorato et al., 2007).

Absence of water in association with high temperatures results in suppression of nutrient uptake by soybean plants, impairing their development and/or causes die before the seed maturity, resulting in a high index of greenish seeds. This coloring is due to the reduction of the chlorophyllase enzyme activity that leaves chlorophyll in harvested seeds that are still immature. Besides, there are differences in response between cultivars, as some are more sensitive than others (França-Neto et al., 2012).

The presence of greenish seeds reduces the physiological quality of seed lots because they present reduced germination and vigor, and even can cause the unfeasibility of soybean lots. Rates greater than 10% of greenish seeds prevent the soybean lot commercialization as inspected seed (Toledo et al., 2015). The soybean grains quality is also reduced and, consequently, its derivatives, reducing oil content than the mature grains.

Lots of soybean seeds with 37 and 16% of greenish seeds show germination below 80%, which are considered unsuitable for sowing (Bordignon et al., 2017). Nowadays, considering the rationalization of production, the use of soybeans with compromised germination and vigor is not recommended, as they result in an inadequate plant population, reduction in production, and, in many situations, in need for reseeding and thereby raising production costs (Bordignon et al., 2017). Thus, greenish seeds reflect problems beyond one season, as they compromise the quality of the installation of the crops of the subsequent season.

The hypothesis is that if the soybean crop were submitted to water deficit stress in the reproductive period, there would be more greenish seeds. Thus, the physiological seed quality is reduced, which compromises the use of these seeds in the next season. Therefore, the aim of this study was to compare the physiological seed quality of soybean cultivars produced under or without water deficit stress.

MATERIAL AND METHODS

Plant material and growth conditions

The 2019/2020 season was characterized by a water deficit. February and March 2020 were considerably dry and extremely dry, respectively (Junges et al., 2020) in several cities in the Rio Grande do Sul state (Figure 1). These months culminate in the filling of the soybean seeds, so the water deficit associated with high temperatures in this stage interferes with the physiological seed quality produced in the season. This condition was not uniform among the soybean producing regions of the state, as the rains were sparse, which reflected in areas with the presence of greenish seeds and others not. The presence of greenish seeds is one of the effects of the water deficit in the seed filling stage.

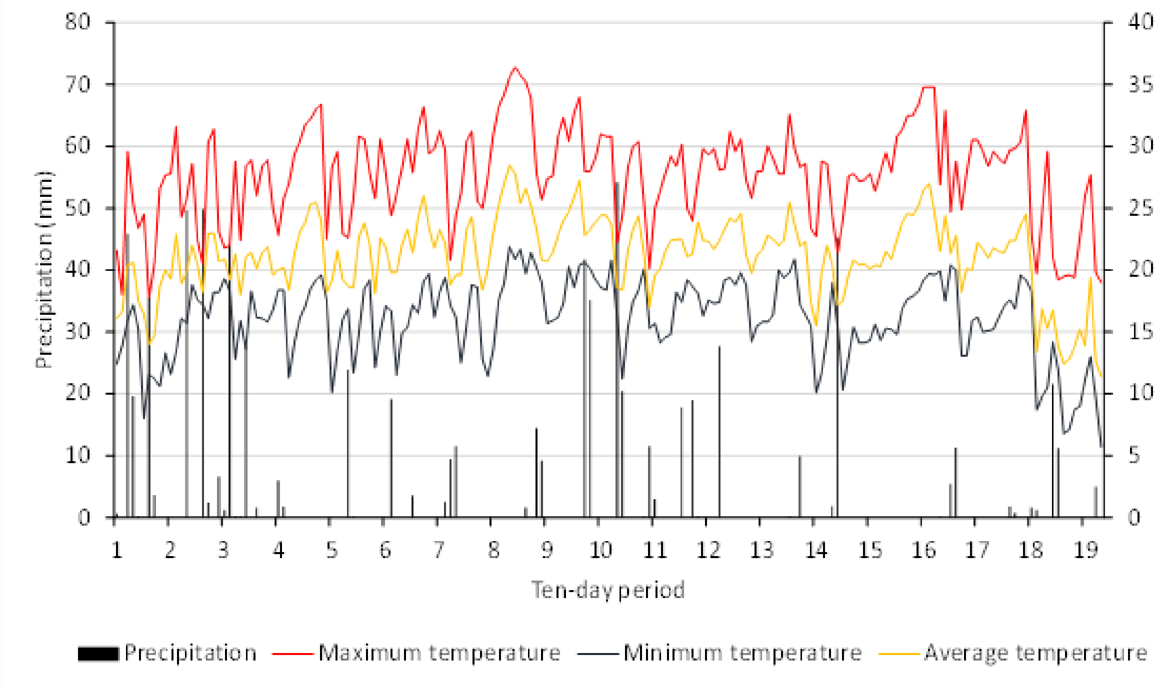

Figure 1. Precipitation, maximum temperature, minimum temperature and average temperature in the period of soybean cultivation (15/10/2019 - 21/04/2020) in Passo Fundo/RS.

The cultivars used in this study were DM 53i54 IPRO, BMX Zeus IPRO, BMX Ativa RR. Samples of 1 kg of seeds were collected of each cultivar from both: a rural property with greenish seeds, since the plants were affected by water stress deficiency; and the company that obtain the cultivars, with no presence of greenish seeds. On the rural property, the seeds were produced under water deficit stress and high temperatures during the reproductive phase of the soybean crop in the 2019/2020 season (Figure 1), so were characterized by the presence of greenish seeds. The determination of the percentage of greenish seeds was carried out from a sample of 100 seeds of each cultivar randomly taken from the 1 kg lot, where the number of greenish seeds was counted. The percentage of greenish seeds presented by each cultivar was 33%, 37%, and 9% for DM 53i54 IPRO, BMX Zeus IPRO, BMX Ativa RR, respectively (Figure 2).

In the company that obtains the cultivars, the sample consisted of certified seeds produced under normal rainfall conditions and temperature in the 2019/2020 season without greenish seeds (Figure 2).

The soybean cultivars DM 53i54 IPRO, BMX Zeus IPRO, BMX Ativa RR, with different relative maturity groups, were chosen to this experiment. DM 53i54 IPRO is an indeterminate growth cultivar with a relative maturity group of 5.4 and recommended to Brazilian soybean macro-regions 1 and 2. BMX Zeus IPRO is an indeterminate growth cultivar with a relative maturity group of 5.5 and recommended to Brazilian soybean macro-regions 1 and 2. BMX Ativa RR cultivar is a determinate growth cultivar with a relative maturity group of 5.6 and recommended to Brazilian soybean macro-region 1. Therefore, all cultivars are recommended for the Rio Grande do Sul state.

The experiment to evaluate the germination and vigor of the seeds collected on farm/rural property (with water deficit stress) and with the certified seed producer (normal rainfall conditions) was conducted in a greenhouse and also at the Histology Laboratory in August 2020. The experimental design used was a completely randomized design with six treatments and four replications. The treatments consisted of seeds of three cultivars (DM 53i54 IPRO, BMX Zeus IPRO, BMX Ativa RR) produced under two different rainfall conditions during the crop's reproductive phase at field: under water deficit stress on a rural property and normal rainfall conditions on the seed production area of the certified seed producer. Seeds obtained by the producers were sown in rectangular plastic planters with a volumetric capacity of 13

Figure 2. Seed samples of each soybean cultivars produced under normal rainfall conditions (*) and under water deficit stress (**).

liters with sterile sand as substrate, which were the experimental units. Each experimental unit comprised 25 soybean seeds, distributed in two rows per pot, and was kept in a greenhouse where the temperature was monitored to ensure good germination of the seeds and irrigation was carried out every two days, as needed. All samples were submitted to the same environmental conditions in order to enable comparison between cultivars.

Germination and shoot and root traits

Germination, average germination time, germination speed index, average germination speed, and the number of normal and abnormal seedlings were evaluated in a greenhouse and/or in laboratory as described below. The seedling height and dry weight, the root length, surface area, volume, average diameter, and dry mass, and the total seedling dry mass were also evaluated.

For germination evaluation, the germinated seeds in greenhouse were counted on the 14th day after sowing (DAS), and the results obtained were calculated and expressed as a percentage for each experimental unit (Brasil, 2009). Germination (%G) was calculated according to the formula proposed by Labouriau and Valadares (1976):

$$G\ (\%) = N/A \times 100$$

where *G (%)* = germination expressed as a percentage; *N* = number of germinated seeds; *A* = total number of seeds sown.

Classification and counting of the normal and abnormal seedlings were performed according to the model presented by Brasil (2009) at 14th DAS. The average germination time (AGT), the germination speed index (GSI), and the average germination speed (AGS) were conducted with the germination test. First, the seedlings that emerged every 24 hours until the 14th DAS were considered and at the end of the test, the AGT, GSI, and AGS were calculated using the following formulas proposed by Maguire (1962).

AGT was calculated by:

$$AGT = \frac{G1T1 + G2T2 + \cdots + GiTi}{G1 + G2 + G3}$$

where *AGT* = average time to reach maximum germination (days); *G1* to *Gi*= number of germinated seedlings in each day; and *T1* to *Ti* = time in days.

For the GSI:

$$GSI = \frac{G1}{T1} + \frac{G2}{T2} + \cdots + \frac{Gi}{Ti}$$

where *GSI* = germination speed index; *G1* to *Gi* = number of germinated seedlings that occurred each day; *T1* to *Ti* = time in days.

For the AGS:

AGS = 1/t

where AGS = average germination speed (seeds.day^{-1}); t = average germination time (days^{-1}).

At 21 DAS, five seedlings by replication were collected and evaluated at the Histology Laboratory. The height and dry mass of the aerial part were evaluated. The root was washed to evaluate the length, surface area, volume, average diameter, and, subsequently, dry mass. The height expressed in millimeters was measured with a digital caliper. The cotyledons were removed from the seedlings, packed in paper bags, identified, and taken to a drying oven with forced air circulation under a temperature of 80 ^{o}C for 24 hours, to evaluate the dry mass. Afterward, each sample was weighed on a precision scale, and the results were expressed in grams.

Fresh roots were evaluated using the WinRhizo software (Regent Instruments Inc., Sainte-Foy, QC, Canada), where the length, surface area, average diameter, and root volume were measured and expressed in millimeters, square centimeters, millimeters, and cubic centimeters, respectively. Subsequently, the roots were packed in paper bags, identified, and taken to a drying oven with forced air circulation under a temperature of 80 °C for 24 hours. Afterward, each sample was weighed on a precision scale, and the results were expressed in grams. Considering the root and shoot dry matter evaluations, the values were added together, resulting in the seedling dry mass value expressed in grams.

Statistical analysis

The data were submitted to the T-test (≤ 0.05). This test was chosen to identify the differences between the seed conditions and the variations in the physiological seed quality among the cultivars produced under normal rainfall and temperature conditions, and water deficit stress and high temperatures during the soybean crop's reproductive stage.

RESULTS AND DISCUSSION

The soybean seeds produced under water deficit stress showed a reduction in physiological quality. This result was directly proportional to the percentage of greenish seeds present in each seed lot.

The seeds produced under water deficit stress showed reduced germination compared to seeds produced under normal rainfall conditions (Table 1). The cultivars BMX Zeus IPRO and DM 53i54 IPRO showed germination percentage of 100 and 98% in the absence of water deficit stress, presenting a reduction of 77% and 33% in germination, respectively, when the seeds were produced under water stress conditions (Table 1). The water deficit for soybean cultivation during

Table 1. Germination, normal and abnormal seedlings of soybean cultivar seeds from conditions with and without water deficit stress in the reproductive stage of seed production.

Cultivars	Germination (%)			Normal seedlings (%)			Abnormal seedlings (%)		
	With water deficit stress	Without water deficit stress	P-value	With water deficit stress	Without water deficit stress	P-value	With water deficit stress	Without water deficit stress	P-value
DM 53i54 IPRO	65.00	98.00	<0.00001	48.50	97.00	<0.00001	18.00	0.00	<0.001
BMX Zeus IPRO	33.00	100.00	<0.00001	26.50	98.00	<0.00000001	7.00	2.00	0.1074
BMX Ativa RR	97.00	98.00	0.3352	93.80	97.00	0.016	6.00	1.00	0.0084

P-value = probability. The difference was considered significant when the p values were equal to or less than 5% probability ($p \leq 0.05$).

the reproductive period in the final stages results in less accumulation of reserves for the seeds, reducing the size, weight, vigor, and germination (Wijewardana et al., 2019). This effect is variable according to the cultivar and the presence of greenish seeds. Arruda et al. (2016) also verified a decreasing in the germination percentage due to the presence of greenish seeds, where the presence of 17, 36 e 49% greenish seeds resulted in a germination percentage of 79, 56, and 55%, respectively, whereas the control presented 83% of germination, confirming that greenish seeds in the lot decrease the physiological quality of the seeds.

Similar results were observed by Zorato et al. (2007). These authors in lots of seeds with 11.8% and 37.4% of greenish seeds, designated by A and B, observed a germination percentage of the greenish seeds by 51 and 31%, respectively, and 78 and 56% for the original lots. When evaluated in the field, the emergence of the original lots was 81 and 56%, respectively, and 60 and 34% for greenish seeds. As germination, vigor was 60 and 36% in the original lots with 11.8% and 37.4% of greenish seeds, remarking that the percentage of greenish seeds influences the physiological quality of soybeans. By decreasing germination, the seeds are considered unsuitable for sowing. According to the regulation, seed lots with germination lower than 80% are considered unsuitable for sowing (Brasil, 2009), as well as, commercial lots of soybeans with greenish seed rates above 17% are also considered unsuitable (Arruda et al., 2016).

The number of normal soybean seedlings from seeds produced under water deficit stress was reduced. The percentage of normal seedlings or vigor in the presence of water stress deficiency was 48.5, 26.5 and 93.8% for DM 53i54 IPRO, BMX Zeus IPRO and BMX Ativa RR, respectively. Whereas the cultivar BMX Ativa RR presented the lowest percentage of greenish seeds (9%) it also showed the greatest vigor. BMX Zeus IPRO was the cultivar that showed the greatest influence of water stress in the formation of greenish seeds and on its vigor as it presented 37% of greenish seeds and 26.5% of vigor. DM 53i54 IPRO showed an intermediary influence by water stress deficiency with 33% of greenish seed and 48.5% of vigor. So, the greatest decrease in vigor was observed in the cultivar BMX Zeus IPRO, with a 74% reduction in normal seedlings, followed by the cultivars DM 53i54 IPRO and BMX Ativa RR, which showed a reduction of 51 and 6%, respectively (Table 1).

For the number of abnormal seedlings, a higher incidence was observed for seedlings from seeds produced under water deficit stress as all cultivars presented a higher number of abnormal seedlings in the presence on water deficit stress in comparison to seeds produced in an appropriated environmental condition (without stress) (Table 1). These results state that there is a reduction in vigor for seeds produced under water deficit stress conditions, scenario that characterized the 2019/2020 season. February and March 2020 were characterized as quite dry and extremely dry, respectively (Junges et al., 2020). These months culminate with the filling of soybeans grains (Figure 1). The seed's vigor provides the expression of the maximum productive potential of the crop, as this is characterized by providing rapid emergence and production of normal seedlings even under adverse conditions. Therefore, the greater the number of normal seedlings emerged, the greater the percentage of the seed's vigor, and the greater the number of abnormal seedlings emerged, the lower the percentage of vigor presented by the seeds (Krzyzanowski et al., 2018). This characteristic is altered according to the cultivar. Some cultivars present greater capacity to maintain the water status, which provides greater resistance when exposed to water deficit stress and heat conditions. BMX Ativa RR cultivar is older and more stable to the climatic adversities, reflecting less effect of water deficit stress on the production of greenish seeds and, consequently, on the level of physiological quality of the produced seeds.

The cultivars showed a longer AGT when the seeds came from water deficit stress in the reproductive stage. The cultivar DM 53i54 IPRO presented the highest AGT and the greatest negative correlation between water deficit stress, with an increase of 1.46 days when the seed was produced under water deficit stress. For the cultivar BMX Zeus IPRO the response was similar, but with an increase of 1.38 days, and the cultivar BMX Ativa RR showed the least differentiation between water deficit stress (Table 2).

The lowest rates of GSI were for seedlings from seeds produced under water deficit stress conditions. The lowest GSI under water deficit stress and the greatest differentiation between the conditions of water deficit stress were presented by the cultivar BMX Zeus IPRO, which reduced the GSI for 3.27 to 0.93, and the cultivar DM 53i54 IPRO, which reduced the GSI for 3.19 to 1.81 (Table 2).

As for the GSI, the lowest values of AGS were for seedlings from seeds produced under water deficit stress. The cultivar BMX Zeus IPRO showed the greatest differentiation between water deficit stress conditions with a reduction of 23% in AGS, from 0.13 to 0.10, whereas cultivar DM 53i54 IPRO showed a decrease in AGS of 16.6%, from 0.12 to 0.10, and the cultivar BMX Ativa RR showed a reduction of only 8.3% in AGS, from 0.12 to 0.11 (Table 2).

The results of AGT, GSI, and AGS, and the number of normal and abnormal seedlings obtained in this study (Table 2), affirm the reduction in seed vigor when produced under water deficit stress. The increase in the AGT values and the decrease in the AGS values indicate that germination occurred slowly and gradually. The AGT is inversely proportional to the GSI, so seeds with a higher percentage of vigor germinate faster. Seeds that germinate more quickly tend to have a greater number of normal seedlings indicating a higher percentage of vigor reflecting a shorter exposure to soil pathogens and faster plant establishment in the field.

Seed lots with the same germination percentage do not always show the same development performance. One can reach the total number of germinated seedlings in less time than the other. Then, the values of speed (AGS), time (AGT), and germination speed index (GSI) are also considered to determine the germination percentage because the higher the index, the higher the germination speed and the higher the percentage of vigor (Nakagawa, 1999).

The height and dry mass of soybean seedlings were reduced when they originated from seeds produced under water deficit stress. Cultivar DM 53i54 IPRO showed the greatest difference between water deficit stress for both evaluations, with a reduction of 24.5% in height and 48.9% in dry seedling mass. The cultivar BMX Zeus IPRO presented

Table 2. Average germination time (AGT), germination speed index (GSI), and average germination speed (AGS) of soybean seedlings from conditions with and without water deficit stress in the reproductive stage of seed production.

Cultivars	AGT (days)			GSI			AGS (days^{-1})		
	With water deficit stress	Without water deficit stress	P-value	With water deficit stress	Without water deficit stress	P-value	With water deficit stress	Without water deficit stress	P-value
DM 53i54 IPRO	9.25	7.79	<0.001	1.81	3.19	<0.000001	0.10	0.12	<0.001
BMX Zeus IPRO	9.16	7.78	<0.001	0.93	3.27	<0.000001	0.10	0.13	<0.0001
BMX Ativa RR	9.00	8.12	0.013	2.79	3.03	0.064	0.11	0.12	0.048

P-value = probability. The difference was considered significant when the p-values were equal to or less than 5% probability (p ≤ 0.05).

a similar response with a decrease of 16.4% in height and 41.3% in dry mass of the aerial part, whereas the cultivar BMX Ativa RR presented the least reduction and differentiation between the presence or absence of water deficit stress, decreasing 10.1% in height and 15.3% in dry mass of the aerial part (Table 3).

The results show a reduction in the plants development when they come from seeds produced under water deficit stress and reaffirm the data presented previously. Soybean seeds with a high percentage of germination and vigor result in plants that grow and develop quickly, regardless of edaphoclimatic conditions, culminating in a rapid establishment of crops and closing of the lines, which also helps the control of weeds (Krzyzanowski et al., 2018). Seeds with higher physiological quality result in seedlings with a greater dry matter accumulation (Oliveira et al., 2020).

Determining the height and dry mass content of seedlings can be a method to assess seed vigor. It is accurate about the seed's ability to transfer reserves to the embryonic axis through growth. Thus, seedlings produced from seeds with greater height and accumulation of dry mass have a higher percentage of vigor (Nakagawa, 1999).

As in the aerial part, the roots were also negatively affected when the seedlings came from seeds produced under water deficit stress. The length of roots in soybean seedlings from seeds produced under stress was reduced only for cultivar DM 53i54 IPRO, which had roots 49.3% smaller than seedlings from seeds produced without stress (Table 4). A similar response was found for the root surface area of soybean seedlings, with a 52.5% reduction in seedling roots from seeds produced under stress for cultivar DM 53i54 IPRO (Table 4).

The results obtained for the length and surface area of the root coincided with the results obtained in the aerial part (Tables 1 and 2), which indicate reduced vigor for the seeds produced under water deficit stress.

There was no difference between water stress for any of the three cultivars comparing the average root diameter of soybean seedlings. However, the roots of soybean seedlings from the seeds produced under water deficit stress

Table 3. Height and dry mass of soybean seedlings from conditions with and without water deficit stress in the reproductive stage of seed production.

Cultivars	Height (cm)			Dry mass (g)		
	With water deficit stress	Without water deficit stress	P-value	With water deficit stress	Without water deficit stress	P-value
DM 53i54 IPRO	49.90	66.09	<0.001	0.25	0.49	<0.001
BMX Zeus IPRO	50.99	61.00	<0.001	0.27	0.46	<0.0001
BMX Ativa RR	43.12	47.98	0.037	0.33	0.39	0.037

P-value = probability. The difference was considered significant when the p-values were equal to or less than 5% probability ($p \leq 0.05$).

Table 4. Length and surface area of soybean seedling roots from conditions with and without water deficit stress in the reproductive stage of seed production.

Cultivars	Lenght (cm)			Surface area (cm^2)		
	With water deficit stress	Without water deficit stress	P-value	With water deficit stress	Without water deficit stress	P-value
DM 53i54 IPRO	22.63	44.66	0.031	65.79	138.65	0.017
BMX Zeus IPRO	34.84	39.88	0.219	101.79	129.84	0.08
BMX Ativa RR	33.46	42.95	0.082	95.13	125.59	0.056

P-value = probability. The difference was considered significant when the p-values were equal to or less than 5% probability ($p \leq 0.05$).

showed a lower volume. The cultivar DM 53i54 IPRO presented a reduction of 56.2% and the cultivar BMX Zeus IPRO showed a reduction of 30.2% (Table 5). These results reinforce the previous results of root length and surface area, indicating a reduction in the vigor of the seeds produced under water deficit stress. Vigorous seeds develop a larger root system in less time, which gives greater efficiency in the absorption of water and nutrients (Pêgo et al., 2011).

The roots are important organs for supporting the plants and for absorbing water and nutrients. Any adverse changes such as decreased length, volume, or other characteristics will negatively affect the plants' development. Some cultivars have a higher allocation of biomass in the roots, which ensures greater water and solute absorption capacity of the soil, thus giving the plant a characteristic of adaptability to water deficit stress. These characteristics give the plants prolonged photosynthetic activity and are a tolerance strategy (Mathur et al., 2014).

Alterations in the roots are not interesting, as they are supporting and absorbing water and nutrients. Work has been carried out to identify changes in roots resulting from competition with weeds. Competition between horseweed and soybean plants, from crop emergence to the V6 stage, in general, affects shoot and root morphological traits and the biochemical composition of soybean roots (Rockenbach and Rizzardi, 2019). If soybean cultivars with the presence of greenish seeds and consequently with less potential for root growth are cultivated, and in addition there is some other competitive factor such as weeds, great losses will occur.

In this work, in general, the use of seeds produced under water deficit stress presented lower performance than seeds produced without water stress, regardless of the cultivar. The climatic conditions in the maturation period of the soybean crop presented great interference in producing quality seeds. Exposure to water stress situations culminating in the occurrence of high temperatures can lead the immature plants to premature death. Also, it will result in the production of smaller, greenish seeds, with a drastic decrease in crop productivity and a considerable reduction in the physiological seed quality (França-Neto et al., 2012).

The DM 53i54 IPRO and BMX Zeus IPRO showed the most remarkable differences between rainfall conditions for all evaluations. The BMX Ativa RR cultivar, on the other hand, showed the least oscillation between rainfall conditions. Thus, it is possible to affirm that the cultivars DM 53i54 IPRO and BMX Zeus IPRO have less stability in the presence of water deficit stress than the cultivar BMX Ativa RR, which is more stable. In Figure 1 is possible to affirm this, the precipitation was very irregular from January 31st, period that culminates with the filling of soybeans. An example of this is that during the period from February 27th to April 21th the accumulated total rainfall was only 60 mm.

This effect can be observed by the level of greenish seeds in the samples collected on the property. The cultivars DM 53i54 IPRO and BMX Zeus IPRO presented the levels of 33 and 37% greenish seeds, whereas for the cultivar BMX Ativa RR, it was 9% (Figure 2). Therefore, the highest percentage of greenish seeds produces less physiological seed quality. When correlating the development of seedlings on the twenty-first DAS with the original sample (Figure 2), it is noticed that seedlings from seed lots with a higher number of greenish seeds presented the lowest emergence index and less development (Figure 3).

Table 5. Average diameter and root volume of seedlings of soybean cultivars from conditions with and without water deficit stress in the reproductive stage of seed production.

Cultivars	Average diameter (mm)			Root volume (cm^3)		
	With water deficit stress	Without water deficit stress	P-value	With water deficit stress	Without water deficit stress	P-value
DM 53i54 IPRO	0.95	1.00	0.309	1.53	3.50	0.019
BMX Zeus IPRO	0.93	1.04	0.088	2.37	3.40	0.044
BMX Ativa RR	0.90	0.95	0.348	2.20	2.97	0.111

P-value = probability. The difference was considered significant when the p-values were equal to or less than 5% probability ($p \leq 0.05$).

Figure 3. Seedlings at 21 days after sowing soybean cultivars from conditions with and without water deficit stress during the reproductive stage of seed production. *seed produced under normal rainfall conditions; ** seed produced under water deficit stress.

Soybean cultivars have different levels of enzyme activity. When exposed to situations of environmental adversity, cultivars with higher enzyme activity have less greenish seed production. So, the genotypic characteristics also interfere in reducing the physiological quality of the seeds produced under conditions of water and temperature stress (França-Neto et al., 2012).

The use of quality seeds, with high germination and vigor, is a fundamental factor to obtain good results of grain and seed yield. Seeds with high physiological quality provide greater productivity, being the high vigor results in plants with greater agronomic performance, providing an increase in productivity of up to 10% in the commercial field (Krzyzanowski et al., 2018). The sowing of seeds with less vigor results in plants with less initial development, both in aerial part and root system, low mass accumulation, and less productivity (Tavares et al., 2013).

The losses caused by water stress combined with high temperatures in the soybean reproductive stages can negatively impact productivity for more than a single season. Originate seeds with lower physiological quality interferes indirectly in the productive potential of the subsequent season.

CONCLUSIONS

Soybean seeds produced under water deficit stress present a reduction in physiological quality. This result is directly proportional to the percentage of greenish seeds present in each seed lot. The occurrence of water stress on the soybean crop during the reproductive and maturation stages causes negative impacts on the installation of the soybean crops of the subsequent season, due to the low physiological seed quality.

REFERENCES

ARRUDA, M.H.M.; MENEGHELLO, G.E.; VIEIRA, J.F.; GADOTTI, G.I. Qualidade fisiológica de lotes de sementes de soja com diferentes percentuais de sementes esverdeadas. *Magistra*, v.28, n.2, p. 194-200, 2016. https://magistraonline.ufrb.edu.br/index.php/magistra/article/view/79

BRASIL. Ministério da Agricultura, Pecuária e Abastecimento. *Regras para Análise de Sementes.* Ministério da Agricultura, Pecuária e Abastecimento. Secretaria de Defesa Agropecuária. Brasília: MAPA/ACS, 2009. 399p. https://www.gov.br/agricultura/pt-br/assuntos/insumos-agropecuarios/arquivos-publicacoes-insumos/2946_regras_analise__sementes.pdf

BORDIGNON, B.C.S.; VEIGA, V.V.; BIANCHINI, F.; SHIMOIA, E.P. Percentual de sementes esverdeadas e sua influência na qualidade fisiológica de doze cultivares de soja. *Perspectiva*, v.41, n.155, p.25-33, 2017. https://www.uricer.edu.br/site/pdfs/perspectiva/155_632.pdf

FRANÇA-NETO, J.B.; PÁDUA, G.P.; KRZYZANOWSKI, F.C.; CARVALHO, M.L.M.; HENNING, A.A.; LORINI, I. Semente esverdeada de soja: causas e efeitos sobre o desempenho fisiológico - Série sementes. *Circular Técnica,* Londrina: Embarap Soja, 2012. 15p. https://www.infoteca.cnptia.embrapa.br/handle/doc/924805

JUNGES, A.H.; VARONE, F.; TAZZO, I.F.; CARDOSO, L.S. *Comunicado Agrometeorológico "Estiagem" 2019/2020*. Rio Grande do Sul, Comunicado Agrometeorológico Extra – Estiagem. 2020. https://www.agricultura.rs.gov.br/upload/arquivos/202105/25144309-comunicado-agrometeorol-gico-12-extra-estiagem-2020-revisado.pdf

KRZYZANOWSKI, F.C.; FRANÇA-NETO, J.B.; HENNING, A.A. *A alta qualidade da semente de soja: fator importante para a produção da cultura.* Circular Técnica, Londrina: Embrapa Soja, 2018. 136p. https://www.embrapa.br/busca-de-publicacoes/-/publicacao/1091765/a-alta-qualidade-da-semente-de-soja-fator-importante-para-a-producao-da-cultura

LABOURIAU, L.G.; VALADARES, M.E.B. On the germination of seeds *Calotropis procera* (Ait.) Ait.f. *Anais da Academia Brasileira de Ciências,* v.48, n.2, p.263-284, 1976.

MAGUIRE, J.D. Speed of germination-aid in selection and evaluation for seedling emergence and vigor. *Crop Science*, v.2, n.2, p.176-177, 1962. https://doi.org/10.2135/cropsci1962.0011183X000200020033x

MATHUR, S.; AGRAWAL, D.; JAJOO, A. Photosynthesis: Response to high temperature stress. *Journal of Photochemistry and Photobiology B: Biology*, v.137, p.116-126, 2014. https://doi.org/10.1016/j.jphotobiol.2014.01.010

NAKAGAWA, J. Testes de vigor baseados no desempenho das plântulas. In: KRZYZANOWSKI, F.C.; VIEIRA, R.D.; FRANÇA-NETO, J.B (Eds.). *Vigor de sementes: conceitos e testes.* Londrina: ABRATES, 1999. p. 1-24.

OLIVEIRA, T.F.; SANTOS, H.O.; CARVALHO, R.A.; SILVA, H.W.; PIRES, R.M.O.; CARVALHO, E.R. Reserve mobilization in soybean seeds under water restriction after storage. *Journal of Seed Science,* v.42, e202042024, p.1-8, 2020. https://doi.org/10.1590/2317-1545v42231384

PARDO, F.F.; BINOTTI, F.F.S.; CARDOSO, E.D.; COSTA, E. Qualidade fisiológica de sementes de soja esverdeadas em diferentes tamanhos. *Revista de Agricultura Neotropical,* v.2, n.3, p.39-43, 2015. https://doi.org/10.32404/rean.v2i3.275

PÊGO, R.G.; NUNES, U.R.; MASSAD, M.D. Qualidade fisiológica de sementes e desempenho de plantas de rúcula no campo. *Ciência Rural*, v.41, n.8, p.1341-1346, 2011. https://doi.org/10.1590/S0103-84782011000800008

ROCKENBACH, A.P.; RIZZARDI, M.A. Competition at the soybean V6 stage affects root morphology and biochemical composition. *Plant Biology,* v.22, n.2, p.252-258, 2019. https://doi.org/10.1111/plb.13070

TAVARES, L.C.; RUFINO, C.A.; TUNES, L.M.; BARROS, A.C.S.A. Rendimento e qualidade de sementes de soja de alto e baixo vigor submetidas ao déficit hídrico. *Interciencia,* v.38, n.1, p.73-80, 2013. https://www.redalyc.org/articulo.oa?id=33926506010

TOLEDO, M.Z.; FACHIN, C.A.; ZUCARELI, V. Qualidade fisiológica de sementes esverdeadas de soja tratadas com bioestimulante. *Brazilian Journal of Agriculture - Revista de Agricultura,* v.90, n.1, p.63-76, 2015. https://doi.org/10.37856/bja.v90i1.208

TUNES, L.M.; PEDROSO, D.C.; BADINELLI, P.G.; TAVARES, L.C.; RUFINO, C.D.E.A.; BARROS, A.C.S.A.; MUNIZ, M.F.B. Envelhecimento acelerado em sementes de azevém com e sem solução salina e saturada. *Ciência Rural*, v.41, n.1, p.33-37, 2011. https://doi.org/10.1590/S0103-84782011000100006

WIJEWARDANA, C.; REDDY, K.R.; KRUTZ, L.J.; GAO, W.; BELLALOUI, N. Drought stress has transgenerational effects on soybean seed germination and seedling vigor. *Plos One*, v.14, n.9, e0214977, 2019. https://doi.org/10.1371/journal.pone.0214977

ZORATO, M.F.; PESKE, S.T.; TAKEDA, C.; FRANÇA-NETO, J.B. Presença de sementes esverdeadas em soja e seus efeitos sobre seu potencial fisiológico. *Revista Brasileira de Sementes,* v.29, n.1, p.11-19, 2007. https://doi.org/10.1590/S0101-31222007000100002