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Physiological quality of sesame seeds produced from plants subjected to water stress[1]

Qualidade fisiológica de sementes de gergelim produzidas a partir de plantas submetidas ao estresse hídrico

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ABSTRACT - Germination and seed vigor may be influenced by several factors, such as water stress during production, which affect crops differently according to the phenological stage of the plant. The aim of this study therefore was to evaluate the physiological quality of sesame seeds from plants subjected to water stress at different phenological stages. To this end, sesame plants were subjected to water stress at the following stages: I - germination to the start of vegetative growth (T1); II - vegetative growth to flowering (T2); III - flowering to pod formation (T3); IV - fruit maturation (T4); also for stress at all stages (T5) and full irrigation (T6). By weighing and daily irrigation of the containers, levels were kept at 50% of pot capacity (CV) for treatments with water deficit, and at 100% CV for treatments with no deficit. At 90 days after planting, the plants were harvested. The seeds were evaluated by germination test, first germination count, germination speed index, mean germination time, accelerated aging, electrical conductivity, seedling emergence, emergence speed index, mean time of emergence, seedling length and seedling dry weight. Sesame seeds from plants grown under water deficit display lower physiological quality. Between germination and the start of vegetative growth, and between flowering and fruit formation, the sesame is more sensitive to water stress, so that water limitation during these periods results in the production of seeds of low physiological quality.

Key words: *Sesamum indicum* L.. Water deficit. Phenology. Germination. Gas exchange.

RESUMO - A germinação e vigor das sementes podem ser influenciadas por diversos fatores, como o déficit hídrico durante sua produção, o qual pode afetar diferentemente as culturas de acordo com a fase fenológica da planta. Assim, o objetivo desse trabalho foi avaliar a qualidade fisiológica de sementes de gergelim oriundas de plantas submetidas ao estresse hídrico em diferentes fases fenológicas. Para tanto, plantas de gergelim foram submetidas à deficiência hídrica nas seguintes fases: I - germinação ao início do crescimento vegetativo (T1); II - crescimento vegetativo até a floração (T2); III - floração até a formação das vagens (T3); IV - maturação dos frutos (T4); estresse em todas as fases (T5); e irrigação plena (T6). Manteve-se, por meio da pesagem e irrigação diária dos baldes, 50% da capacidade de vaso (CV) para os tratamentos com deficiência hídrica e 100% da CV para os tratamentos sem deficiência. Aos 90 dias após o plantio realizou-se a colheita das plantas, sendo as sementes avaliadas através do teste de germinação, 1ª contagem de germinação, índice de velocidade de germinação, tempo médio de germinação, envelhecimento acelerado, condutividade elétrica, emergência de plântulas, índice de velocidade de emergência, tempo médio de emergência, comprimento de plântulas e massa seca das plântulas. Sementes de gergelim provenientes de plantas cultivadas sob déficit hídrico apresentam menor qualidade fisiológica. Entre a germinação e o início do crescimento vegetativo e entre a floração e formação dos frutos o gergelim é mais sensível à deficiência hídrica, de modo que a limitação de água nesses períodos resulta em produção de sementes de qualidade fisiológica inferior.

Palavras-chave: *Sesamum indicum* L.. Déficit hídrico. Fenologia. Germinação. Trocas gasosas.

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INTRODUCTION

Sesame is a crop that is adapted to deep soils which have a loamy texture, are well drained and of good natural fertility. Despite having an optimal range of between 500 and 650 mm of water during its production cycle (GRILO JÚNIOR, AZEVEDO, 2013), the species is considered resistant to drought and is productive with a rainfall of up to 300 mm, if this is well distributed throughout its development.

In general, water deficiency is caused by the transpiration of water exceeding the rate of absorption, thereby acting directly on the water balance in plants (COSTA *et al*., 2008). Damage to the plants, which can be more or less severe, depends on the intensity of the stress, exposure time and stage of development of the crop, (TAVARES *et al*., 2013).

It is known that in addition to suitable climatic conditions, for a successful crop, it is necessary to use seeds of high physiological quality, as this contributes to high productivity, whereas seeds of low quality compromise an adequate stand of plants, directly affecting productivity. The most vigorous seeds are generally more resistant to such abiotic stresses as a soil water deficit, for example (MAGALHAES *et al.,* 2013; OLIVEIRA; GOMES-FILHO, 2011).

In recent years, some research has been carried out into seed production under conditions of water deficit. During such conditions, differences between crops have been detected, where great variability in the characteristics related to seed viability and vigor can be seen. Freitas *et al*. (2013), in a study of the cowpea, found that stress due to water deficit reduced the physiological quality of the produced seeds. On the other hand, Pedroso *et al*. (2009) found that the effect of drought on seeds of the coffee plant varied for the age of the plant. With the soybean, Tavares *et al.* (2013) concluded that a water deficit from 20 days after sowing, causes a reduction in the physiological quality of the seeds, being more severe in plants originating from seeds of low vigor.

Because it is a species which is often recommended as an alternative for generating income in the Brazilian semi-arid region, it is extremely important to know the response to water availability during the different phenological stages of the plant. These results become even more relevant with regard to the physiological quality of the seeds, in order that seed producers be able to carry out irrigation management or schedule crop planting in a more appropriate and sustainable way, with a view to obtaining seeds of a physiological quality and vigor which are within the recommended standards.

The aim of this study was to evaluate the physiological quality of sesame seeds from plants which were subjected to water stress at different phenological stages.

MATERIAL AND METHODS

The experiment to obtain the seeds was carried out from August 14 to November 14, 2014, in a greenhouse of the teaching garden of the Federal University of Ceará (UFC) in Fortaleza, in the State of Ceará, Brazil, located at 3º44’ S, 38º33’ W and an altitude of 21 meters.

The plants were grown in soil collected from the surface layer (0-20 cm) of the agricultural sector of UFC, and which displayed the following characteristics: pH (in H_2O) = 6.48; Ca^{2+} = 1.4 $cmol_c$ kg^{-1}; Mg^{2+} = 0.8 $cmol_c$ kg^{-1}; K^+ = 0.77 $cmol_c$ kg^{-1}; Al3 + = 0.1 $cmol_c$ kg^{-1}; SB = 3 $cmol_c$ kg^{-1}; CTC = 3.6 $cmol_c$ kg^{-1}; P^{5+} = 7.43 mg kg^{-1} and OM = 0.6%.

Cultivation was in polyethylene pots with a capacity of 20 liters. Nonwoven geotextile fabric (Bidim OP 30) was placed at the bottom of each pot to prevent soil loss during drainage. Just above this covering, a 3cm layer of gravel was placed with another geotextile layer to facilitate water drainage. All the pots were then filled with 18.5 kg of air-dry soil. Sowing was carried out using four seeds per pot, with thinning performed 10 days after sowing, leaving one plant per pot.

Soil moisture was maintained at 100% and 50% of pot capacity (PC) for the treatments with no water stress and with water stress respectively. To do this, irrigation was carried out daily, and the amount of water for each pot was calculated by daily weighing.

The sesame cycle was divided into four phases, following the phenology of the crop (GRILO JÚNIOR; AZEVEDO, 2013), so that water stress be applied in the different phenological phases, namely: phase 1 (from germination to early vegetative growth - T1); phase 2 (vegetative growth to flowering - T2); phase 3 (flowering to pod formation - T3); and phase 4 (fruit maturation - T4). The control treatments were T5 (stress in all phases) and T6 (full irrigation).

At 90 days after sowing, the seeds were harvested and taken to the Seed Analysis Laboratory for processing and testing to evaluate their physiological quality. The tests were: 1) Germination (G%) - carried out with four replications of 50 seeds, with the counts being made at 3 and 6 days after sowing, following criteria set forth in the Regulations for seed Analysis (BRAZIL, 2009); 2) First Germination Count (FGC) - carried out together with the test for germination; 3) Germination Speed Index (GSI) - the seeds were evaluated daily until the last count (sixth day after sowing); and, 4) Mean Germination Time (MGT) - obtained by counting the germinated seeds daily until the sixth day after sowing.

To evaluate the seedlings, the following were determined: 1) Seedling Emergence (SE%) - carried out on four replications of 25 seeds, distributed in beds, 1 m wide by 9.60 m in length, with a spacing of 0.10 m between rows and 0.004 m between holes. The evaluations were made at 15 days after sowing (DAS) to determine the percentage of emerged seedlings; 2) Emergence Speed Index (ESI) - determined by observing the number of emerged seedlings daily until 15 DAS, being considered as emerged, those seedlings with open cotyledons and the stem axis in a vertical position; 3) Mean Time of Emergence (MTE) - obtained by counting the emerged seeds daily until 15 DAS; 4) Seedling Length (SL) - measurements were taken, with the aid of a rule graduated in centimeters, from the base of the stem to the insertion point of the last leaf originating from the apical meristem; 5) Seedling Dry Weight (SDW) - after taking the measurements, the seedlings from each treatment were placed into paper bags and kept in an oven set at 65 °C for 24 h and then weighed on a precision scale, the results being expressed in g.seedling^{-1}.

Seed vigor was in turn evaluated by the following tests: 1) Accelerated Aging (AA) - carried out as described by Marcos Filho (1999) but with one modification, the seeds from each treatment were placed into cloth bags. This modification was due to the seeds being small, i.e. smaller than the diameter of the holes in the aluminum screens present in the evaluation containers. The bags with the seeds were then distributed over the surface screen of plastic boxes containing 40 mL of distilled water. The boxes were maintained in a BOD chamber at 42 ºC for 48 hours. After this period, the germination test was carried out using four replications of 50 seeds. The count was taken at three DAS, counting the normal and abnormal seedlings and any non-germinated seeds. The results were expressed as a percentage, following criteria set forth in the Regulations for Seed Analysis (BRAZIL, 2009); 2) Electrical Conductivity (EC) - evaluation of electrical conductivity was carried out using four replications of 50 seeds per treatment. The seeds were placed into 200 ml plastic cups containing 75 ml of distilled water. The cups were kept at 25ºC for 24 h, and readings taken using a Marconi ® model MA-521 conductivity meter (VIEIRA; KRZYŻANOWSKI, 1999), the results being expressed in μS cm^{-1} g^{-1} seed.

The design was completely randomised, comprising six treatments, each with four replications. Analysis of variance was performed by F-test and, when significant, the Scott-Knott test at 5% was used to compare the means. Statistical analysis of the data was carried out with the aid of the Sisvar 5.0 statistical software (FERREIRA, 2008).

RESULTS AND DISCUSSION

There was a significant effect at a level of 1% from all the treatments under evaluation for each characteristic, indicating that the physiological quality of the seeds was affected by the water deficit during production (Table 1).

By means of percentage germination, it was possible to observe differences between seeds produced at the different stages of water deficit. It can be seen that when a deficit was caused in phase III (flowering to fruit maturation), the reduction was more intense, similar to that observed with the treatment subjected to water deficit throughout the cycle (T5), when compared to the other phases (Table 2). This result may be related to the fact that the phases of flowering and fruiting in most plants display the greatest levels of water consumption, with those phases being the most sensitive to a condition of water deficit. Similar results were found in a soybean crop, where the authors attributed the periods between R3 (beginning of vegetable formation) and R5 (beginning

Table 1 - Summary of the analysis of variance for the characteristics percentage germination (G%), first germination count (FGC), germination speed index (GSI) and mean germination time (MGT), in seeds of the sesame cv . BRS Seda from plants subjected to a water deficit in different phenological phases

SV	DF	MS			
		G(%)	FGC	GSI	MGT
Treatment	5	665.50**	1157.87**	80.34**	0.70**
Error	18	38.39	125.24	5.52	0.06
CV (%)		7.35	14.74	12.23	10.48
General Mean		84.25	75.67	19.21	2.25

** significant at 1%, * significant at 5% and ns - not significant of grain filling) as being the most critical to the crop as regards water deficit (RAMBO *et al*., 2002; RASSINI; LIN, 1981; TAVARES *et al.*, 2013).

For the variable first germination count, water deficit throughout the cycle and in phase I (from germination to the beginning of vegetative growth) resulted in a low percentage of normal seedlings, 57% and 59% respectively. This shows that the lack of water in the vegetative phase may compromise the yield and quality of the grain, mainly due to less vegetative development in the plants (MUNDSTOCK; THOMAS, 2005). However, when the water deficit occurs during fruit maturation (T4), no reduction in seed quality is seen (88% of normal seedlings) with the FGC test, a possible explanation being that the plants do not require high volumes of water as the fruits are already almost fully formed (Table 2).

From the germination speed index, it is possible to see in Table 2 that the seeds produced under full irrigation (T6) were more vigorous. According to Nakagawa (1999), the greater the value obtained for this variable, the higher the rate of germination and greater the vigor implied; whereas the seeds produced under a water deficit in phase I (germination to the beginning of vegetative growth) and with no irrigation (T5) displayed a reduced GSI, being considered less vigorous. From these results it can be inferred that such environmental conditions favor the expression of vigor in sesame seeds, perhaps by making better cell formation and the deposition of reserves possible (ZIMMER, 2012). Similar results were obtained by Koch *et al*. (2014), when studying the quality of soybean seeds both with and without irrigation.

Water deficit in the early stage of plant development resulted in seeds that took longer to germinate, having an MGT of three days. These results agree with the behavior seen for the GSI variable, which for this treatment had the lowest values, differing from the remaining treatments.

Table 3 presents a summary of the analysis of variance for the variables SE, ESI, MTE, AA, EC, SL and SDW. All treatments were significant at a level of 1% for the variables under study.

Table 2 - Results of the tests for first germination count (FGC), germination (G%), germination speed index (GSI) and mean germination time (MGT) in seeds of the sesame cv. BRS Seda from plants subjected to a water deficit in different phenological phases

Treatment	G (%)	FGC (%)	GSI	MGT (days)
(T1) Stress in phase I.	80.00 b	58.50 c	13.50 c	3.00 c
(T2) Stress in phase II.	97.00 a	88.50 a	22.70 a	2.00 a
(T3) Stress in phase III.	70.00 c	67.00 b	17.50 b	2.00 a
(T4) Stress in phase IV.	89.50 a	88.00 a	22.50 a	2.00 a
(T5) Stress throughout the cycle.	70.00 c	56.50 c	15.00 b	2.50 b
(T6) Full irrigation.	99.00 a	95.50 a	24.25 a	2.00 a

*Mean values followed by the same letter in a column do not differ at 5% by Scott-Knott test

Table 3 - Summary of the analysis of variance for the characteristics seedling emergence (SE%), emergence speed index (ESI), mean time of emergence (MTE), accelerated aging (AA), electrical conductivity (EC), seedling length (SL) and seedling dry weight (SDW) from seeds of the sesame cv. BRS Seda originating from plants subjected to a water deficit in different phenological phases

SV	DF	MS						
		SE	ESI	MTE	AA	EC	SL	SDW
Treatment	5	555.87**	16.93**	2.37**	1483.20**	215.42**	0.38**	0.004**
Error	18	29.29	0.57	0.14	179.73	27.18	0.05	0.001
CV (%)		6.00	10.12	11.40	20.95	3.27	7.58	13.53
General Mean		90.17	7.48	3.33	64	159.59	2.99	0.29

** significant at 1%, * significant at 5% and ns - not significant

Seedling emergence in a bed is of paramount importance in seed production programs, since this test approaches the reality of the field, where the seedlings are exposed to the conditions of weather and temperature of the growing region. According to Marcos Filho (1999), the test for seedling emergence constitutes a parameter for indicating the efficiency of tests that evaluate the physiological potential of the seeds.

For the variables SE, ESI and MGT, there was a reduction in the physiological quality of the seeds (Table 4) when comparing treatments T5 (stress throughout the cycle) and T6 (full irrigation). This result can be attributed to the occurrence of a water restriction during the development period of the seeds, which may have affected the deposition of reserves, the proper formation of cell membranes and the correct establishment of the hydrolytic enzyme system of the seeds (SILVA *et al*., 2010).

In this respect, the lower quality seen in seeds produced under restricted irrigation may be related to three main factors: 1) the need for more time to repair cell structures; 2) the slow recovery of enzyme activity; and 3) the decreased ability to remobilize assimilates (OLIVEIRA *et al*., 2012; ZIMMER, 2012), all a direct or indirect consequence of the growing environment.

As regards the results of the test for seedling emergence in beds, a reduction in this variable was only demonstrated for seeds produced under conditions of water stress throughout the cycle (T6), displaying 67% of emerged seedlings.

The data for the accelerated aging test, Table 4, show seeds produced by plants under a water deficit throughout the cycle as being less vigorous, displaying 32% of normal seedlings after the test. Stress in phase III (flowering to fruit maturation) and phase II (vegetative growth to flowering) also produced a lower percentage of normal seedlings (52% and 67% respectively). Such a result indicates that the physiological quality of the seeds decreased for the period of exposure to water stress.

This result may have a negative influence on the storage time of such seeds, as verified by Guarçoni *et al*. (2001), who found during storage that maize seeds were more affected when obtained from plants grown under water stress. The data from that study differ from those found by Tavares *et al*. (2013), who when working with soybean seeds under water deficit found that for the variable accelerated aging, there was no difference between treatments with or without water stress.

The values for vigor from the test for electrical conductivity ranged from 151.85 to 171.03 $\mu S.cm^{-1} g^{-1}$. When comparing the phases of water deficit, it can be seen that the deficits in phase III (flowering to fruit maturation) and throughout the cycle (T5) produced the less vigorous seeds, since a greater leaching of electrolytes (171 and 165 $\mu S.cm^{-1} g^{-1}$ respectively) were seen, whereas the other treatments displayed greater membrane integrity due to the low values for electrical conductivity, and so showed themselves to be more vigorous (Table 4).

For the variable SL, it can be seen that there was a difference between the phases of water stress. Seedling length ranged from 2.56 cm, obtained from seeds of the plants that were subjected to water stress throughout the cycle, to 3.41cm, from plants that had a water restriction during fruit maturation (Table 4). These results agree with those presented by Koch *et al*. (2014), who when studying the effect of irrigation on the physiological performance of soybean seeds found differences between treatments for the same variable.

For seedling dry weight, similar behavior was found to that seen for length, with T4 (water stress at fruit maturation) displaying the greatest weight (0.33 g) and differing from the other treatments.

Table 4 - Results of the tests for seedling emergence (SE%), emergence speed index (ESI), mean time of emergence (MTE), accelerated aging (AA), electrical conductivity (EC), seedling length (SL) and seedling dry weight (SDW) in seeds of the sesame cv. BRS Seda from plants subjected to a water deficit in different phenological phases

Treatment	SE (%)	ESI	MTE (days)	AA (%)	EC ($\mu S.cm^{-1} g^{-1}$)	SL (cm)	SDW (cm)
(T1) Stress in phase I.	96.00 a	7.18 b	3.5 b	71.0 a	160.20 a	2.90 b	0.29 b
(T2) Stress in phase II.	97.00 a	10.05a	2.5 a	67.0 b	153.90 a	2.84 b	0.28 b
(T3) Stress in phase III.	89.00 b	7.95 b	3.0 a	52.0 c	171.03 b	3.29 a	0.28 b
(T4) Stress in phase IV.	94.00 a	7.80 b	3.0 a	76.0 a	155.55 a	3.41 a	0.33 a
(T5) Stress throughout the cycle.	67.00 c	3.78 c	4.7 b	32.0 c	165.03 b	2.56 b	0.24 b
(T6) Full irrigation.	98.00 a	8.13 b	3.0 a	86.0 a	151.85 a	2.94 b	0.28 b

*Mean values followed by the same letter in a column do not differ at 5% by Scott-Knott test

Water restriction induces stomatal closure, limiting carbon dioxide input to the mesophyll cells of the leaves, and consequently, assimilation into the carbonated compounds destined to make up the seed reserves. Water deficit affects dry matter accumulation in seedlings, the level of tolerance to this abiotic factor being dependent on the genetic makeup of the individual plant (VIEIRA *et al*., 2013).

CONCLUSIONS

1. Sesame seeds from plants grown under water deficit have lower physiological quality;
2. The stages of crop development between germination and the start of vegetative growth, and between flowering and fruit formation, are more sensitive to water deficit, so that water limitation during these periods results in the production of seeds of inferior physiological quality.

REFERENCES

BRASIL. Ministério da Agricultura, Pecuária e Abastecimento. Secretaria de Defesa Agropecuária. **Regras para análise de sementes**. Brasília, DF: Mapa :ACS, 2009. 395 p.

COSTA, R. C. L. *et al*. Biochemical and physiological responses in two *Vigna unguiculata* (L.) Walp. cultivars under water stress. **Journal of Agronomy**, v. 7, n. 1, p. 98-101, 2008.

FERREIRA, D. F. Sisvar: um programa para análises e ensino de estatística. **Revista Symposium**, v. 6, n. 2, p. 36-41, 2008.

FREITAS, R. M. O. *et al.* Produção e qualidade de sementes de feijão-caupi em função de sistemas de plantio e estresse hídrico. **Pesquisa Agropecuária Tropical**, v. 43, n. 4, p. 370-376, 2013.

GRILO JUNIOR, J. A. S.; AZEVEDO, P. V. Crescimento, desenvolvimento e produtividade do gergelim BRS seda na agrovila de canudos, em Ceará Mirim (RN). **Revista HOLOS**, v. 2, n. 29, p. 19-33, 2013.

GUARÇONI, R. C. *et al*. Efeito do armazenamento na qualidade fisiológica das sementes de populações de milho cultivadas sob estresses hídrico e mineral. **Pesquisa Agropecuária Brasileira**, v. 36, n. 12, p. 1479-1484, 2001.

KOCH, F. *et al*. Efeito da irrigação no desempenho fisiológico e na atividade respiratória de sementes de soja. **Enciclopédia Biosfera**, v. 10, n. 19, p. 2936, 2014.

MAGALHÃES, I. D. *et al.* Viabilidade do consórcio mamona-gergelim para a agricultura familiar no semiárido paraibano: influência de diferentes épocas de plantio. **Revista Brasileira de Agroecologia**, v. 8, n. 1, p. 57-65, 2013.

MARCOS FILHO, J. Teste de envelhecimento acelerado. *In*: KRZYZANOWSKI, F. C.; VIEIRA, R. D.; FRANÇA NETO, J. B. **Vigor de sementes**: conceitos e testes. Londrina: ABRATES, 1999, p.1-24.

MUNDSTOCK, C. M.; THOMAS, A. L. **Soja**: fatores que afetam o crescimento e rendimento de grãos. Porto Alegre: Universidade Federal do Rio Grande do Sul, 2005. 31 p.

NAKAGAWA, J. Testes de vigor baseados no desempenho das plântulas. *In*: KRZYZANOWSKI, F. C.; VIEIRA, R. D.; FRANÇA NETO, J. B. **Vigor de Sementes**: conceitos e testes. Londrina: ABRATES, 1999. p. 2-24.

OLIVEIRA, A. B. *et al.* Seed priming effects on growth, lipid peroxidation and activity of ROS scavenging enzymes in NaCl-stressed sorghum seedlings from aged seeds. **Journal of Plant Interactions**, v. 7, n. 2, p. 151-159, 2012.

OLIVEIRA, A. B.; Gomes-Filho, E. Estabelecimento de plântulas de sorgo oriundas de sementes osmocondicionadas de diferentes qualidades fisiológicas. **Agrária**, v. 6, n. 2, p. 223-229, 2011.

PEDROSO, T. Q. *et al.* Qualidade de sementes de cafeeiro produzidas em diferentes densidades de plantio e regimes hídricos. **Coffee Science**, v. 4, n. 2, p. 155-164, 2009.

RAMBO, L. *et al.* Rendimento de grãos de soja e seus componentes por estrato do dossel em função do arranjo de plantas e regime hídrico. **Scientia Agrária**, v. 3, n. 2, p.79-85, 2002.

RASSINI, J. B.; LIN, S. S. Efeito de períodos de estiagens artificiais durante estádios de desenvolvimento da planta no rendimento e qualidade da semente de soja (*Glycine max* L.) Merrill. **Agronomia Sul Riograndense**, v. 17, n. 2, p. 225-237, 1981.

SILVA, J. B. *et al.* Efeito da irrigação sobre o potencial fisiológico de sementes de soja em semeadura de inverno. **Revista Brasileira de Sementes**, v. 32, n. 2, p. 73-82, 2010.

TAVARES, L. C. *et al.* Desempenho de sementes de soja sob deficiência hídrica: rendimento e qualidade fisiológica da geração F1. **Ciência Rural**, v. 43, n. 8, p. 1357-1363, 2013.

VIEIRA, F. C. F. *et al*. Aspectos fisiológicos e bioquímicos de cultivares de soja submetidos a déficit hídrico induzido por PEG 6000. **Bioscience Journal**, v. 29, n. 2, p. 543-552, 2013.

VIEIRA, R. D.; KRZYZANOWSKI, F. C. Teste de condutividade elétrica. *In*: KRZYZANOWSKI, F. C.; VIEIRA, R. D.; FRANÇA NETO, J. B. Vigor de sementes: conceitos e testes. Londrina: ABRATES, 1999. p.1, 4, 26.

ZIMMER, P. D. Fundamentos da qualidade de sementes. *In*: PESKE, S. T.; VILLELA, F. A.; MENEGHELLO, G. E. (Ed.). 3 ed. **Sementes**: fundamentos científicos e tecnológicos. Pelotas: UFPel, 2012. p.106-160.