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Physiological quality: the effect of different levels of seed vigour and waterlogging stress[1]

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ABSTRACT - The aim of this study was to evaluate the agronomic traits of soya bean cultivars as well as the physiological quality of the produced seeds based on the initial vigour of seeds from different cultivars subjected to waterlogging stress at different phenological stages. Soya beans of mixed vigour were used, obtained under controlled conditions from the NA5909RG, NS6209RR, TMG7363RR and TECIRGA6070RR cultivars. The study comprised three factors: four cultivars, two levels of seed vigour (high and low), and three cultivation regimes (no waterlogging, five days temporary waterlogging from stage V6, and five days temporary waterlogging from stage R2). The following parameters were determined: number of pods per plant, number of seeds per pod, number of seeds per plant, 1000-seed weight, plant height, number of productive nodes on the main stem, height of the first pod insertion, seed yield per plant, and centesimal protein and oil content. Waterlogging stress results in a reduction in the number of pods per plant, number of seeds per plant, number of productive nodes on the main stem, number of secondary branches, seed yield per plant, oil content, and the physiological quality of the produced seeds. The high vigour of the seeds affords an increase in seed yield per plant, in the 1000-seed weight, number of nodes on the main stem, height of the first pod insertion, and oil content of the seeds.

Key words: *Glycine max* (L.) Merrill. Water stress. Development stage.

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INTRODUCTION

The soya bean (Glycine max (L.) Merrill) is a commodity of major global economic importance and is the principal crop of the agribusiness sector in Brazil. The country is the world's largest producer of soya beans, with a total of 154,617.4 million tons in the 2022/23 harvest (CONAB, 2023).

In the floodplains or lowlands of the state of Rio Grande do Sul the predominant soils are Planosols. Drainage is limited by the presence of an impermeable B horizon and the low hydraulic conductivity of the surface horizon, in addition to the flat topography, which hampers surface runoff (Dutra; Tavares; Sartoretto, 1995). As a result, the soil remains covered by a layer of water for long periods during heavy rainfall.

Waterlogged soil is considered one of the principal abiotic stresses in various ecosystems. These stresses are characterised by environmental conditions that cause a reduction in the genetic potential for plant growth and yield (Mickelbart; Hasegawa; Bailey-Serres, 2015). When the soil is waterlogged, the oxygen available to plants is reduced due to the poor oxygen diffusion (Zabalza *et al*., 2008), which limits growth in several species (Rosa *et al*., 2015; Coelho *et al*., 2013). In response to the waterlogging, changes in architecture, metabolism and biomass accumulation occur, which depend on the genetic diversity of the plants. In addition to the growth environment, other factors, such as the appropriate choice of cultivar and the quality of the seeds, as well as the interaction between these factors, all contribute to the establishment and development of a productive crop (Procópio *et al*., 2014).

Seed vigour has a strong influence on seedling emergence and their establishment in the field, especially under adverse environmental conditions (Caverzan *et al*., 2018; Ebone *et al*., 2020; Panozzo *et al*., 2009; Scheeren *et al*., 2010; Silva *et al*., 2013). Stand uniformity is directly related to seed vigour (Bagatelli *et al*., 2019; Cantarelli; Schuch; Tavares, 2015), where high quality seeds result in strong, vigorous seedlings that, under different types of soil and climate conditions, develop and become established more easily, emerge and develop more quickly, and rapidly close the gap between plant rows (França Neto; Krzysanowski; Henning, 2018; Tavares *et al*., 2013).

Studying seed vigour and the performance of different genotypes under waterlogged conditions at different stages of crop development is important to help describe plant performance under this type of environmental stress. The aim of this study, therefore, was to evaluate the agronomic characteristics of soya bean cultivars based on the initial vigour of the seeds subjected to waterlogging stress at different phenological stages of the crop.

MATERIAL AND METHODS

The study was conducted both in a greenhouse and at the Flávio Farias Rocha Seed Analysis Teaching Laboratory of the Eliseu Maciel School of Agronomy of the Federal University of Pelotas (FAEM/UFPel), in Capão do Leão, Rio Grande do Sul.

The experimental design was of randomised blocks in a 4 x 2 x 3 triple factorial scheme, including four indeterminate soya bean cultivars (NA 5909 RG, NS 6209 RR, TMG 7363 RR and TEC IRGA 6070 RR), two levels of seed vigour (high and low), and three cultivation regimes (no waterlogging (control), five days temporary waterlogging from the start of the vegetative stage – V6, and five days temporary waterlogging from the start of the reproductive stage – R2), with four replications, giving a total of 24 treatments and 96 experimental units. The experimental unit consisted of four pots, each containing two plants, giving a total of eight plants per unit.

Cultivar 5909 RG - Maturity group: 6.7; Flowering: 32 to 44 days; Physiological maturity: 88 to 104 days; Harvest: 94 to 112 days; Anthracnose: Tolerant. Early, with high productivity.

Cultivar NS 6209 RR - Growth habit: Indeterminate; Maturity group: 6.2; Flower colour: purple; Pubescence colour: grey. Excellent branching potential, high production potential and high grain weight.

TMG 7363 RR - high production potential, stability, resistance to Asian rust and tolerance to waterlogging. Relative maturity: 6.3; Indeterminate growth; Flower colour: white; Pubescence colour: grey; Hilum colour: light brown; Fertiliser requirement: medium/high; Resistant to lodging; TGW: 185 g.

TEC IRGA 6070RR - Excellent tolerance to excess water. Recommended for rotation in areas of irrigated rice. Relative maturity: 6.3; Indeterminate growth; Flower colour: white; Pubescence colour: light grey; Hilum colour: light brown; Fertiliser requirements; Resistant to lodging; TGW: 140 to 160 g.

High-vigour seeds were obtained from batches with an average germination of 92% and average emergence in seedbeds of 89%, while for low-vigour seeds, the average germination was 89% and average emergence in seedbeds was 63%.

Immediately before sowing, the seeds were treated with a commercial product based on fungicides and insecticides (Pyraclostrobin (25 g. L^{-1}) + Thiophanate methyl (225 g. L^{-1}) + Fipronil (250 g. L^{-1})) at a dose of 200 mL. 100 kg^{-1} seeds. The seeds were inoculated with the SEMIA 587 and SEMIA 5019 strains of *Bradyrhizobium elkanii* (BRASILEC TS IN-BOX), using 480 g. 100 kg^{-1} seeds (four doses), and moistened with a 10% sugar solution (600 mL. 100 kg^{-1} seeds) to help fix the peat inoculant, which was mixed in with the seeds.

The plants were grown in pots containing 8 kg of sieved soil collected from the A1 horizon of a Haplic Planosol (Streck *et al*., 2008). Liming was carried out as per the Liming and Fertilisation Manual for the states of Rio Grande do Sul and Santa Catarina (CQFS - RS/SC, 2016). Potassium and phosphate fertilisation was carried out using potassium chloride (KCl) and ground Triple Superphosphate mixed into the soil at a three times the dose recommended in the above Manual to ensure that the concentrations of these nutrients in the soil did not limit crop development; this is necessary in most floodplain soils in the tropical region, since they are more acidic, which limits agricultural production.

To ensure that the average behaviour of the batches was representative, three to four seeds were sown per hole and then thinned out to leave one plant per hole and two plants per pot. As the more-vigorous batches emerged more quickly than those of lower vigour, thinning took place between four and seven days after sowing. In order to avoid intraspecific competition during the experiment, a spacing of 10 cm was used between the plants in each pot to represent 50 cm between rows in the field. An irrigation system (individual microtubes per pot), automatically activated three times a day, was used to keep the soil close to field capacity, since waterlogging modifies the soil atmosphere, promotes O_2 deficiency, the accumulation of CO_2, methane, ethylene, and hydrogen sulphide (H_2S), and a reduction in aerobic respiration (Costa, 1996).

Temporary five-day waterlogging was achieved by placing a perforated (cultivated) pot inside another slightly larger pot with a waterproof plastic film between the two. Water was then added to the pots until a 5-cm layer formed on the soil surface. After five days, the perforated (cultivated) pots were removed and allowed to drain naturally. The control plants were not subjected to waterlogging. Some of the other plants were waterlogged during the vegetative stage only, and the remainder, during the reproductive stage, as determined by each treatment. Phytosanitary management was carried out whenever necessary to control pests, disease and weeds, following the recommendations for the crop.

At the end of the cycle, eight plants were collected from each experimental unit, using pruning shears to cut the main stem close to the ground. The yield components were assessed by determining the following variables: number of pods per plant (NPP), number of seeds per pod, number of seeds per plant (NSP), 1000-seed weight (TSW) (Brazil, 2009), plant height, number of productive nodes on the main stem, and height of the first pod insertion. Plant height was measured in centimetres using a graduated ruler from the base of the plant (close to the ground) to the last node at the apex of the main stem. The height of the first pod insertion was measured in centimetres using a graduated ruler from the base of the plant (close to the ground) to the first pod insertion along the main stem. After sorting, drying, weighing the seeds and determining their moisture content, the seed yield was calculated and expressed in grams of seeds per plant, with the moisture content corrected to 13% (wet basis).

The centesimal protein and oil content was determined in clean, intact seeds using near-infrared (NIR) spectroscopy as per Heil (2012). Readings were taken in triplicate, using an Antaris™ II FT-NIR analyser from Thermo Scientific (Thermo Electron Co., USA).

The data were tested for the assumptions of normality and homogeneity of variances using the Shapiro-Wilk and Bartlett tests, respectively, both at 5% significance. Since both assumptions were met, the results of the treatments were subjected to analysis of variance, and the mean values were compared by Tukey's test at 5% probability.

RESULTS AND DISCUSSION

The waterlogging stress applied in this study, regardless of the phenological stage of the crop, caused a reduction of around 20% in the number of pods per plant, as shown in Table 1.

Excess soil water during different stages of soya bean development strongly affects the yield components, with variations in the number of pods per plant, number of seeds per pod, and seed production (Schoffel *et al*., 2001). Working with crops under soil hypoxia, Sá (2005) found a 30% reduction in the average number of pods in soya bean plants subjected to stress from excess soil water during the reproductive stage.

Soil hypoxia during the reproductive stage reduces the length of flowering and the number of flowers, which results in a reduction in the number of pods (Sionit; Kramer, 1977). Among the yield components, the number of pods per plant is the most sensitive to waterlogging due to its heavy dependence on nitrogen fixation, which in turn depends on the presence of O_2 (Bacanamwo; Purcell, 1999).

Plants from the TEC IRGA 6070 RR and NS 6209 RR cultivars had the highest number of pods, with 47.0 and 43.3 pods per plant, respectively (Table 1), while the TMG 7363 RR and NA 5909 RG cultivars had the lowest values, with 37.5 and 36.3 pods per plant.

Table 1 - Number of pods per plant in plants from high and low-vigour seeds of the NA 5909 RG, NS 6209 RR, TMG 7363 RR, and TEC IRGA 6070 RR cultivars subjected to waterlogging stress

Cultivar	Number of pods per plant
TEC IRGA 6070 RR	47.0 a
NS 6209 RR	43.3 a
TMG 7363 RR	37.5 b
NA 5909 RG	36.3 b
Mean	41.0
Stress from temporary waterlogging	Number of pods per plant
Control (no waterlogging)	47.0 a
Waterlogging during the reproductive stage	38.9 b
Waterlogging during the vegetative stage	37.2 b
Mean	41.0

Mean values followed by the same lowercase letter in a column do not differ by Tukey's test ($P < 0.05$)

The number of seeds per pod was influenced by the interaction between the factors 'waterlogging stress' and 'seed vigour', and by the simple effects of the factor 'cultivar', as shown in Table 2. Cultivar TMG 7363 RR had a higher number of seeds per pod in relation to the other cultivars, and no interactions were found between this and the other factors.

Plants generated from low-vigour seeds that were subjected to temporary waterlogging may have a lower number of seeds per pod compared to the control plants, regardless of the phenological stage at which the stress was applied (Table 2). However, there was no significant reduction in the number of seeds per pod in plants from high-vigour seeds subjected to waterlogging stress. A significant reduction in the number of seeds per pod was also seen by Sá (2005) in plants that were subjected to waterlogging at the reproductive stage. There were also different responses between cultivars in relation to the average number of seeds per pod.

When subjected to stress from temporary waterlogging during the vegetative stage, plants generated from high-vigour seeds produced more seeds per pod compared to plants from low-vigour seeds. Tavares *et al*. (had 2013), studying the performance of soya bean seeds under water deficit, found that plants from high-vigour seeds produced more seeds than plants from low-vigour seeds, regardless of the water conditions of the soil, showing increases of more than 15% in seed yield. High-performance plants generated from high-vigour seeds tend to have higher growth rates, more significant productive structures, and a deep root system, with increases in pod and seed production that result in higher grain yields (França-Neto; Krzysanowski; Henning, 2018).

Due to the negative effects of waterlogging stress on the number of pods per plant, the number of seeds was also reduced (Table 3). However, due to the intrinsic characteristics of the cultivars for the number of pods per plant and the number of seeds per pod, the number of seeds per plant varied between the cultivars under study. On this basis, cultivar TEC IRGA 6070 RR had the best performance for this variable, with a production of 97.4 seeds per plant, while NA 5909 RG produced only 75.7 seeds per plant.

Morphological characterisation of the cultivars described in the material and methods

As shown in Table 4, the thousand-seed weight (TSW) was influenced by the interaction between the factors 'cultivar' and 'seed vigour'. It was found that the TSW of plants from high-vigour seeds differed statistically between cultivars, where cultivar TMG 7363 RR stood out with a TSW of 201 grams, followed by cultivar NS 6209 RR with a TSW of 179 g, and NA 5909 RG with the lowest TSW of 150 g. TEC IRGA 6070 RR had a TSW of 163 g, differing only from TMG 7363 RR. For the plants generated from low-vigour seeds, cultivar TMG 7363 RR had the highest TSW.

Comparing the effects of initial seed vigour on TSW, there were no significant differences between the TMG 7363 RR, TEC IRGA 6070 RR, and NA 5909 RG cultivars; this was in line with the findings of Schuch, Kolchi Nski and Finatto (2009). For plants of cultivar NS 6209 RR obtained from high-vigour seeds, there was an increase of 27 grams in TSW compared to seeds produced by plants from low-vigour seeds. Bagateli *et al*. (2019) found increasing values for the 1000-seed weight, with the use of batches with increasing levels of vigour.

According to Glier *et al*. (2015), the thousand-seed weight in the soya bean is closely related to the leaf area during the reproductive stage. Caverzan *et al*. (2018) also found that plants from high-vigour seeds produced seeds with a greater 1000-seed weight, as well as greater leaf area, shoot and root dry weight, stem diameter and plant height.

There was no interaction between the factors for plant height (Table 5), which showed simple effects for 'cultivar' and 'stress from temporary waterlogging'. TEC IRGA 6070 RR presented the greatest height for the cultivars under study, of 120.3 cm, followed by TMG 7363 RR and NA 5909 RG, with 112.6 and 107.1 cm, respectively. NS 6209 RR was the smallest, with a height of 97.3.

Temporary waterlogging during the reproductive stage resulted in the shortest length for the main stem; this was statistically different from plants subjected to waterlogging stress during the vegetative stage, which had the greatest stem length. Regardless of the stage at which waterlogging was applied, the control plants achieved average lengths and were not statistically difference from the waterlogged plants. This is due to the indeterminate growth habit of the cultivars. Excess water during the vegetative stage has a significant effect on plant lodging and a negative relationship with productivity, promoting an increase in the length of the main stem in an attempt to more efficiently absorb the solar radiation, and resulting in excessive plant growth and disruption of the canopy.

Table 2 - Number of seeds per pod in plants from high and low-vigour seeds of the NA 5909 RG, NS 6209 RR, TMG 7363 RR, and TEC IRGA 6070 RR cultivars subjected to waterlogging stress

Stress from temporary waterlogging	Number of seeds per pod	
	High vigour	Low vigour
Control (no waterlogging)	2.16 aA	2.16 aA
Waterlogging during the reproductive stage	2.12 aA	2.06 bA
Waterlogging during the vegetative stage	2.11 aA	1.99 bB
Mean	2.13	2.07
Cultivar	Number of seeds per pod	
TMG 7363 RR	2.19 a	
NA 5909 RG	2.08 b	
NS 6209 RR	2.07 b	
TEC IRGA 6070 RR	2.06 b	
Mean	2.10	

Mean values followed by the same lowercase letter in a column and uppercase letter in a row do not differ by Tukey's test (P < 0.05)

Table 3 - Number of seeds per plant in plants from high and low-vigour seeds of the NA 5909 RG, NS 6209 RR, TMG 7363 RR, and TEC IRGA 6070 RR cultivars subjected to waterlogging stress

Cultivar	Number of pods per plant
TEC IRGA 6070 RR	97.0 a
NS 6209 RR	90.0 ab
TMG 7363 RR	82.0 bc
NA 5909 RG	76.0 c
Mean	86.0
Stress from temporary waterlogging	Number of pods per plant
Control (no waterlogging)	101.0 a
Waterlogging during the reproductive stage	81.0 b
Waterlogging during the vegetative stage	76.0 b
Mean	86.0

Mean values followed by the same lowercase letter in a column do not differ by Tukey's test (P < 0.05)

Table 4 - Thousand-seed weight (g) in plants from high- and low-vigour seeds of the NA 5909 RG, NS 6209 RR, TMG 7363 RR, and TEC IRGA 6070 RR cultivars subjected to waterlogging stress

Cultivar	Thousand-seed weight (g)		Mean
	High vigour	Low vigour	
TMG 7363 RR	201 aA	188 aA	194
NS 6209 RR	179 bA	152 bB	166
TEC IRGA 6070 RR	163 bcA	151 bA	157
NA 5909 RG	150 cA	164 bA	157
Mean	174	164	169

Mean values followed by the same lowercase letter in a column and uppercase letter in a row do not differ by Tukey's test (P < 0.05)

Table 5 - Plant height (cm) in plants from high- and low-vigour seeds of the NA 5909 RG, NS 6209 RR, TMG 7363 RR, and TEC IRGA 6070 RR cultivars subjected to waterlogging stress

Cultivar	Plant height (cm)
TEC IRGA 6070 RR	120.3 a
TMG 7363 RR	112.6 b
NA 5909 RG	107.1 b
NS 6209 RR	97.3 c
Mean	109.4
Stress from temporary waterlogging	Plant height (cm)
Control (no waterlogging)	113.5 a
Waterlogging during the reproductive stage	108.0 ab
Waterlogging during the vegetative stage	106.5 b
Mean	109.4

Mean values followed by the same lowercase letter in a column do not differ Tukey's test (P < 0.05)

There were no effects from initial seed vigour on the final height of the plants at the time of the harvest. In contrast, Schuch, Kolchi Nski and Finatto (2009) observed greater height in plants generated from high-vigour seeds, compared to those from low-vigour seeds.

A study by Bagateli *et al*. (2019) found more pronounced gains in plant height with increasing initial seed vigour up to 60 days after emergence, the effect of vigour on plant height differing between the cultivars; there was, however, a general increase in plant height throughout the crop cycle which was due to the increase in seed vigour. Positive effects from seed vigour on plant height were also reported by Panozzo *et al*. (2009), Scheeren *et al*. (2010), Silva *et al*. (2013) and Caverzan *et al*. (2018).

Plants generated from high-vigour seeds (Table 6) have a greater number of nodes on the main stem than do plants from low-vigour seeds. Caverzan *et al*. (2018), studying soybean plants, found no significant response from the initial vigour level of the seeds on the number of productive or unproductive nodes.

Stress from temporary waterlogging during the vegetative stage affected plant growth, with an average reduction of 1.2 nodes compared to plants that were not subjected to waterlogging stress (Table 6). Similar findings were reported by Ludwig *et al*. (2016) and Ludwig *et al*. (2018), who noted a reduction in the number of nodes on the main stem of soybean plants subjected to temporary waterlogging during the vegetative stage. Changes in aerobic respiration, photosynthesis and the nutritional status of waterlogged plants can affect the growth and development of the different parts of the plant (Batista *et al*., 2008).

Cultivar TEC IRGA 6070 RR had the highest value for this variable (Table 6), with 17.4 nodes on the main stem. TMG 7363 RR presented intermediate values, with 15.1

nodes on the main stem, while NS 6209 RR and NA 5909 RG had the lowest values, with 14.2 and 13.4 nodes, respectively. Different responses for the number of nodes between cultivars were also found by Ludwig *et al*. (2018); this may be related to characteristics that are intrinsic to the genotype and expressed under the conditions of the experiment (Neto *et al*., 2009). Differences in the behaviour of cultivars in the face of adverse conditions, such as waterlogging, can be attributed to the genetic diversity of the materials, allowing cultivars to express greater tolerance or susceptibility to waterlogged soils (Mommer *et al*., 2006).

As shown in Table 7, there were only simple effects from each factor on the height of the first pod insertion, with the highest insertion seen in cultivar NA 5909 RG. The influence of vigour levels on the height of the first pod insertion in this study shows that in plants generated from high-vigour seeds, the first pod insertion is higher than in plants from low-vigour seeds. These data corroborate Rossi *et al*. (2017), who found a higher value for first pod insertion in plants from high-vigour seeds of cultivar BRS 243 RR compared to plants from low-vigour seeds of the same cultivar grown at the highest plant density; this they attributed to the delayed emergence of seedlings from low-vigour seeds. Under stress from temporary waterlogging, there was no significant difference in the height of the first pod insertion between the vegetative and reproductive stages.

Seed yield (Table 8) showed a significant interaction between the cultivars and levels of seed vigour, with the effects of vigour expressed differently among the cultivars under study. Plants of cultivar NS 6209 RR generated from high-vigour seeds produced 21.7% more seeds than did plants of the same cultivar from low-vigour seeds. This cultivar shows excellent branching potential, high grain weight and guaranteed high yield, all of which were seen in the high-vigour batches. This also shows the importance of quality control in launching higher-vigour seeds on the market, ensuring better performance in the field.

Kolchinski, Schuch and Peske (2006) reported that plants from high-vigour seeds resulted in a 35% increase in grain yield, compared with plants from low-vigour seeds. A gain of 9% in grain yield was also seen by Scheeren *et al.* (2010) with the use of high-vigour seeds, confirming the observations of Tavares *et al*. (2013), who found an increase in productivity of more than 15% with the use of high-vigour seeds. Furthermore, according to França-Neto, Krzysanowski and Henning (2018), high-vigour seeds result in the establishment of high-performance plants, generating increases in productivity of around 10% in commercial soya bean crops.

In this study, there were no significant differences between the cultivars from low-vigour seeds. However, among the plants from high-vigour seeds, cultivar NA 5909 RG had the poorest performance, with an average production per plant approximately 31.7% lower than the most productive cultivar. Sá (2005) found a difference of 11% in production per plant between cultivars subjected to soil hypoxia during the reproductive stage.

Table 6 - Number of productive nodes on the main stem in plants from high- and low-vigour seeds of the NA 5909 RG, NS 6209 RR, TMG 7363 RR, and TEC IRGA 6070 RR cultivars subjected to waterlogging stress

Cultivar	Number of productive nodes on the main stem
TEC IRGA 6070 RR	17.4 a
TMG 7363 RR	15.1 b
NS 6209 RR	14.2 c
NA 5909 RG	13.4 c
Mean	15.0
Seed vigour	Number of productive nodes on the main stem
High vigour	15.3 a
Low vigour	14.7 b
Mean	15.0
Stress from temporary waterlogging	Number of productive nodes on the main stem
Control (no waterlogging)	15.5 a
Waterlogging during the reproductive stage	15.2 a
Waterlogging during the vegetative stage	14.3 b
Mean	15.0

Mean values followed by the same lowercase letter in a column do not differ by Tukey’s test ($P < 0.05$)

Table 7 - Height of the first pod insertion in plants from high- and low-vigour seeds of the NA 5909 RG, NS 6209 RR, TMG 7363 RR, and TEC IRGA 6070 RR cultivars subjected to waterlogging stress

Cultivar	Height of the first pod insertion
NA 5909 RG	21.0 a
TEC IRGA 6070 RR	19.0 b
NS 6209 RR	17.9 b
TMG 7363 RR	17.7 b
Mean	18.9
High vigour	Height of the first pod insertion
Low vigour	19.8 a
Mean	18.0 b
High vigour	18.9
Stress from temporary waterlogging	Height of the first pod insertion
Control (no waterlogging)	19.7 a
Waterlogging during the reproductive stage	19.3 a
Waterlogging during the vegetative stage	17.8 b
Mean	18.9

Mean values followed by the same lowercase letter in a column do not differ by Tukey's test ($P < 0.05$)

Table 8 - Seed yield per plant (g) in plants from high- and low-vigour seeds of the NA 5909 RG, NS 6209 RR, TMG 7363 RR, and TEC IRGA 6070 RR cultivars subjected to waterlogging stress

Cultivar	Seed yield per plant (g.plant^{-1})		Mean
	High vigour	Low vigour	
TMG 7363 RR	16.5 aA	16.3 aA	16.4
TEC IRGA 6070 RR	16.2 aA	15.1 aA	15.7
NS 6209 RR	17.0 aA	13.3 aB	15.1
NA 5909 RG	11.6 bA	13.4 aA	12.5
Mean	15.3	14.5	14.9
Stress from temporary waterlogging	Rendimento de sementes por planta (g.planta-^{1})		
Control (no waterlogging)	17.5 a		
Waterlogging during the reproductive stage	14.5 b		
Waterlogging during the vegetative stage	12.8 c		
Mean	14.9		

Mean values followed by the same lowercase letter in a column and uppercase letter in a row do not differ by Tukey's test ($P < 0.05$)

The stress from temporary waterlogging used in this study to evaluate the number of pods per plant and number of seeds per pod, resulted in a significant reduction in seed yield per plant. The control plants, i.e. those that were not subjected to waterlogging stress, showed superior performance to the other plants, while stress from temporary waterlogging during the V6 vegetative stage caused a greater reduction in yield compared to the temporary stress applied during the reproductive stage.

The highest protein content was seen in seeds from cultivar NS 6209 RR, of 35.15 g. 100 g^{-1} (Table 09), approximately 0.56 g. 100 g^{-1} greater than cultivar TEC IRGA 6070 RR. According to Oliveira (1981), the protein content of the seeds is an intrinsic characteristic of the cultivars. Waterlogging also had an effect on the protein content of the seeds, and differed statistically depending on the phenological stages in which the stress occurred, with seeds from plants that were subjected to waterlogging stress during the reproductive stage presenting 0.5 g. 100 g^{-1} less protein in relation to plants that were subjected to stress during the vegetative stage. On the other hand, the control plants, which were not subjected to waterlogging, showed average behaviour, with no statistical difference from plants that underwent stress during the different phenological stages.

In a study by Sá (2005), waterlogging of the soil during the reproductive stage of the plants had no significant effect on protein accumulation in seeds of the FT-Abyara and CD 205 soya bean cultivars; it was found, however, that the protein content of the seeds from plants subjected to waterlogging was lower than that from non-waterlogged plants.

The oil content of the seeds was influenced by the interaction between the factors 'cultivar' and 'seed vigour'. Plants of the TEC IRGA 6070 RR cultivar (generated from high-vigour seeds) produced seeds with approximately 0.54 g. 100 g^{-1} more oil compared to plants from low-vigour seeds from the same cultivar. There were no significant differences between the cultivars for seed vigour.

In addition, simple effects were seen for the factor 'stress from temporary waterlogging'. The control plants (not subjected to waterlogging) presented the highest levels for this variable, 0.65 g. 100 g^{-1} higher than plants that underwent stress during the vegetative stage. An intermediate oil content was seen in seeds from plants that were subjected to waterlogging during the reproductive stage, with no difference between the control plants and those that underwent stress due to waterlogging during the vegetative stage.

Table 9 - Centesimal protein composition in the seeds of plants from high- and low-vigour seeds of the NA 5909 RG, NS 6209 RR, TMG 7363 RR, and TEC IRGA 6070 RR cultivars subjected to waterlogging stress

Cultivar	Protein (g 100g^{-1})
NS 6209 RR	35.15 a
TEC IRGA 6070 RR	34.59 b
TMG 7363 RR	34.49 b
NA 5909 RG	34.48 b
Mean	34.68
Stress from temporary waterlogging	Protein (g 100g^{-1})
Control (no waterlogging)	34.93 a
Waterlogging during the reproductive stage	34.67 ab
Waterlogging during the vegetative stage	34.43 b
Mean	34.68

Mean values followed by the same lowercase letter in a column do not differ by Tukey's test ($P < 0.05$)

Table 10 - Centesimal oil composition in the seeds of plants from high- and low-vigour seeds of the NA 5909 RG, NS 6209 RR, TMG 7363 RR, and TEC IRGA 6070 RR cultivars subjected to waterlogging stress

Cultivar	Oil content (g 100g^{-1})		Mean
	high vigour	low vigour	
NS 6209 RR	14.48 aA	14.24 aA	14.36
NA 5909 RG	13.95 aA	14.39 aA	14.17
TEC IRGA 6070 RR	14.35 aA	13.81 aB	14.08
TMG 7363 RR	13.96 aA	13.92 aA	13.94
Mean	14.19	14.09	14.14
Stress from temporary waterlogging	Oil content (g 100g^{-1})		
Control (no waterlogging)	14.49 a		
Waterlogging during the reproductive stage	14.09 ab		
Waterlogging during the vegetative stage	13.84 b		
Mean	14.14		

Mean values followed by the same lowercase letter in a column and uppercase letter in a row do not differ by Tukey's test ($P < 0.05$)

CONCLUSIONS

1. Soil waterlogging stress has a negative effect on the agronomic characteristics and performance of soya bean plants, and may result in a reduction in the number of pods per plant, number of seeds per plant, seed yield per plant, and number of productive nodes on the main stem;
2. Depending on the cultivar, a high level of seed vigour may afford increases in seed yield per plant, as well as the thousand-seed weight, the number of productive nodes on the main stem, and the height of the first pod insertion.

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