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Physiological quality of white oat seeds at different temperatures

Qualidade fisiológica de sementes de aveia branca em diferentes temperaturas

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Highlights

The cultivars were affected by low temperature, with no germination at 15 ºC.
The seed vigor of the cultivars was lower at 30 ºC.
The seeds underwent less physiological changes at 25 ºC.
There was a reduction in vigor at 20 °C.
The final germination rate was similar for 20 and 25 ºC.

Abstract

White oats are cereals that are grown in different regions of the globe because they have good adaptability and final destination. Thus, their cultivation has shown significant increases in order to meet demand, especially for forage production, grains, and animal and human consumption. High-quality seeds are necessary for crop cultivation and white oats are sown in winter when thermal fluctuations may occur. Therefore, the objective of this study was to evaluate the physiological changes in oat seeds exposed to different temperatures during the germination phase. The experiment was a completely randomized design with four replications in a 6 × 4 factorial design. Six cultivars were evaluated: Aphrodite, Altiva, Artemis, Brava, Corona, and Guará at temperatures of 15, 20, 25, and 30 °C, and the following measurements were taken: first germination count, germination, germination speed index (IVG), and seedling length and mass. The results were analyzed using analysis of variance (F test) and the means were compared using Tukey's test. The cultivars were physiologically affected at the minimum and maximum temperatures. At 15 °C, normal seedlings did not form, whereas the highest germination values were recorded at 20 and 25 ºC, which showed that these temperatures were the most favorable temperatures for the germination process. Vigor declined at 30 °C and there was a greater number of abnormal seedlings and dead seeds.
Key words: *Avena sativa* L. Physiological quality. Vigor.

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Resumo

A aveia branca é um cereal cultivado em diversas regiões do mundo, pois possui boa adaptabilidade e destino final, de modo que seu cultivo tem apresentado acréscimos significativos visando atender a demanda, com destaque para produção de forragem, grãos e alimentação animal e humana. O uso de sementes de alta qualidade é necessário para a formação da lavoura. O cultivo acontece no inverno e ocorrem oscilações térmicas durante a implantação da cultura, sendo assim, o objetivo do presente trabalho foi avaliar as alterações fisiológicas em sementes de aveia expostas a diferentes temperaturas durante a fase de germinação. O experimento foi disposto em delineamento inteiramente casualizado, com quatro repetições, em fatorial 6 × 4. Foram avaliadas seis cultivares, Afrodite, Altiva, Artemis, Brava, Corona e Guará nas temperaturas 15, 20, 25 e 30 °C por meio de testes de primeira contagem de germinação, germinação, índice de velocidade de germinação (IVG), comprimento e massa seca de plântulas. Os resultados foram submetidos à análise de variância (teste F) e as médias comparadas pelo teste Tukey. As cultivares foram afetadas fisiologicamente nas temperaturas mínima e máxima. A 15 °C não houve formação de plântulas normais. A 20 e 25 ºC foram obtidos os maiores valores de germinação, mostrando-se, portanto, como temperaturas mais propícias ao processo germinativo. A 30 °C, o vigor foi reduzido, apresentando ainda uma tendência de maior número de plântulas anormais e sementes mortas.
Palavras-chave: *Avena sativa* L. Qualidade fisiológica. Vigor.

Introduction

White oats (*Avena sativa* L.), a cereal belonging to the Poaceae family and are grown in different regions across the globe, such as northwest Europe, Latin America, and Iceland, because they are highly adaptable. However, their culture is influenced by environmental conditions, which means that it is important to grow them in suitable edaphoclimatic regions. These regions have an altitude of up to 1,000 m, rainfall between 600 and 800 mm per year, and an average temperature of 23 °C (Castro, Costa, & Ferrari, 2012).

White oats are an important alternative agricultural crop and can be used as forage, grains, and in animal and human foods because they have a unique chemical and structural composition among cereals (Crestani et al., 2010). They are also used in succession and crop rotations, and have an important role in areas that have adopted the no-till system because their straw and root system have properties that restore the soil and improve its physical, chemical, and biological characteristics (Tunes et al., 2013).

In Brazil, the cultivation of oats for grain production began in the 1960s and 1970s, and the cultivated area has increased to approximately 398,000 hectares. Rio Grande do Sul is the main producing state for white oats, with approximately 271,000 hectares and an estimated productivity of 2,452 kg ha^{-1} (Companhia Nacional de Abastecimento [CONAB], 2020). In Paraná, the area cultivated in the 2019 harvest was 89,600 hectares, representing an increase of 12% compared to the previous harvest. Paraná produced 1,889 kg ha^{-1} in 2019 with a final production of 169,300 tons, which was 9% more than the 2018 harvest (CONAB, 2020).

We investigated the cultivars IPR Afrodite and IPR Artemis, which were developed in Paraná, and URS Altiva, URS Brava, URS Corona, and URS Guará, which were developed in Rio Grande do Sul. These cultivars have unique genetic characteristics that differentiate them, and these should be considered when selecting seeds of high physiological quality for cultivar reproduction and when attempting to obtain seeds with adequate physiological potential (Nerling, Coelho, & Nodari, 2013).

The quality of the seeds is expressed by their genetic, physical, physiological, and sanitary attributes, which are some of the main factors that affect the formation and quality of the crop. They also influence their ability to produce plants with high productivities (Marcos, 2015). Among these attributes, it is essential to evaluate the physiological potential of the seeds through germination and vigor tests because these tests can identify lots with different performances under different environmental conditions (Sponchiado, Souza, & Coelho, 2014) and temperature fluctuations.

Temperature is one of the factors that affects seed germination. It has a great influence on the germination final percentage and speed, and the biochemical reactions that regulate the metabolism necessary to start the germination process (Carvalho & Nakagawa, 2012). The ideal thermal amplitude is the interval between the minimum, optimum, and maximum temperatures, within which the germination process takes place in a short space of time (Marcos, 2015).

It is known that the ideal temperature range for the germination of white oat seeds is between 20 and 25 °C (Penning de Vries, Jansen, Tem Berge, & Bakema, 1989). However, further studies on the temperatures at which germination may occur and the special care requirements regarding the physiological changes that can occur in the seeds are necessary because of the possible oscillations that may occur during implantation of the crop. In addition, demand for this information is growing due to white oat expansion across other regions, such as the central west of Brazil, which has a hotter climate.

Thus, the objective of this study was to evaluate the physiological changes in oat seeds exposed to different temperatures during germination.

Material and Methods

The experiment was arranged in a completely randomized design with four replications in a 6 × 4 factorial design. The cultivars IPR Afrodite, IPR Artemis, URS Altiva, URS Brava, URS Corona, and URS Guará were used. They were produced in Paraná and have different genetic characteristics. The cultivars were evaluated at 15, 20, 25, and 30 °C and the first germination count, germination, germination speed index (IVG), seedling length, and dry mass were evaluated.

For the germination test, four repetitions of 100 seeds were placed between germitest paper moistened with distilled water at a proportion of 2.5 × the dry paper mass. Rolls were made and taken to the germinator at the indicated temperatures. The rolls were exposed to a 12-hour photoperiod. The first germination count was performed on the fifth day after the test was installed to quantify seed vigor, and the number of normal seedlings was recorded. A second, count took place on the tenth day when the final number of normal seedlings, abnormal seedlings, and dead seeds were recorded (Ministério da Agricultura, Pecuária e Abastecimento [MAPA], 2009).

The germination speed index (IVG) was determined using a germination test. There were daily counts of the number of germinated seeds until the final count. Seeds that had a primary root of at least 2 mm in length were considered to have germinated (Maguire, 1962).

For the seedling length test, rolls containing 10 seeds were made, which were then distributed on the upper third of germitest paper that had previously been moistened as described for the germination test. The rolls were placed in a germinator at the indicated temperatures, and the evaluation was carried out on the seventh day after installation of the test. The seedling length was determined according to Nakagawa (1999) using a graduated ruler to measure the length of the primary root and the aerial part.

The dry mass was determined using the seedlings from the previous test after removing any remnants of the reserve tissue. The seedlings were packed in paper bags, and kept in an oven with forced air circulation at a temperature of 65 °C for 48 h. After this period, the samples were immediately weighed using an analytical balance. The results were expressed in mg seedling^{-1} (Nakagawa, 1999).

The data were subjected to analysis of variance (F test) performed using a 6 × 4 factorial scheme (cultivars × temperatures) and the averages were compared using Tukey's test at 5% probability. All the statistical tests were performed using the SISVAR version 5.3, statistical program (Ferreira, 2011).

Results and Discussion

The analysis of variance results for the variable first count (Table 1) showed that cultivar, temperature, and the interaction cultivar × temperature were significant at the 1% probability level. The cultivars Afrodite, Altiva, and Artemis were not significantly different between 20 and 25 °C. At 30 °C, the cultivars with the highest first counts were Aphrodite and Altiva, but they did not differ from each other.

Table 1
First germination count (%) of the oat cultivars at different temperatures

Cultivars	First Germination Count (%)			
	Temperature (ºC)			
	15	20	25	30
Afrodite	0 Ca	66 Ba	86 Aa	59 Ba
Altiva	0 Ca	57 Bab	86 Aa	55 Bab
Artemis	0 Da	62 Ba	83 Aa	40 Cbc
Brava	0 Ca	43 Bb	64 Ab	40 Bbc
Corona	0 Da	15 Cc	64 Ab	38 Bc
Guará	0 Ca	44 Ab	53 Ab	17 Bd
Cultivar (C)	28,8**			
Temperature (T)	360,1**			
C x T	7,2**			
CV %	19,22			

Averages followed by the same lowercase letter in the column and uppercase letter in the row do not differ from each other according to the Tukey test. Fc: calculated F value; CV: coefficient of variation; **: significant at 1% probability.

The results for cultivars differences at each temperature (Table 1) showed that all cultivars performed better at 25 °C, except Guará, where there was no difference in the results compared to when the temperature was 20 °C. There was a reduction in seed vigor of the cultivars Afrodite, Altiva, Artemis, Brava, and Corona at 20 and 30 °C, and in Guará at 30 °C compared to 25 °C.

Seed vigor is characterized by the sum of attributes that make it possible for rapid and uniform emergence when normal seedlings are subjected to a wide variety of environmental conditions, including optimal conditions and under stress (França, Krzyzanowski, & Henning, 2011).

There was no seed germination up to the fifth day for the cultivars evaluated at 15 °C. Bewley, Bradford, Hilhorst and Nonogaki (2013) stated that the speed of germination is sensitive to variations in temperature. The 15 °C temperature probably compromised the development of the embryo growth process, thus reducing the speed of germination.

For germination, the analysis of variance results (Table 2) were similar to the first count results with a significant effect at 1% probability for cultivar, temperature, and the interaction cultivar × temperature. There was no difference between the cultivars at 20 °C, but at 25 °C, Guará showed the lowest percentage germination (78%). At 30 °C, the cultivar Afrodite showed the best germination result (83%). The germination rates for cultivars Artemis, Corona, and Guará were 52%, 49%, and 42%, respectively, and there was no significant differences among them.

Regarding the cultivar split at each temperature (Table 2), the cultivars Afrodite, Altiva, Artemis, Brava, and Corona did not differ at 20 °C and 25 °C. There was a decrease in the germination percentage for all cultivars at 30 °C, and Aphrodite, Altiva, and Brava produced the best results. In general, vigor and germination were greater at 25 °C.

Table 2
Germination test (%) results for the oat cultivars at different temperatures

Cultivars	Germination (%)			
	Temperature (ºC)			
	15	20	25	30
Afrodite	0 Ca	90 Aa	96 Aa	83 Ba
Altiva	0 Ca	90 Aa	94 Aa	78 Bab
Artemis	0 Ca	93 Aa	93 Aa	52 Bc
Brava	0 Ca	94 Aa	90 Aab	70 Bb
Corona	0 Ca	84 Aa	80 Abc	49 Bc
Guará	0 Da	92 Aa	78 Bc	42 Cc
Cultivar (C)	17,1**			
Temperature (T)	1.212,2**			
C x T	7,6**			
CV %	9,85			

Averages followed by the same lowercase letter in the column and uppercase letter in the row do not differ from each other according to the Tukey test. Fc: calculated F value; CV: coefficient of variation; **: significant at 1% probability.

The cultivar Guará (Table 2) showed a decrease in germination as the temperature increased. The germination rates were 92% at 20 °C, 78% at 25 °C, and 42% at 30 °C. The studied cultivars have different genetic characteristics, which means that temperature has a greater influence on some of the cultivars compared to the others. According to Martins, Silva, Silva and Oliveira (2007), high temperatures can cause loss of seed viability and thermal dormancy through the stress caused. Silveira, Negreiros and Fernandes (2004) found that a temperature of 35 °C completely inhibited the germination of *Marcetia taxifolia* seeds.

There was no development of normal seedlings (Table 2) at 15 °C in the period described by the Rules for Seed Analysis. Germination tests were performed in the germinator at 15 °C for another 6 days. At the end of the sixteenth day, they were evaluated and the results showed that normal seedlings had formed with roots and shoots, but with reduced size and vigor.

Guan, Hu, Wang and Shao (2009) observed that low temperatures stimulated damage to the cell membrane, which affected plant physiological functions, such as preventing or delaying germination, and made seeds more susceptible to adverse factors. Sbrussi and Zucareli (2014) found that low temperatures delayed the germination of seeds, especially those with low vigor. They reported that corn seeds did not germinate at 16 °C.

The analysis of variance results for the number of abnormal seedlings and dead seeds (Table 3) showed that cultivar, temperature, and the interaction cultivar × temperature were significant at 1% probability. At 20 °C, the cultivar Brava produced a lower number of abnormal seedlings, and was significantly different from the cultivars Altiva and Corona, which produced the highest number of abnormal seedlings. The Aphrodite cultivar produced the lowest number of abnormal seedlings at 25 and 30 °C, but was not significantly different from Artemis at 30 °C.

The differences among the cultivars at each temperature (Table 3) showed that all the cultivars produced a larger number of abnormal seedlings at 30 °C. The semi-permeability of membranes is lost at higher temperatures because of the inability to recover functions due to the disorganization of the lipoprotein bilayer. Elevated temperatures can also be harmful to the germination of some species because the proteins essential for the germination process become denatured (Flores, Borges, Guimarães, Ataíde, & Castro, 2014), resulting in plant development abnormalities.

Abnormal seedlings are those that do not show the potential to continue their development and give rise to normal plants, even when grown under favorable conditions (MAPA, 2009). At 20 °C (Table 3), there was a lower incidence of abnormal seedlings for all the cultivars studied, which corroborated the high germination percentage that was obtained at the same temperature.

Table 3
Germination test results for the oat cultivars at different temperatures, evaluated using the percentage numbers of abnormal seedlings and dead seeds

Abnormal Seedlings (%)				
Cultivars	Temperature (ºC)			
	15	20	25	30
Afrodite	0 Ca	6 BCab	1 ABb	8 Ac
Altiva	0 Ca	7 Ba	6 Bab	16 Aab
Artemis	0 Ca	4 ABab	3 ABab	7 Ac
Brava	0 Ba	0,5 Bb	3 Bab	10 Abc
Corona	0 Ca	9 Ba	7 Ba	20 Aa
Guará	0 Ba	4 Bab	4 Bab	20 Aa
Cultivar (C)	12,5**			
Temperature (T)	104,9**			
C x T	4,5**			
CV (%)	48,02			
Dead Seeds (%)				
Cultivars	Temperature (ºC)			
	15	20	25	30
Afrodite	0 Ba	5 Aba	4,5 Bb	14 Acd
Altiva	0 Aa	3,5 Aa	1,5 Ab	8 Ad
Artemis	0 Aa	2,5 Aa	3 Ab	7,5 Ad
Brava	0 Ba	5 Ba	6 Bb	19 Abc
Corona	0 Ca	5,5 BCa	9,5 Bab	29 Aab
Guará	0 Ca	3,5 Ca	18 Ba	38 Aa
Cultivar (C)	13,0**			
Temperature (T)	64,3**			
C x T	5,2**			
CV (%)	66,46			

Averages followed by the same lowercase letter in the column and uppercase letter in the row do not differ from each other according to the Tukey test. Fc: calculated F value; CV: coefficient of variation; **: significant at 1% probability.

For the variable dead seeds (Table 3), there was no significant difference between the cultivars at 20 °C. There were more dead Guará seeds at 25 and 30 °C and this result differed from all the other cultivars, except Corona. There was a lower number of Altiva dead seeds at 30 °C. This result was not significantly different from the cultivars Artemis and Afrodite, but was significantly different from the cultivars Brava, Corona, and Guará.

There were more dead Afrodite, Brava, and Corona seeds at 30 °C than at 20 and 25 °C, The results showed that 38% of the Guará seeds were dead at 30 °C, 18% at 25 °C, and 3.5% at 20 °C, which is in agreement with the germination test results (Table 2).

The analysis of variance results for the germination speed index (IVG) (Table 4) showed that the cultivar and temperature factors, and the cultivar × temperature interaction were significant at 1% probability. The cultivars did not differ within 5 °C. However, all the cultivars at 15 °C, with the exception of Guará, showed lower germination speeds compared to the other temperatures. Although the germination process took place, a temperature of 15 °C inhibited the development of the germination process, preventing the formation of normal seedlings during the evaluation period.

Table 4
Germination speed indexes of the oat cultivars at different temperatures

Cultivars	Germination Speed Index			
	Temperature (ºC)			
	15	20	25	30
Afrodite	10,6 Ca	62,3 Ba	77,0 Aa	61,7 Ba
Altiva	11,7 Ca	56,6 Bab	74,2 Aab	62,3 Ba
Artemis	10,5 Ba	67,3 Aa	74,6 Aab	67,7 Aa
Brava	7,1 Ca	48,1 Bb	64,0 Abc	47,5 Bb
Corona	6,8 Da	22,4 Cc	53,5 Acd	39,8 Bb
Guará	10,3 Ba	49,3 Ab	45,4 Ad	21,1 Bc
Cultivar (C)	53,83**			
Temperature (T)	387,01**			
C x T	9,78**			
CV %	13,54			

Averages followed by the same lowercase letter in the column and uppercase letter in the row do not differ from each other according to the Tukey test. Fc: calculated F value; CV: coefficient of variation; **: significant at 1% probability.

The cultivars Afrodite, Altiva, and Artemis had the highest germination speeds (Table 4) at 20, 25, and 30 °C, but there were no differences among them at the same temperatures. Temperature affects the speed of water absorption by seeds and causes a delay in germination. Temperatures above or below the optimum reduce the speed of germination and expose the seeds to adverse factors for a longer time, which can lead to a reduction in the total germination (Carvalho & Nakagawa, 2012).

With regard to the spread of the germination speed indexes for the cultivars at each temperature (Table 4), it was noted that the best germination speed indexes for Aphrodite, Altiva, Brava, and Corona were recorded at 25 °C. The cultivar Artemis did not differ between 20, 25, and 30 °C, and Guará did not differ between 20 and 25 °C.

According to the Maguire (1962) germination speed index, the higher the value obtained, the higher the germination speed, and consequently, the greater the vigor of the lot since the calculated index estimates the average number of normal seedlings per day.

The analysis of variance results for the shoot and root lengths (Table 5) showed that there was a significant effect of cultivar, temperature, and the interaction cultivar × temperature for both variables. For shoot length, the cultivars Artemis and Guará did not differ at the 20 and 25 °C temperatures, and they were the cultivars that showed best results at these temperatures. At 30 °C, the cultivar Guará differed from all other cultivars, with the highest average of 14.33 cm.

The seedling length test aims to measure seed vigor by determining the average length of normal seedlings. More vigorous seeds mobilize the storage tissue reserves for the embryonic axis more efficiently, which favors the rapid growth of seedlings (Marcos, 2015).

For the variable root length, the cultivar Artemis stood out at 25 °C because it had the best average and differed from Brava, Corona, and Guará. The cultivars Artemis and Brava did not differ at 30 ºC and had averages of 17.74 and 18.13 cm, respectively.

Regarding the cultivar split at each temperature (Table 5), the average aerial part length did not significantly differ among cultivars at 25 and 30 °C, with the exception of Guará at 30 °C. However, the aerial lengths at 20 °C for all the cultivars were significantly longer than their aerial lengths at 25 °C and 30 °C. There were no significant differences in the root lengths at 20, 25, and 30 °C for the cultivars Afrodite, Altiva, and Guará.

Regarding the dry mass averages (Table 6), the cultivar and temperature factors were significantly different at 1% probability, while the cultivar × temperature interaction was significant at 5% probability. There was no statistical difference between the cultivars at 20 °C. However, at 25 °C, the cultivar with the largest amount of dry matter was Altiva, whereas it was Corona at 30 °C.

Table 5
Shoot length (cm) and root length (cm) results for the oat cultivars at different temperatures

Aerial Part Length (cm)				
Cultivars	Temperature (ºC)			
	15	20	25	30
Afrodite	0 Ca	7,24 Bb	9,12 Ad	8,51 Abc
Altiva	0 Ca	7,54 Bb	11,27 Abc	10,35 Ab
Artemis	0 Ca	10,24 Ba	12,19 Aab	11,39 ABb
Brava	0 Ca	6,80 Bb	10,30 Acd	10,10 Abc
Corona	0 Ca	7,73 Bb	10,99 Abc	11,40 Ab
Guará	0 Ca	11,01 Ba	13,08 Aa	14,33 Aa
Cultivar (C)	32,1**			
Temperature (T)	898,7**			
C x T	5,1**			
CV (%)	11,22			
Root Length (cm)				
Cultivars	Temperature (ºC)			
	15	20	25	30
Afrodite	0 Ba	15,24 Aa	16,84 Aab	16,16 Aab
Altiva	0 Ba	14,18 Aa	16,70 Aab	15,30 Aab
Artemis	0 Ca	15,72 Ba	18,60 Aa	17,74 Aba
Brava	0 Ca	15,97 Aba	14,89 Bbc	18,13 Aa
Corona	0 Ca	10,26 Bb	12,86 ABc	14,14 Ab
Guará	0 Ba	14,51 Aa	14,69 Abc	15,26 Aab
Cultivar (C)	10,9**			
Temperature (T)	608,1**			
C x T	2,49**			
CV (%)	13,31			

Averages followed by the same lowercase letter in the column and uppercase letter in the row do not differ from each other according to the Tukey test. Fc: calculated F value; CV: coefficient of variation; **: significant at 1% probability.

Table 6
Dry mass of the oat cultivar seedlings at different temperatures

Cultivars	Dry Mass (mg seedling^{-1})			
	Temperature (°C)			
	15	20	25	30
Afrodite	0 Ba	10,0 Aa	10,9 Aab	8,97 Ac
Altiva	0 Ca	10,1 Ba	13,2 Aa	12,2 ABab
Artemis	0 Ba	10,5 Aa	11,7 Aab	10,8 Abc
Brava	0 Ba	10,2 Aa	10,0 Ab	10,7 Abc
Corona	0 Ca	10,6 Ba	12,5 ABab	13,5 Aa
Guará	0 Ba	11,3 Aa	11,7 Aab	13,3 Aab
Cultivar (C)	4,93**			
Temperature (T)	452,97**			
C x T	2,00*			
CV %	15,42			

Averages followed by the same lowercase letter in the column and uppercase letter in the row do not differ from each other according to the Tukey test. Fc: calculated F value; CV: coefficient of variation; **: significant at 1% probability; *: significant at 5% probability.

As for the cultivar split at each temperature (Table 6), the results showed that Aphrodite, Artemis, Brava, and Guará did not differ between 20, 25, and 30 °C, and Corona had the highest dry mass at 30 °C.

Conclusion

The cultivars were physiologically affected at the minimum and maximum temperatures. Normal seedlings did not form at 15 °C and the highest germination values were recorded at 20 and 25 °C which showed that these were the most favorable temperatures for the germination process. At 30 °C, the vigor declined and there were a greater numbers of abnormal seedlings and dead seeds.

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