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Physiological quality of common bean seeds under soil water availability factor

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ABSTRACT: Water availability is one of the main factors responsible for the productivity of the bean plant, as well as the quality of the common bean seeds produced. This study aimed to evaluate the physiological quality of the common bean seeds cultivars subjected to soil water availability factor (f factor). The experiment was carried out in a randomized block design, with four replications. The treatments were arranged in split plots, with the plots consisting of five water availability factors f (0.20, 0.35, 0.50, 0.65 and 0.80, being 0,8 the most stressful f factor) and the subplots consisting of two bean cultivars (BRS Pérola and BRS Estilo). At the end of the crop cycle, physiological quality of the seeds was evaluated through the following analyses: water content, germination, emergence, emergence speed index, length, fresh mass of seedlings and electrical conductivity. Water stress (after 0,45) negatively affected the physiological quality of seeds, since the maximum physiological quality was obtained with f factors closer to field capacity, being better with f factors up to 0.45. The cultivar BRS Estilo was more tolerant to water stress than BRS Pérola.

Key words: *Phaseolus vulgaris* L.; vigor; water stress

Qualidade fisiológica de sementes de feijoeiro sob fatores de disponibilidade hídrica do solo

RESUMO: A disponibilidade hídrica é um dos principais fatores responsáveis pela produtividade do feijoeiro, bem como da qualidade das sementes produzidas. O objetivo deste trabalho foi avaliar a qualidade fisiológica de sementes de cultivares de feijoeiro submetidas a fatores de disponibilidades hídricas no solo (fator f). O experimento foi conduzido em delineamento de blocos casualizados, com quatro repetições. Os tratamentos foram arranjados em parcelas subdivididas, sendo as parcelas constituídas por cinco fatores de disponibilidade hídrica f (0,20, 0,35, 0,50, 0,65 e 0,80) e as subparcelas constituídas por duas cultivares de feijão (BRS Pérola e BRS Estilo). Ao final do ciclo da cultura avaliou-se a qualidade fisiológica das sementes por meio das seguintes análises: teor de água, germinação, emergência, índice de velocidade de emergência, comprimento, massa fresca de plântulas e condutividade elétrica. O estresse hídrico afetou negativamente a qualidade fisiológica das sementes, visto que a máxima qualidade fisiológica foi obtida com fatores f mais próximos à capacidade de campo, sendo melhores com fatores f até 0,45 para ambas cultivares. A cultivar BRS Estilo é mais tolerante ao estresse hídrico em relação a BRS Pérola.

Palavras-chave: *Phaseolus vulgaris* L.; vigor; estresse hídrico

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Introduction

Common bean (*Phaseolus vulgaris* L.) is one of the most important components of the brazilian diet (Santos et al., 2020), being the more important source of proteins, fibers, carbohydrates and minerals (Hummel et al., 2018), mainly to poor population. The brasilian beans production is in Paraná (409.000 t), Minas Gerais (306.000 t) and Goiás (138.000 t) corresponding to more than 50% of national production, around 2.899.864 t (IBGE, 2021).

Over 80% of bean production in developing countries is from subsistence farming of semi-arid regions and sub-humid to humid growing environments, being drought stress one of the most limiting factors for the sustainability of agriculture (Assefa et al., 2019).

In Brazil, bean is cultivated mainly by small producers. However, due to several production restrictions, such as low water availability, its cultivation is often limited. Due to being cultivated predominantly by small producers from regions with low water supply, it is necessary to use irrigation in order to have good crop yields in the field. Still, in order to maintain the productive cycle of the culture, the small farmer usually uses seeds from his own crop to form the next crop. Thus, developing a management strategy that allows productivity and satisfactory physiological quality of the seeds with the least possible water consumption is of great importance, as this will allow the constancy of the activity in the field, generating income with low water consumption.

Common bean needs a sufficient soil moisture for its development and maintenance, thus, the irrigation suppression at different stages of development compromises the yield components and contribute to low crop productivity (Cunha et al., 2013; Dipp et al., 2017). Furthermore, the growth of common bean grown decreases linearly as the level of water deficit in the soil increases (Martins et al., 2018). On the other hand, beans are sensitive to the excess of soil moisture, due to changes in plant physiology (Osakabe et al., 2014; Lanna et al., 2016). Moreover, water stress can cause damage to the seeds produced, influencing the final quality and quantities and types of accumulated reserve substances (Marcos Filho, 2015). Thus, the maintenance of a satisfactory soil water level is necessary for a good crop performance.

Therefore, the adoption of cultivars more adapted to low soil water conditions, associated with the use of efficient irrigation managements, can contribute to increase the crop yield (Nepomucemo et al., 2001, Ambachew et al., 2015) and to decrease the water consumption. This response depends on the genotype and age of the plants and intensity and duration of the stress conditions to which they are subjected (Olsovska et al., 2016). BRS Pérola is a common bean cultivar released in 1994 that is tolerant to water and thermal deficits and is still preferred by producers, mainly because of its rusticity (Hoffman Júnior et al., 2007; Vale et al., 2012), despite new cultivars have been released with similar or superior characteristics.

The water demand for common bean is between 250 mm and 300 mm (Oliveira et al., 2018). In order to improve the crop water use applied, it is possible to establish a soil water storage limit to satisfactorily provide water to plants (Vieira et al., 2015). These limits can be adjusted by using the f factor (Mantovani et al., 2009), which needs to be determined for each condition, since it may vary depending on the characteristics of the plant, environment, and soil (Marouelli et al., 2011) The f factor should be 0.5 for an evapotranspiration demand of 5 mm day^{-1} for the common bean crop, i.e., plants can consume up to 50 % of all available water in the soil (Allen et al., 2006). Therefore, the objective of this study was to evaluate the physiological quality of the common bean seeds cultivars subjected to soil water availability factor (f factor).

Materials and Methods

The experiment was conducted at the Experimental Area of the Department of Agricultural Sciences from State University of Montes Claros (UNIMONTES), Janaúba-MG, (15°49’44’’S, 43°16’09’’W and altitude of 544 m). The climate of the region is Aw (tropical with dry winter) according to the Köppen classification (Alvares et al., 2013).

The soil of the experimental area is classified as a Typic Quartzipsamment ((Neosol Fluvic Psamment), which presented a total water storage capacity of 38 mm in the 0-0.2 m layer, due to its high content of medium and fine sands in the sand fraction.

Data of maximum, average and minimum temperatures were collected from a meteorological station at the experimental area (Figure 1).

The physical-hydrological properties of soil density, and the water retention curve at tensions of 6, 10, 33, 100, 500 and 1,500 kPa, were determined considering the 0.0-0.20 and 0.20-0.40 m layer (Table 1).

Soil moisture sensors (Watermark®) were installed at 0.1 and 0.3 m depths in each plot, representing the 0.0-0.2 and

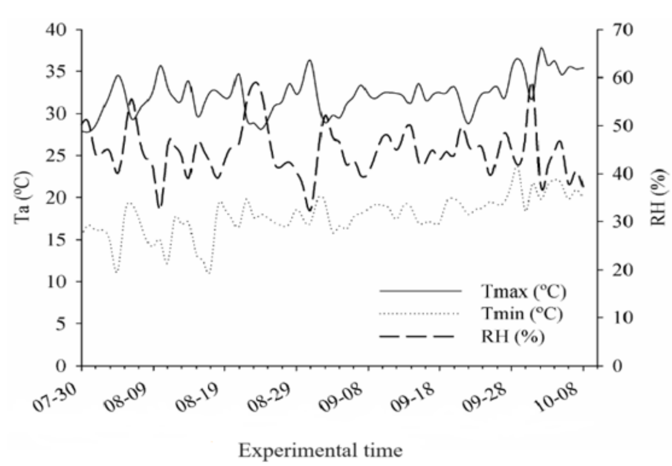

Figure 1. Air temperature (Ta, °C) and relative humidity (RH, %) during the experiment period (Janaúba, Minas Gerais state, Brazil, 2017).

Table 1. Soil water retention equations and their coefficient of determination (R^2); soil moisture at field capacity (FC, $m^3 m^{-3}$) and at permanent wilting point (PWP, $m^3 m^{-3}$); and apparent soil density (ρs, g cm^3), from two soil depths in the experimental area.

Soil depth (m)	Equation[1]	R^2	FC	PWP	ρ_s
0.0-0.2	$\theta = 0.0299 + \frac{(0.410 - 0.0299)}{[1 + (0.10 \times \tau)^{1.7475}]^{0.4278}}$	0.99	0.2324	0.039	1.39
0.2-0.4	$\theta = 0.0221 + \frac{(0.425 - 0.0221)}{[1 + (0.10 \times \tau)^{1.7543}]^{0.4300}}$	0.98	0.2357	0.033	1.39

[1]θ - Volume-based moisture; τ - Soil water tension (kPa).

0.2-0.4 m layers, respectively, with daily readings throughout the experiment.

The readings of the sensors installed at 0.1 m were used to define the irrigation regime (variable watering shift) according to the water availability factors (f factors) evaluated.

The irrigation regime maintained the soil moisture to a tension corresponding to the field capacity (20 kPa), which was defined by the basin method up to the effective depth of the root system (0.3 m), thus determining the irrigation depths to be applied in each treatment (Bernardo et al., 2019).

The experiment was conducted in a randomized block design, with four replications. The treatments were arranged in split plots, with plots consisting of five soil water availability factors (f factors) (f1 = 0.20; f2 = 0.35; f3 = 0.50; f4 = 0.65; f5 = 0.80) and subplots consisting of two common bean cultivars (BRS Pérola and BRS Estilo). Each subplot consisted of two 4-m double plant rows spaced at 0.3 × 0.7 m, sowed with 12 seeds m^{-1}. The two central rows were considered for evaluation, disregarding 1.5 m of each end.

The treatments were differentiated at 27 days after sowing (DAS), according to the irrigation water depths based on the moisture sensors. Before of the treatments differentiation, from one to 26 days, the irrigation was similar for all treatments, increasing the soil moisture to the field capacity to promote a uniform development of plants and favor the initial growth and establishment of the crop. Subsequently, they were irrigated whenever the soil moisture reached the value established for each treatment, by replacing the water to the limits of the soil water availability (f factor) of each treatment.

A drip-irrigation system was used, with spacing of 1 m between tubes and 0.33 m between emitters, a wet area of 60%, flow rate of 2 L h^{-1} (average of five evaluations), working pressure of 150 kPa and application efficiency of 94%.

The soil was fertilized after planting through fertigation, which was divided into six applications, until the application of the treatments, using 40 kg ha^{-1} of N (45 % of N urea, 12 % of N MAP and 13 % of N KNO_3), 70 kg ha^{-1} of P_2O_5 (60 % of P_2O_5 purified MAP) and 30 kg ha^{-1} of K_2O (44 % of K_2O KNO_3), according to Vieira et al. (2015). Micronutrients were applied using FTE BR12 (1.8 % of B, 0.8 % of Cu, 3.0 % of Fe, 2.0 % of Mn and 0.1 % of Mo), at a rate of 15 kg ha^{-1}. Foliar fertilization was applied at 35 DAS (R5 stage), using CoMo (Co, Mo and P_2O_5 at 10.56 g L^{-1}, 105.6 g L^{-1} and 132 g L^{-1}, respectively) at a rate of 300 mL ha^{-1}.

The harvest in each plots occurred as soon as the seeds reached physiological maturity (at the same time). The pods were manually threshed, and the seeds were placed in paper bags and maintained at 65% air relative humidity and 10 °C for one week and were taken to the Seed Analysis Laboratory of the UNIMONTES. For all the evaluations four repetitions of 50 seeds per treatment were evaluated, and a completely randomized experimental design was performed.

The seed moisture content was determined by the standard oven method at 105 ± 3 °C, for 24 hours, according to the methodology described in the Rules for Seed Analysis (Brasil, 2009).

For the germination test were utilized Germitest® papers wetted with distilled water at 2.5-fold the dry paper weight. The rolls were placed in a germinator at temperature of 25 °C. The evaluation of the germination was at 9 after sowing, and the results were expressed in percentages of normal seedlings (Brasil, 2009).

The seedling emergence was evaluated under laboratory conditions (25 ± 3 °C); the seeds were sown to a depth of 0.03 m in plastic trays containing sterilized washed sand as substrate (Brasil, 2009). The sand moisture was maintained with the aid of sprayers, according to the need of the plant. The seedlings were evaluated at 9 DAS, and the results were expressed in percentage of emerged normal seedlings (shoots exposed above the substrate surface).

The emergence speed index (ESI) was evaluated by daily counting of the number of emerged seedlings. The ESI was calculated at the end of the test, using the formula described by Maguire (1962).

At the end of the emergency test, the length of 10 normal seedlings/replicates was determined, and the results were expressed in mm $seedling^{-1}$.

To obtain the weight of the fresh matter, the normal seedlings required the emergency test were weighed on a digital scale with an accuracy of 0.01 g, and the results were expressed in g $seedling^{-1}$.

The electrical conductivity test was performed by the use of 50 seeds, placing them in 200-mL plastic cups containing 75 mL of distilled water. The cups were kept in a BOD incubator at 25 ºC for 24 hours and then, the solution was read using a portable conductometer (DM-31). The results were expressed in μS cm^{-1} g^{-1} of seeds.

The data were subjected to analysis of variance; the effects of the bean common cultivars were studied by the F test at $p \leq 0.05$, whereas the effects of the f factor were studied by regression analysis, choosing the models that better represent the data based on their coefficients of significance and coefficients of determination (R^2). The analyses were performed by the R statistical program.

Results and Discussion

The water applied to the common bean crops reached 137.7 mm for each treatment up to the application of the treatments (27 DAS) (Figure 2A). Subsequently, the total water depths varied from 221.7mm to 309.9 mm according to the f factor (Figure 2A). The lower the f factor, the higher was the irrigation frequency (Figure 2B).

Operationally, the minimum number of irrigations is ideal, requiring less labor and electricity consumption for irrigation (Vieira et al., 2015). However, long intervals between irrigations generate drier soil conditions for the crops, making it difficult for plants to absorb water and leading to water stress, in addition to increasing the risk of percolation due to the high-water depths to reach the field capacity.

The interaction between bean common cultivars and soil water availability factors (f factor) for emergency, emergency speed index and electrical conductivity was significant ($p \leq 0.05$). The other variables were affected by isolated effects, for one or both source of variation except to germination and seedling fresh matter, which were not influenced by any of the studied factors (Table 2).

The seed moisture content, which was determined as an initial procedure, reached 8.53% (average). The climatic conditions, especially the temperature and relative humidity (Figure 1), observed in the field production, contributed to maintenance of the ideal humidity level, which agrees with Marcos Filho (2015).

All the treatments presented germination of 93%, value higher than the minimum required (80%) for seeds commercialization in all categories (Brasil, 2013).

Considering the interaction between the cultivars and f factor, when we analyze cultivar within each f factor (Table 3), was found that the highest seedling emergence values and the emergence speed index were obtained from seeds produced by BRS Estilo cultivar for each f factor imposed, which can be attributed to a high sensitivity of the BRS Pérola cultivar to the water deficit, since the tolerance to water deficit condition varies according to the stage of development and the cultivar adopted.

For the interaction, f factor and cultivar, the seeds vigor basing on the seedling emergence test and emergence speed index (ESI) it is noted that the result of the bean common cultivars adjusted quadratic model (Figure 3).

For both cultivars (Figure 3A), in the treatment with f factor of 0.20, the seeds produced presented vigor of 96% evaluated by the seedling emergence test for BRS Estilo and 82% for a BRS Pérola cultivar, and both reached maximum values (98 and 85% respectively) in the treatments with f

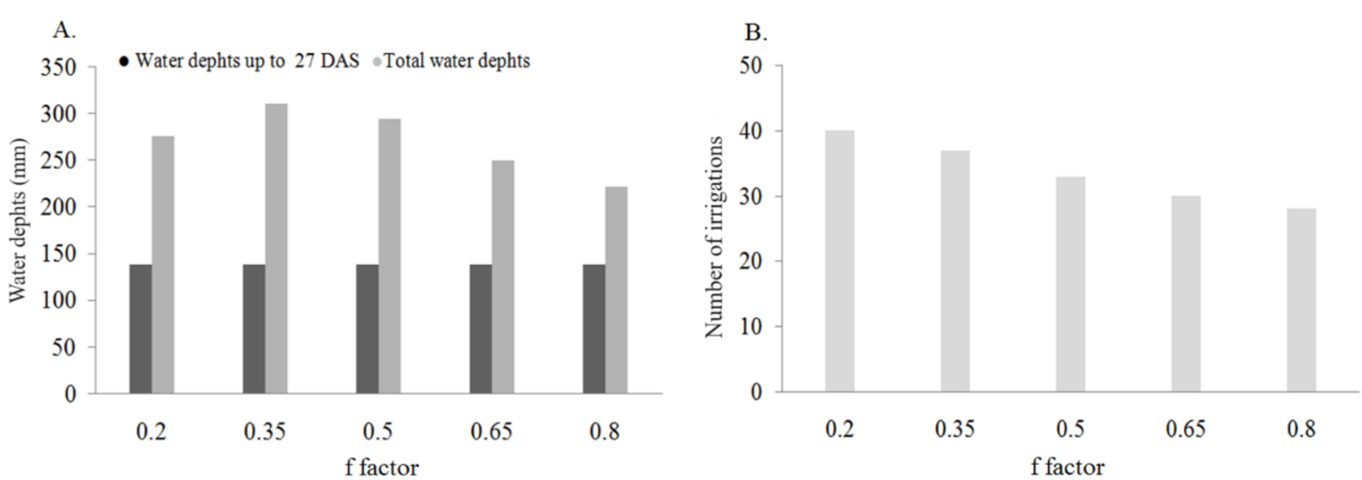

Figure 2. Water depths before and after application of the treatments, mm (A), and number of irrigations (B), applied on common bean cultivars submitted to soil water availability factors (f factor).

Table 2. Analysis of variance for moisture content (MC, %), germination (GER, %), seedling emergency (SE,%), emergence speed index (ESI), length of seedless (LS, cm), weight of the fresh matter (WFM, g), electrical conductivity(EC, µS cm^{-1} g^{-1}) of beam common under water availability factors (f factor).

Source of variation	DF	Mean squares						
		MC	GER	SE	ESI	LS	WFM	EC
f factor	4	0.176^{ns}	3.35^{ns}	223.9^{**}	28.36^{**}	3.36^{ns}	231.44^{ns}	1100.04^{**}
Cultivar	1	0.326^{ns}	16.9^{ns}	1155.6^{**}	192.06^{**}	49.46^{**}	320.75^{ns}	2694.52^{**}
f fator × Cultivar	4	0.043^{ns}	1.15^{ns}	46.75^{**}	4.22^{**}	5.47^{ns}	331.07^{ns}	175.15^{**}
Error	30	0.12	5.5	13.29	0.83	4.59	198.97	17.11
CV (%)		4.09	2.52	4.18	4.74	5.02	17.53	4.43
Overall mean		8.53	93.05	87.23	19.18	42.69	80.46	93.4

* and ** significant values by the F-test at 5 % or 1 % of probability, respectively; ns not significant values by the F-test at 5 % of probability.

Table 3. Seedling emergence (SE,%), emergence speed index (ESI) and electrical conductivity (EC, $\mu Scm^{-1} g^{-1}$) for common bean cultivar seeds under soil water availability factors (f factor).

Cultivar	f factor				
	0.2	0.35	0.5	0.65	0.8
			SE (%)		
BRS Pérola	83 b	83 b	85 b	84 b	75 b
BRS Estilo	98 a	98 a	96 a	89 a	82 a
			ESI		
BRS Pérola	16.83 b	17.08 b	17.92 b	18.37 b	14.75 b
BRS Estilo	21.58 a	23.41 a	22.54 a	22.51 a	17.08 a
			EC ($\mu S\ cm^{-1}\ g^{-1}$)		
BRS Pérola	79.68 b	76.13 b	85.77 b	77.49 b	105.88 b
BRS Estilo	87.06 a	101.69 a	93.92 a	103.83 a	121.57 a

Means followed by different letters in the columns are different by the F-test at 0.05 of probability.

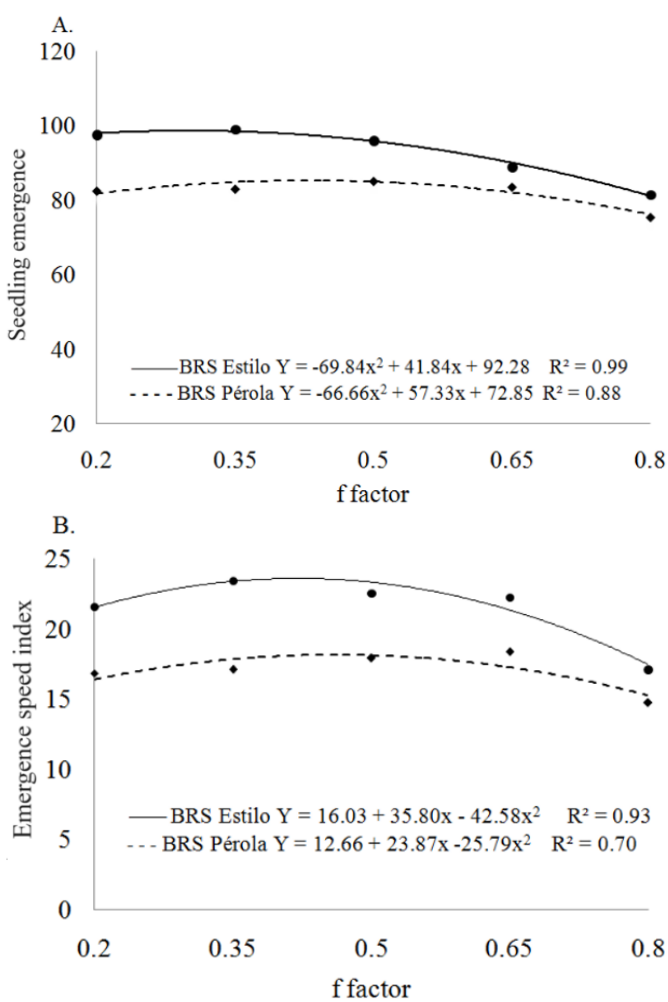

Figure 3. A - Seedling emergence (SE%) and B - emergence speed index (ESI) from common bean cultivar seeds under soil water availability factors (f factor).

factor of 0.33 and 0.43, respectively. The lowest emergency values (81% BRS Estilo and 76% BRS Pérola) were obtained in the f factor of 0.80.

The f factor of 0.33 and 0.43, respectively, was sufficient to promote good soil water availability during the development phase of the common bean plant and consequently the formation of maximum quality seeds, since during the period of seed formation is needed an adequate soil water availability to occur the translocation of plant nutrients to the seeds.

The lower result of the seeds vigor produced from plants cultivated with a f factor of 0.80, can be attributed to soil water deficit, which when it occurs in the reproductive stage of the plant, there is a reduction in leaf expansion and reduction in leaf area index because of the reduction in the use of soil nutrients, generating a primary consequence in the physiological quality of the seeds produced.

The water deficit in the seed formation stages can negatively affects cell differentiation and expansion, as well as reflect the lower allocation of assimilates (Marcos Filho, 2015) resulting in low seeds vigor. According to Carvalho & Nakagawa (2012), any factor that affects the development and accumulation of reserves by the seed will damage its vigor, highlighting water availability among these factors. Oliveira et al. (2020) observed that soybean seeds cultivated under water stress had a lower translocation of reserves to the embryo, reducing seed vigor.

Regarding the emergence speed index, it is observed that the maximum ESI values (23.55 BRS Estilo and 18.18 BRS Pérola) were obtained in the f factor of 0.42 and 0.46 respectively. From the maximum point, there was reduction in seed vigor for both cultivars, reaching 17.23 for BRS Estilo and 15.86 BRS Pérola cultivar at f factor of 0.80 (Figure 3B).

The bean common is a C3 plant and the occurrence of water deficit in the crop during the vegetative and reproductive phase, associated with high temperatures, as verified during the conduct of the experiment (Figure 1), promoted the bean plants to stomata closure, thus restricting the entry of CO_2 into the leaves, with reduction in photosynthetic activity and a reduction in the production and transport of compounds for the formation of reserves in the forming seeds, thus justifying the lower vigor results of seeds from plants cultivated with f factor of 0.80.

Analyzing the results of electrical conductivity (Table 4), it is verified that in all the f factors the BRS Estilo cultivar presented superior results in relation to BRS Pérola cultivar, indicating greater leaching of solutes, which in agreement with Marcos Filho (2015), it is associated with the integrity of the cell membrane system.

The results corroborate with Silva et al. (2013), who found that electrical conductivity vary according to the evaluated cultivar and may differ between genotypes of the same

Table 4. Electrical conductivity (EC, $\mu S\ cm^{-1}\ g^{-1}$) for common bean cultivar seeds under soil water availability factors (f factor).

Cultivar	f factor				
	0.2	0.35	0.5	0.65	0.8
BRS Pérola	79.68 a	76.13 a	86.77 a	77.49 a	105.88 a
BRS Estilo	87.06 a	101.69 a	93.92 a	103.83 a	121.57 a

Means followed by different letters in the columns are different by the F-test at 0.05 of probability.

commercial group depending on the genetic constitution of the materials.

BRS Estilo cultivar seeds produced under higher water availability (f factor of 0.20), presented low solute leaching, obtaining lower conductivity value (93.4 µS cm^{-1} g^{-1}). However, the maximization of water stress due to the increase in the f factor promoted an increase in the amount of leachate released by the seeds, reaching the maximum result (119.23 µS cm^{-1} g^{-1}) in the f factor of 0.80, representing an increase of 27.65% in relation to f factor of 0.2 (Figure 4).

For BRS Pérola cultivar the lowest conductivity (76.60 µS cm^{-1} g^{-1}) was obtained in seeds produced under water availability corresponding to the f factor of 0.37, from which the release of solutes increased, verifying an increase of 33.41% up to the factor of greater water limitation (f factor of 0.80), where the maximum result was verified (102.19 µS cm^{-1} g^{-1}).

The result can be attributed to the occurrence of water restriction during the seed development period, which may have affected the deposition of reserves, the adequate formation of cell membranes and the correct establishment of the hydrolytic enzyme system of the seeds (Silva et al., 2010).

Seed development is highly dependent on a continuous requirement of assimilated compounds, photosynthesis aggregation, which is impaired when a plant is under water stress, simply because it does not have sufficient reserves to maintain seed development (Pereira et al., 2018), preventing the complete structuring of cell membranes with consequent damage to the physiological quality of seeds.

Common bean cultivars had different results for the variables seedling length (Table 5). As both cultivars were subjected to the same experimental conditions, this behavior can be attributed to genetic characteristics of the BRS Estilo cultivar.

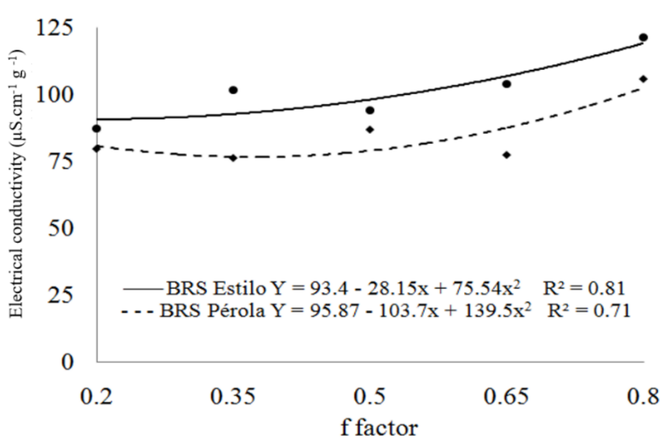

Figure 4. Electrical conductivity (EC, µS cm^{-1} g^{-1}) for common bean cultivar seeds under soil water availability factors (f factor).

Table 5. Seedling length (SL, cm) of bean common cultivars.

Variables	Cultivars	
	BRS Pérola	BRS Estilo
Seedling length (cm)	41.58 b	43.90 a

Means followed by different letters on the lines differ from each other by the F test at 0.05 probability.

Conclusion

Water stress negatively affected the physiological quality of seeds, since the maximum physiological quality was obtained with f factors closer to field capacity, being better with f factors of up to 0.45. The cultivar BRS Estilo was more tolerant to water stress than BRS Pérola.

Compliance with Ethical Standards

Author contributions: Conceptualization: EFD, SRS; Data curation: JCF; EFS; CDS; Formal analysis: EFS; CDS; Investigation: EFS; CDS; JCF; AMSSD; Methodology: EFS; CDS; JCF; AMSSD; SRS; Project administration: SRS; Supervision: AMSSD; SRS ; Validation: AMSSD; SRS; Writing – original draft: EFS; CDS; JCF; Writing – review & editing: EFS; CDS; JCF.

Conflict of interest: The authors declare no conflict of interest.

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