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Physiological and biochemical potential of wheat seeds produced in different brazilian states

Potencial fisiológico e bioquímico de sementes de trigo produzidas em diferentes estados do Brasil

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ABSTRACT

The objective of this work was to evaluate the physiological and biochemical performance of wheat seeds produced in different locations in Brazil. This study was conducted in a randomized block design with 11 treatments and three replications. The analysis of variance revealed significance for the Germination (G), Germination Speed (GS), Accelerated Aging (AA), Root Length (RL), Emergence Speed (ES), Seedling Length (SL), Thousand Seed Mass (TSM), Hectolitre Weight (HW), Leaf Area (LA) and the content of Protein (PTN), Lipids (LIP), Crude Fiber (FB), Ashes (CNZ), Starch (AMD), Total Carbohydrates (CT), and Non-fibrous Carbohydrates (CNF). The seeds of the cultivar TBIO Audaz originated from Brasília presented superior quality, with higher vigor in the accelerated ageing test, shoot length and emergence speed. It was also the cultivar with the highest starch content. Among the studied material, it is verified that regardless of the cultivar and local of wheat seeds production there is a positive association between the biochemical and physical attributes that influence the physiological quality of seeds, standing out the starch, fiber content and mineral material, as well as the thousand seeds mass, germination, vigor, and seedling length.

Keywords: *Triticum aestivum* L.; seed production; physiology and storage.

RESUMO

O objetivo deste trabalho foi avaliar o desempenho fisiológico e bioquímico de sementes de trigo produzidas em diferentes estados do Brasil. Este estudo foi conduzido em delineamento de blocos casualizados com 11 tratamentos dispostos em três repetições. A análise de variância revelou significância para Germinação (G), Velocidade de germinação (GS), Envelhecimento acelerado (AA), Comprimento da raiz (RL), Velocidade de emergência (ES), Comprimento da plântula (SL), Massa de mil sementes (TSM), Peso hectolitro (HW), Área foliar (LA), Teor de proteína (PTN), lipídios (LIP), fibra bruta (FB), cinzas (CNZ), amido (AMD), carboidratos totais (CT) e carboidratos não fibrosos (CNF). As sementes da cultivar TBIO Audaz oriundas de Brasília apresentaram qualidade superior, com maior vigor no teste de envelhecimento acelerado, comprimento da parte aérea e velocidade de emergência, sendo também a cultivar com maior teor de amido. Dentre os materiais estudados, verifica-se que independente da cultivar e local de produção das sementes de trigo existe uma associação positiva entre os atributos bioquímicos e físicos que influenciam na qualidade fisiológica do trigo, destacando-se o teor de amido, fibra e material mineral, bem como - massa de mil sementes, germinação, vigor e comprimento de plântulas.

***Palavras-chave**: Triticum aestivum L.; produção de sementes; fisiologia e armazenamento de sementes.*

1. INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the most produced cereals in the world. The Brazilian area for wheat farming is of around 3.031 million hectares (CONAB, 2022) with production concentrated mainly in the southern Brazilian states of Rio Grande do Sul, Paraná, and Santa Catarina. The improvement of wheat genotypes that are more adaptable to these production sites and that produce seeds with better quality stands out as one of the practices for the development of the wheat production chain in Brazil. (MACHADO *et al.*, 2018).

The use of high-quality seeds positively impacts the crop’s initial stand per hectare and its yield components. (PRANDO *et al.*, 2012). In addition, to achieve high yields, it is necessary to consider other factors such as the ideal sowing season, production site, and adequate cropping management practices. (KOCH, 2012). For the seed to express its productive potential it must detain high physiological, physical, genetic, and sanitary attributes. (CARVALHO; NAKAGAWA, 2012).

The physiological quality of the seeds is closely associated with environmental conditions. (KAPPES *et al*., 2009). The greatest physiological quality is reached at the point of physiological maturity when maximum vigor, germination, and dry mass content are obtained. (MARCOS FILHO, 2015). Thereafter, seeds are exposed to environmental conditions and enter a deterioration process involving physiological, physical, and biochemical attributes. (KRZYZANOWSKY *et al*., 2008). Germination and vigor are among the physiological attributes that determine the initial performance and storage potential of the seeds. (SMANIOTTO *et al*., 2013).

The development of cultivars adapted to the edaphoclimatic conditions found in southern Brazilian States, and the need of cold conditions for a better development of the crop, explains why these states detain the largest areas for its cultivation. Wheat is one of the best alternatives for extra income for farmers during winter. It is also fundamental to maintain the no-tillage system, serving as a cover crop to soils. (KOCH, 2015).

However, during the past few years, wheat cultivation has expanded to the Central-west, and Southeast regions of Brazil as an alternative to increase its area of cultivation. (SANTOS, 2008). Favorable climatic conditions with abundant solar radiation and flat lands, place the Brazilian “Cerrado” as the perfect alternative to increase the amount of farming land for the insertion of new crops, among them, wheat. The development of cultivars adapted to these “new areas” and the intensive soil management of these areas allowed the expansion of wheat to “Cerrado”. (PIETRO-SOUZA *et al*., 2013). In this context, the purpose of this work was to evaluate the physiological and biochemical performance of wheat seeds produced in different locations in Brazil.

2. DEVELOPMENT

2.1. MATERIAL AND METHODS

The seed quality evaluation was conducted at the Seed Analysis Laboratory and the experimental area of the Eliseu Maciel College of Agronomy of the Federal University of Pelotas (UFPel), located in Capão do Leão/RS (31º52'S and 52º21'E). Seeds of 7 wheat cultivars produced in different regions of Brazil were used (Table 1).

The characterization of the different environments where the seeds were grown was described according to the Köppen classification. The “Brasília region” fits in the Aw type, which characterizes this region as Tropical with a dry winter, an average annual rainfall of 1500 mm, and an altitude of 1100 m. The recommended sowing season for the dryland system is in February and for the irrigated system in April.

Table 1 – Production sites of wheat cultivars in the 2017 harvest season.

GROW CROPS	SITE	GEOGRAPHIC COORDINATES
Tbio Sintonia	Brasília	15° 46' 46'' S - 47° 55' 46'' O
Tbio Energia	Passo Fundo	28° 15' 46" S - 52° 24' 24" O
Tbio Sonic	Brasília	15° 46' 46'' S - 47° 55' 46'' O
BRS-264	Rio verde	17° 47' 53'' S - 50° 55' 41" O
Tbio Audaz	Rio verde	17° 47' 53'' S - 50° 55' 41" O
Tbio Sonic	Rio verde	17° 47' 53'' S - 50° 55' 41" O
Tbio Sintonia	Rio verde	17° 47' 53'' S - 50° 55' 41" O
Tbio Sintonia	Passo Fundo	28° 15' 46" S - 52° 24' 24" O
Tbio Audaz	Brasília	15° 46' 46'' S - 47° 55' 46'' O
Tbio Sossego	Passo Fundo	28° 15' 46" S - 52° 24' 24" O
Tbio Toruk	Passo Fundo	28° 15' 46" S - 52° 24' 24" O

Font: Authors.

The “Rio Verde region” fits the Aw type, characterized by tropical humid climates, with two well-defined seasons: dry in winters and humid in summers. An altitude of 760 m. The average annual temperature ranges between 20 °C to 25 °C. The soil of the experimental area was classified as dystrophic red Latosol. The recommended sowing season for this region is from April to May.

The “Passo Fundo region” has an average altitude of 684 m. This region fits the Cfa 1 type (subtropical and rainy). The soil of the region is classified as a typical dystrophic red oxisol with undulating relief and basalt substrate. The recommended sowing season for this region is from June to the second half of July.

Seed samples were collected in the same harvest season (2017) after field maturity and stored in a cold chamber for five months. To evaluate the physiological, physical, and biochemical attributes of the seeds, the following evaluations were performed:

Germination (G): Eight replicates of 50 seeds were used, distributed on germitest paper sheets moistened with distilled water with a volume of 2.5 times the dry weight of the paper sheets, placed in a germination chamber set at a constant temperature of 20 °C. Counts were made on the eighth day after sowing, and evaluations were performed according to the official method described in the “Regras para Análise de Sementes”. (BRASIL, 2009).

First Germination Count (FGC): Eight samples with eight subsamples of 50 seeds each were used. Seeds were arranged to germinate between two germitest paper sheets moistened with distilled water with a volume of 2.5 times the mass of the dry weight of the paper sheets. Paper sheets were rolled and placed in a germination chamber set at a constant temperature of 20 °C. Counts were performed on the fourth day after sowing, and the results were expressed as a percentage of normal seedlings. (BRASIL, 2009).

Germination Speed (GS): Obtained through eight samples with eight subsamples of 50 seeds each. Seeds were arranged to germinate between two germitest paper sheets moistened with distilled water with a volume of 2.5 times the mass of the dry weight of the paper sheets. Paper sheets were rolled and placed in a germination chamber set at a constant temperature of 20 °C. Counts were performed daily from the second to the eighth day after sowing. The formula used to calculate the germination speed was proposed by Edmond and Drapala (1958).

Accelerated Ageing (AA): Seeds were distributed on a fixed wire mesh and placed inside a gerbox containing 40 mL of saturated saline solution. (PEDROSO *et al.*, 2010). The saturated saline solution was composed of 11 grams of NaCl for each 100 mL of water. The Germboxes containing the seeds and the saline solution were kept in a BOD at 43 °C for a period of 48 h. (LIMA *et al.*, 2006). Thereafter, the seeds were arranged to germinate under the same conditions described for the Germination test. Evaluations followed the same reported for the Germination test.

Seedling Emergence (SE): Eight replicates of 50 seeds each were sown in a greenhouse. The evaluation was performed 21 days after sowing, and the results were determined as a percentage of seedling emergence. (NAKAGAWA, 1994).

Emergence Speed (ES): These assessments were performed in commercial fields by the evaluation of the emergence of the seedlings until their stabilization. Data were submitted to the Edmond and Drapala equation (1958).

Seedling Length (SL): Seeds were submitted to the adapted procedures of AOSA (1983) and Nakagawa (1999). Eight subsamples of 20 seeds were used. Seeds were arranged in the upper third of the germitest paper. Paper sheets were rolled and placed in a germination chamber set at a constant temperature of 20 °C for seven days. Thereafter, 10 random normal seedlings were collected (rejecting seeds from the border of the germitest), and the shoot and root length were measured with the help of a graduated ruler.

Thousand Seed Mass (TSM): Determined by measuring the mass of 8 randomly collected samples of 100 seeds each from the area of the experimental plot. Results were extrapolated to the mass of a one-thousand seeds and expressed in grams. (BRASIL, 2009).

Hectoliter Weight (HW): The hectoliter weight was determined on a hectoliter scale with a capacity of a quarter of a liter. The procedure was performed according to the “Regras para Análise de Sementes” (BRASIL, 2009), and the results were expressed in Kg hL^{-1}.

Chlorophyll (Cha and Chb): At twenty-one days after sowing, five plants were evaluated per repetition. Measurements were performed using the middle third of the third developed leaf with the aid of a CFL 1030 Falker digital chlorophyll meter.

Leaf Area (LA): Leaves were collected from 10 randomly selected plants per repetition 21 days after sowing. Leaf area was determined using a photoelectric determiner (LI-COR model LI-3100 Area meter) which gives a direct reading in cm^2.

Leaf Dry Mass (LDM): Leaf dry mass was obtained by the greenhouse method at 75 °C for 72 hours and then weighed on a precision scale. Results were expressed in grams.

Biochemical Composition: The content of protein (PTN), lipids (LIP), crude fiber (FB), ashes (CNZ), and starch (AMD) were determined by NIRS spectroscopy, brand FOSS DS2500 NIR (HillerØd, DK, Denmark), with a spectral reading range from 1100 to 2500 nm, and a reading range of 2 nm. The average reading time was of 40-45 seconds. Results were expressed as a percentage of the dry matter. To estimate the total carbohydrates (TC), the equation proposed by Sniffen *et al.* (1992) was used.

Isoenzymatic Expression: The enzymatic analysis was determined with a sample of 50 seeds. Seeds were macerated and the expression of isoenzymes esterase (ES), and glutamate oxalacetate - transaminase (GOT) was determined by the polyacrylamide vertical gel electrophoresis system. 200 mg of the macerated extract were placed in Eppendorf with the addition of the extraction solution (gel buffer - 0.15% 2-mercaptoethanol in 1:3 (w/v) proportion). The vertical electrophoresis system was mounted on 7% polyacrylamide gels, with 20 µL of the plant material (seeds), in holes made with the aid of an acrylic comb. The gels were conditioned in moving electrophoretic vats, kept at room temperature for two hours until the racing front was formed by bromophenol blue and reached nine centimeters from the application point. Isoenzymatic patterns were performed by the buffer system described by Scandalios (1969). The result interpretation was based on the visual analysis of the electrophoresis gels, considering the presence or absence, and the quantification of the bands performed using Gel-Pro Analyzer 3.1 software.

This study was conducted in a randomized block design with 11 treatments (Tbio Sintonia, Tbio Energia, Tbio Sonic, BRS-264, Tbio Audaz, Tbio Sonic, Tbio Sintonia, Tbio Sintonia, Tbio Audaz, Tbio Sossego, and Tbio Toruk) arranged in three replications. The data obtained in each evaluation were subjected to analysis of variance (5% probability). Significant variables were submitted to the Duncan test (5% probability). Later, the cultivars were submitted to canonical correlation analysis. For the establishment of the canonical groups, the results were separated into physiological, physical, and biochemical attributes. Each canonical group is composed of physiological attributes (G, FGC, GS, AA, SL, RL, FE, ES, ChA, ChB, LA, LDM), physical attributes (TSM and HW), and biochemical attributes (PTN, LPD, FB, CNZ, AMD, TC, CNF).

3. RESULTS AND DISCUSSION

The analysis of variance (Table 2) revealed a significant difference for G, GS, AA, TSM, ES, HW, LA, SL, RL, PTN, LIP, FB, CNZ, AMD, CT, and CNF. On the other hand, it did not show significance for the variables FGC, FE, ChA, and ChB among the different cultivars. Thus, it is observed that cultivars differ in their physiological, physical, and biochemical quality, requiring the unfolding of the main effects and correlation analyses for a greater inference of the interaction between physiological, physical, and biochemical attributes.

For the analysis of G (Table 3), the seeds of the cultivar Sintonia from Rio Verde presented a value of 97% as the highest percentage. The materials with the lowest germination percentage were from the cultivars Sossego and Toruk, both from Passo Fundo. It is important to highlight that the seeds of cultivars Sossego and Toruk produced in Passo Fundo reached values of 90%, that is, above the required for seed commercialization. Germination is a less sensitive attribute of seed quality compared to vigor; however, it can be influenced by the growing environment, genetics, or even field management. (FRANCESCHI *et al.*, 2010).

Table 2 – Analysis of variance for germination (G), first germination count (FGC), germination speed (GS), accelerated aging (AA), one thousand seed mass (TSM), field emergence (FE), emergence speed (ES), hectoliter weight (HW), leaf area (LA), shoot length (SL), root length (RL), leaf dry mass (LDM), Chlorophyll A (ChA), chlorophyll (ChB), Protein (PTN), Lipid (LIP), Crude Fiber (FB), Ash (CNZ), Starch (AMD), Total Carbohydrates (CT), and Non-fibrous Carbohydrates (CNF).

ANOVA								
PV	**GL**	**Mean square**						
		G	**FGC**	**GS**	**AA**	**FE**	**ES**	**TSM**
Treatment	10	24.1 *	19.42 ns	0.154 *	946.07 *	59.6 ns	0.918 *	141.7 *
Replicate	7th	5.5	14.64	0.042	31.86	27.52	0.098	0.36
Residue	858	9.77	25.1	0.02	28.625	60.39	0.108	0.56
CV%		3.2	5.5	5.17	6.5	9.6	8.5	2.2
		HW	**LA**	**SL**	**RL**	**LDM**	**Cha**	**Chb**
Treatment	10	163.21 *	17.01 *	43.4 *	164.1 *	0.0003 *	130.35 ns	2.38 ns
Replicate	7th	0.55	10.1	28.4	107.1	0.0001	310.2	21.85
Residue	858	0.44	0.76	6.7	14.7	0.00001	96.41	3.78
CV%		8.5	15.1	27.5	31.7	16.8	41.6	37.6
		PTN	**LIP**	**FB**	**CNZ**	**AMD**	**CT**	**CNF**
Treatment	10	5.59 *	0.13 *	0.06 *	0.02 *	4.2 *	7.24 *	9.9 *
Replicate	7th	0.02	0.001	0.001	0.005	0.13	1514.5	81.5
Residue	858	0.04	0.001	0.004	0.001	0.08	0.04	0.12
CV%		1.44	2.5	2.4	2.08	0.51	0.2	1.42

(1) Mean square: * and ns - significant at 5% probability and non-significant, respectively; CV - coefficient of variation; PV - variation points.

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Regarding the GS, it is noteworthy that seeds of the cultivar Audaz produced in Rio Verde presented lower GS values, indicating a smaller number of days required for germination. Higher germination velocity values show lower seed vigor besides, germination speed contributes to the initial performance of a seed lot. (OLIVEIRA *et al.*, 2009).

For SL and RL (Table 3), Toruk produced in Passo Fundo and Audaz produced in Brasilia are highlighted, as they presented an average of 10.6 and 10.3 cm of shoot. Meanwhile, the cultivar Sintonia, produced in the Brasilia region, reached a shorter length compared to the other cultivars. Toruk produced in Passo Fundo also stood out with higher root length compared to the others, in contrast to Sossego produced in the Passo Fundo region, which showed the lowest root length on average. The Toruk cultivar from Passo Fundo presented better initial growth performance than the other cultivars, being related to the genetic characteristics of this cultivar. The seedling length test is considered a test to differentiate vigor between similar lots (MARCOS FILHO *et al.*, 2009), being a complementary test that can be associated, and related to other vigor tests. (VANZOLINI *et al.*, 2007).

Table 3 – Mean results for the germination (G), germination speed (GS), accelerated aging (AA), one thousand seed mass (TSM), emergence speed (ES), hectoliter weight (HW), shoot length (SL), root length (RL), leaf dry mass (LDM) as a function of seeds studied; SBR (Tbio Sintonia; Brasilia), EPF (Tbio Energia; Passo Fundo), OBR (Tbio Sonic; Brasília), BRV (BRS-264; Rio Verde); ARV (Tbio Audaz; Rio Verde), ORV (Tbio Sonic; Rio Verde), SRV (Tbio Sintonia; Rio Verde), SPF (Tbio Sintonia; Passo Fundo), ABR (Tbio Audaz; Brasilia), GPF (Tbio Sossego; Passo Fundo), TPF (Tbio Toruk; Passo Fundo).

ITEM	G (%)	GS (days)	SL (cm)	RL (cm)	AA (%)	TSM (g)	HW (Kg hL^{-1})	ES (days)	LDM (g)
SBR	96 ab	2.6 de	8.2 e	12.2 bcd	84 cd	31.63 e	76.4 e	6.9 bcd	0.024 bcd
EPF	95 ab	2.9 ab	8.6 ed	13.5 ab	56 g	29.89 f	79.2 b	6.9 abc	0.02 cd
OBR	95 ab	2.8 bc	9.8 abc	13.1 bc	86 bcd	41.76 a	77.8 c	6.8 ecd	0.021 bc
BRV	94 ab	2.6 de	9.2 cd	11.1 ed	88 abc	33.31 c	72.8 f	6.4 f	0.018 e
ARV	94 abc	2.5 e	9.4 bcd	10.3 ef	90 ab	32.3 of	77.9 c	6.4 ef	0.02 bc
ORV	94 abc	2.8 bc	9.8 abc	12.4 bcd	86 bcd	41.16 a	77.7 c	6.7 cde	0.019 of
SRV	97 a	2.7 cde	9.2 cd	10.8 ef	84 cd	28.43 g	77.7 c	6.6 edf	0.017 f
SPF	96 ab	2.6 de	8.6 ed	12.7 bc	67 f	33.56 c	79.8 a	6.9 cd	0.017 f
ABR	95 ab	2.7 cde	10.3 ab	12 cd	94 a	32.91 cd	77.0 d	6.3 f	0.019 ed
GPF	91 c	3.04 a	9.04 cde	9.8 f	82 of	36.75 b	77.9 c	7.3 a	0.024 a
TPF	91 c	2.7 cde	10.6 a	14.5 a	78 e	33.68 c	76.4 e	7.3 ab	0.021 b
CV%	3.2	5.17	27.5	31.7	6.5	2.2	8.5	8.5	16.8

* Averages followed by the same lowercase letter in the column and uppercase in the row do not differ at a 5% probability level.

Font: Authors.

For the AA test (Table 3), more expressive results were obtained. Audaz produced in Brasilia had higher germination after the accelerated ageing compared to the others; Audaz produced in Brasilia also stood out with 94% germination, compared to 90% of the Audaz cultivar produced in Rio Verde, in contrast to the cultivar with the lowest value, the cultivar Tbio Energia from Passo Fundo, with 56% germination.

For the ES variable, Audaz from Brasilia presented the lowest days for emergence, which reflects a higher emergence speed, as well as the BRS-264 cultivar produced in Rio Verde which presented the lowest days for emergence for that location. The cultivars that presented a longer period to emerge were obtained by seedlings of the cultivars Sossego and Toruk, both produced in Passo Fundo, reflecting a lower emergence speed.

Audaz produced in Brasília stood out for the AA, SL, and ES variables. High vigorous seeds produce normal and healthy seedlings in a shorter time because they have a greater capacity to transform and use their reserves compared to seeds with low initial performance. (KOLCHINSKI *et al.*, 2006).

It was observed that for TSM the cultivar Sonic produced in Brasilia and Rio Verde presented the largest Thousand Seeds Mass with 41.7 and 41.1 grams, respectively, on the other hand, the cultivars Sintonia produced in the region of Rio Verde and Energia produced in Passo Fundo presented lower mass with 28.4 and 29.8 grams, respectively. Henning *et al.* (2010) state that seeds with higher mass present better initial performance because of stored reserves. However, it is also evident that the utilization of the reserves also maintains the metabolism, transport, and utilization of the compounds by the embryo.

For the HW significant variation between the cultivars was observed. The highest value for HW was found in Sintonia from Passo Fundo, in contrast, the lowest HW was seen for BRS-264 produced in Rio Verde. The cultivars with the highest TSM did not reflect this characteristic to the hectoliter weight, thus showing a low correlation of TSM vs. HW. Hectoliter weight, among other factors, depends on the cultivar and seed size. (ORMOND *et al*., 2013). Cultivars produced in different locations with higher HW did not present the highest percentage germination values after AA.

For the LDM (Table 3) and LA (Table 4), it can be observed that the cultivar Sossego produced in Passo Fundo had the best performance with an average of 0.024 g for the dry mass of leaves and 6.6 cm^2 of leaf area. The cultivars with the lowest performance for these variables were the cultivars Sintonia from Rio Verde and Sintonia produced in Passo Fundo with 0.017 g of LDM and 5 cm^2 of LA for both. The increase in dry mass is related to the increase in leaf area due to the production of photo-assimilates that are soon accumulated in different organs of the plant. (KOCH *et al*., 2015).

For the protein (Table 4), the highest content occurred in seeds of Sintonia produced in Rio Verde (16.7%), in contrast to Sonic produced in Rio Verde (12.2%), being the lowest of all. The cultivar Sintonia produced in Brasilia presented adequate protein content compared to other studies that measured the protein content of wheat seeds (GUTKOSKI *et al*., 2011). Protein accumulation and content are influenced by the growing environment and genotype, and the environment interaction. In addition, it maintains a relationship with the amount of nitrogen available to the plant. (FAVARATO *et al*., 2011).

Regarding the lipid content, Audaz produced in Brasilia (Table 4) showed higher lipid content at 1.98%, and Toruk from Passo Fundo and Sonic from Rio Verde presented the lowest lipid content at 1.26% and 1.42%, respectively. Deterioration during storage is related to oxidation processes (ORTOLAN *et al*., 2010), since both wheat seeds contain a low percentage of lipids it may have some effect on seed quality. (DELIBERALI *et al*., 2010).

For the FB content (Table 4), Sonic produced in Brasilia presented the highest value, reaching 2.8%. On the other hand, the cultivar with the lowest FB content was Audaz produced in Brasilia (2.3%). For ashes, the cultivar with the highest ash content was the cultivar Sintonia from Brasília (1.8%), whereas the cultivar Sonic from Rio Verde showed the lowest content, 1.52%. During wheat seed germination, ash content may increase because of a reduction in the total starch content. (CHAVAN; KADAN, 1989).

Table 4 – Mean results for Leaf Area (LA), Protein (PTN), Lipid (LIP), Crude Fiber (FB), Ash (CNZ), Starch (AMD), Total Carbohydrate (TC), and Non-fibrous Carbohydrate (CNF) according to the seeds studied; SBR (Tbio Sintonia; Brasilia), EPF (Tbio Energia; Passo Fundo), OBR (Tbio Sonic; Brasília), BRV (BRS-264; Rio Verde); ARV (Tbio Audaz; Rio Verde), ORV (Tbio Sonic; Rio Verde), SRV (Tbio Sintonia; Rio Verde), SPF (Tbio Sintonia; Passo Fundo), ABR (Tbio Audaz; Brasilia), GPF (Tbio Sossego; Passo Fundo), TPF (Tbio Toruk; Passo Fundo).

ITEM	LA(cm ^{2})	PT(%)	LIP (%)	FB (%)	CNZ (%)	AMD (%)	CT (%)	CNF (%)
SBR	5.9 c	16.7 a	1.76 cd	2.8 a	1.8 a	55.2 e	79.7 h	24.8 d
EPF	5.8 c	15 c	1.76 cd	2.5 ef	1.6 cd	56.4 cd	81.6 f	25.1 c
OBR	6.2 b	15.8 b	1.73 de	2.7 bc	1.7 a	56.2 d	80.7 g	24.4 d
BRV	5.8 c	14.8 c	1.68 e	2.6 cde	1.6 bc	56.7 cd	62.3 i	20.5 e
ARV	5.8 c	13.4 e	1.53 f	2.5 def	1.6 bcd	57.6 b	83.3 cd	25.7 c
ORV	5.7 c	12.2 f	1.42 g	2.6 bcd	1.5 e	56.4 cd	84.7 a	28.2 b
SRV	5.09 d	13.2 e	1.51 f	2.7 bc	1.6 b	54.2 f	83.5 bc	29.2 a
SPF	5.08 d	14.3 d	1.82 bc	2.4g	1.5 of	56.8 c	82.2 e	25.4 c
APR	5.3 d	13.4 e	1.98 a	2.3 g	1.5 e	58.7 a	81.6 d	24.3 d
GPF	6.6 a	15.7 b	1.87 b	2.4 fg	1.6 bc	56.4 cd	80.7 g	24.2 d
TPF	5.6 c	13.3 e	1.26 h	2.6 bcd	1.6 bcd	55.6 e	83.7 b	28.1 b
CV%	15.1	1.4	2.5	2.4	2.08	0.51	0.2	1.42

* Averages followed by the same lowercase letter in the column and uppercase in the row do not differ at a 5% probability level.

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For AMD (Table 4) Audaz produced in Brasilia stands out with a content of 58.7%. The seeds of Audaz produced in Rio Verde had the lowest average, with a content of 54.2%. Higher AMD contents may provide greater physiological potential in starchy seeds, besides providing longer storage time. (HENNING *et al.*, 2010).

For TC, Sonic from Rio Verde presented the highest value reaching 84.7% (Table 4), while the seeds of cultivar BRS 264 produced in Rio Verde presented the lowest value with 62.3%. For CNF, Sintonia produced in Rio Verde stands out with 29.2%, however, the lowest value was reached by cultivar BRS 264 also produced in Rio Verde (20.5%).

Linear correlations revealed significant differences with a 5% probability by the t-test (Table 5). Composed of all evaluated traits, it aimed to reveal the magnitude and meaning of the associations between physiological, physical, and biochemical traits of seeds of different wheat cultivars.

The linear correlation performed for 17 variables (Table 5) revealed 136 associations, with 33 significant ones. Regarding G, it was observed a negative correlation for ES (r = -0.29). Höfs (2004), in rice seeds, reports that the relationship between germination and emergence rate may be influenced by seed vigor, and different seedling emergence rates may occur for seeds with similar germination, but different levels of vigor.

For GS (Table 5) positive correlation coefficients were revealed with ES (r = 0.26), and HW (r = 0.21), while a negative correlation was encountered for AA (r = -0.28). Pedroso *et al.* (2010), observed that the seed vigor level is reduced when exposed to high temperatures and relative humidity.

Table 5 – Linear correlation between germination (G), first germination count (FGC), germination speed (GS), accelerated aging (AA), one thousand seed mass (TSM), field emergence (FE), emergence speed (ES), hectoliter weight (HW), leaf area (LA), shoot length (SL), root length (RL), leaf dry mass (LDM), Chlorophyll A (ChA), chlorophyll (ChB), Protein (PTN), Lipid (LIP), Crude Fiber (FB), Ash (CNZ), Starch (AMD), Total Carbohydrates (CT), and Non-fibrous Carbohydrates (CNF) as a function of the seeds studied.

Variables	GS	AA	SL	RL	TSM	ES	HW	LA	LDM	PTN	LIP	FB	CNZ	AMD	CT	CNF
G [1]	-0.1 ^{ns}	-0.01 ^{ns}	-0.02 ^{ns}	0.04 ^{ns}	-0.18 ^{ns}	-0.29 *	0.06 ^{ns}	0.05 ^{ns}	-0.10 ^{ns}	-0.03 ^{ns}	0.01 ^{ns}	0.25 ^{ns}	0.07 ^{ns}	0.06 ^{ns}	0.19 ^{ns}	0.15 ^{ns}
GS	.	-0.28 *	0.08 ^{ns}	0.10 ^{ns}	0.20 ^{ns}	0.26 *	0.21 *	-0.12 ^{ns}	0.13 ^{ns}	0.18 ^{ns}	0.26 ^{ns}	-0.13 ^{ns}	-0.11 ^{ns}	0.13 ^{ns}	-0.06 ^{ns}	-0.16 ^{ns}
AA		.	0.04 ^{ns}	-0.20 ^{ns}	0.24 *	-0.37 *	-0.48 *	0.07 ^{ns}	0.03 ^{ns}	-0.2 ^{ns}	-0.16 ^{ns}	0.23 ^{ns}	0.12 ^{ns}	0.11 ^{ns}	-0.07 ^{ns}	-0.16 ^{ns}
SL				0.58 *	0.15 ^{ns}	0.02 ^{ns}	-0.08 ^{ns}	-0.06 *	-0.01 ^{ns}	-0.30 ^{ns}	0.001 ^{ns}	-0.21 ^{ns}	-0.44 *	0.24 ^{ns}	0.05 ^{ns}	0.06 ^{ns}
RL				.	0.07 ^{ns}	-0.19 ^{ns}	0.11 ^{ns}	-0.01 ^{ns}	-0.03 ^{ns}	-0.19 ^{ns}	-0.08 ^{ns}	-0.02 ^{ns}	-0.36 *	0.06 ^{ns}	0.01 ^{ns}	0.04 ^{ns}
TSM					.	-0.10 ^{ns}	0.02 ^{ns}	-0.05 ^{ns}	0.14 ^{ns}	-0.01 ^{ns}	-0.08 ^{ns}	0.01 ^{ns}	-0.07 ^{ns}	0.16 ^{ns}	0.01 ^{ns}	-0.03 ^{ns}
ES						.	0.2 *	0.05 ^{ns}	0.17 ^{ns}	0.32 ^{ns}	-0.02 ^{ns}	-0.01 ^{ns}	0.15 ^{ns}	-0.3 ^{ns}	0.25 ^{ns}	0.27 ^{ns}
HW							.	-0.07 ^{ns}	-0.01 ^{ns}	-0.06 ^{ns}	0.15 ^{ns}	-0.24 ^{ns}	-0.16 ^{ns}	0.02 ^{ns}	0.42 *	0.37 *
LA								.	0.23 *	0.46 *	0.11 ^{ns}	0.34 *	0.46 *	-0.3 ^{ns}	-0.01 ^{ns}	-0.05 ^{ns}
LDM									.	0.28 ^{ns}	-0.01 ^{ns}	0.15 ^{ns}	0.38 *	-0.1 ^{ns}	-0.18 ^{ns}	-0.19 ^{ns}
PTN										.	0.53 *	0.15 ^{ns}	0.70 *	-0.1 ^{ns}	-0.99 *	-0.71 *
LIP											.	-0.55 *	0.07 ^{ns}	0.44 *	-0.61 *	-0.80 *
FB												.	0.54 *	-0.71 *	-0.08 ^{ns}	0.39 *
CNZ														-0.53*	-0,69*	-0,23
AMD															0.13	-0.54
CT																0.91*

(1) * and ^{ns} - Significant at the 5% probability level and not significant, respectively.

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For G obtained after AA (Table 5) there was a positive correlation coefficient with TSM (r = 0.24), and a negative correlation with ES (r = -0.37) and HW (r = -0, 48). For SL, a positive correlation coefficient was observed with RL (r = 0.58) and a negative correlation for LA (r = -0.06) and CNZ (r = -0.44). Studies by Guimarães *et al.* (2002), show that root and shoot length are positively correlated linearly, which corroborates the present study. The RL variable did not show a positive correlation coefficient with the other variables but presented a negative correlation coefficient with CNZ (r = -0.36).

For the ES, the correlation coefficient was positive with HW (r = 0.2), showing no negative correlation coefficient with the other variables (Table 5). Avila *et al*. (2005) showed a negative correlation coefficient for emergence speed and seed mass. Regarding the HW, a positive correlation coefficient was verified with TC (r = 0.42), and CNF (r = 0.37), but did not reveal negative correlation coefficients with the other characters.

For the LA, positive correlation coefficients were observed with LDM (r = 0.23), PTN (r = 0.46), FB (r = 0.34), and ASH (r = 0.46), with no negative correlations being found. For the LDM, there was a positive correlation coefficient with CNZ (r = 0.38) (Table 5). In contrast, no negative correlation coefficient was observed with the other variables. Teodoro *et al.* (2011) found that PTN content and LDM were higher when measured in leaves 15 days after emergence.

For PTN, there was a positive correlation coefficient with LIP (r = 0.53), and CNZ (r=0.7) (Table 5), in contrast, negative correlation coefficients with TC (r = -0.99), and CNF (r = -0.71) were found. For lipids (LIP), a positive correlation coefficient was encountered for AMD (r = 0.44), on the other hand, it was negative for FB (r = -0.55), CT (r = -0.612), and CNF (r = -0.8). Lipids, proteins, and carbohydrates are important components of reserves for seeds and seedlings during germination. (ZIEGLER *et al*., 1995).

The FB showed positive correlation coefficients with CNZ (r = 0.54), and CNF (r = 0.39). However, a negative correlation was seen for AMD (r = -0.71). For the CNZ content, negative correlation coefficients were found for AMD (r = -0.53), and TC (r = -0.69). Starch content presented a negative correlation coefficient with CNF (r = -0.54), and TC showed a positive correlation coefficient with CNF (r = 0.91) (Table 5).

Estimates of the correlation coefficients of canonical groups between biochemical variables and those linked to the physiological quality of seeds (Table 6) demonstrate significance (0.05%) through the chi-square test, where the high magnitudes of the correlation coefficients show the dependence between the groups of variables.

The different seed cultivars reveal associations established by the canonical pair with a maximum likelihood of LRt: 0.0115 between groups (Table 6), in relation to the FB, AMD, and CNZ (Biochemical attributes), which are determinants or tend to generate seeds with greater germination, vigor (by accelerated aging test) and shoot length.

For germination and vigor expression, the seeds involve metabolic processes related to the metabolism of the reserve substances. Starch is the main reserve constituent; therefore, it plays an important role in the initial seed performance. (AREND *et al*., 2013).

Table 6 – Estimated canonical correlations between primary components of biochemical composition, protein, lipid, crude fiber, ash and starch content, and secondary physiological parameters, germination, accelerated aging, seedling dry-mass, shoot length, and root length, in the municipality of Capão do Leão/RS, 2017 harvest season.

Variables	**Biochemicals**
Protein	-0.2695
Lipid	-0.063
Raw fiber	0.3068
Ash	0.0331
Starch	0.1674
	Physiological
Germination	0.4958
Accelerated aging	0.6066
Seedling dry mass	-0.3177
Shoot Length	0.0489
Root Length	-0.0214
r *:	0.83
LRT:	0.0115

* r: Canonical correlation coefficient; LRT: maximum likelihood ratio.

Font: Authors.

The canonical pair of cultivars (Table 6) also revealed associations established between groups, where protein and lipid contents (biochemical attributes) have the same direction as seedling dry mass and root length. Therefore, it can be inferred that seeds with lower protein and lipid content tend to have a reduction in dry mass and root length. Berni and Canniatti-Brazaca (2011) observed that the lipid content increased with germination time, and the increase in lipid content and the dry mass during germination may be due to their synthesis from starch degradation; protein content had the same trend.

Estimates of the correlation coefficients of canonical groups between physical and physiological attributes of seeds presented in Table 7 revealed significance, with 0.05 probability through the chi-square test, where the high magnitudes of the correlation coefficients show the dependence between the groups. The significance was verified with seeds of the cultivars, with associations established through the canonical pair with a maximum likelihood rate of LRT: <0.0001 (Table 7), where the TSM presented the same direction as AA, SL, and RL. Based on these results, seeds with greater TSM within the cultivars and places where the seeds studied were produced tend to be related to a higher percentage of AA, higher seedling length, and RL. Silva *et al.* (2007), observed no influence on germination in seeds of rescue grass, but a positive influence on seed vigor, evaluated through AA and seedling length tests. In some cases, seeds of larger size or higher density have a larger amount of reserve for the embryo, tending to be more vigorous. (PÁDUA *et al.*, 2010).

It was verified in the seeds of the different cultivars (Table 7), associations established within the canonical pair, where the HW revealed the same G direction as SDM. Therefore, the seeds of the cultivars produced in different environments in the present study, in general, have a tendency that seeds with lower HW may also have a decrease in G percentage and SDM. In a study by Kolchinski *et al.* (2004), it was stated that the HW in white oat seeds does not reflect the physiological quality of the seeds.

The cultivars produced in different locations expressed different intensities in the revealed bands of the different evaluated isoenzymes. The expression of the Isoenzyme Esterase (EST) (Figure 1A) revealed variations in the levels of band expression for the seeds of different cultivars. The cultivars that presented the highest band intensity were Sonic from Rio Verde and Energia from Passo Fundo, and the cultivars that presented the lowest band intensity were Audaz from Rio Verde and Audaz from Brasilia. This enzyme is closely linked with lipid catabolism, the carbon source for the synthesis of new molecules in seedlings. Esterase is also a good biochemical marker for seed quality evaluation. (TUNES et al., 2014).

The expression of the isoenzyme glutamate oxalacetate transaminase (GOT) (Figure 1B) revealed band intensity variations for the different cultivars, the holes that showed the highest band intensity were Sintonia from Passo Fundo and Audaz from Brasilia. The holes that showed the lowest band intensity were Sintonia and BRS-264 produced in Rio Verde. The enzyme GOT acts on amino acid oxidation that provides energy to the Krebs cycle to generate new amino acids that allow optimal embryo development. Therefore, this enzyme exerts a fundamental role in the germination process because the enzyme is directly linked to protein metabolism. (TUNES *et al*., 2010). In this manner, the results approximate the data obtained in the germination test.

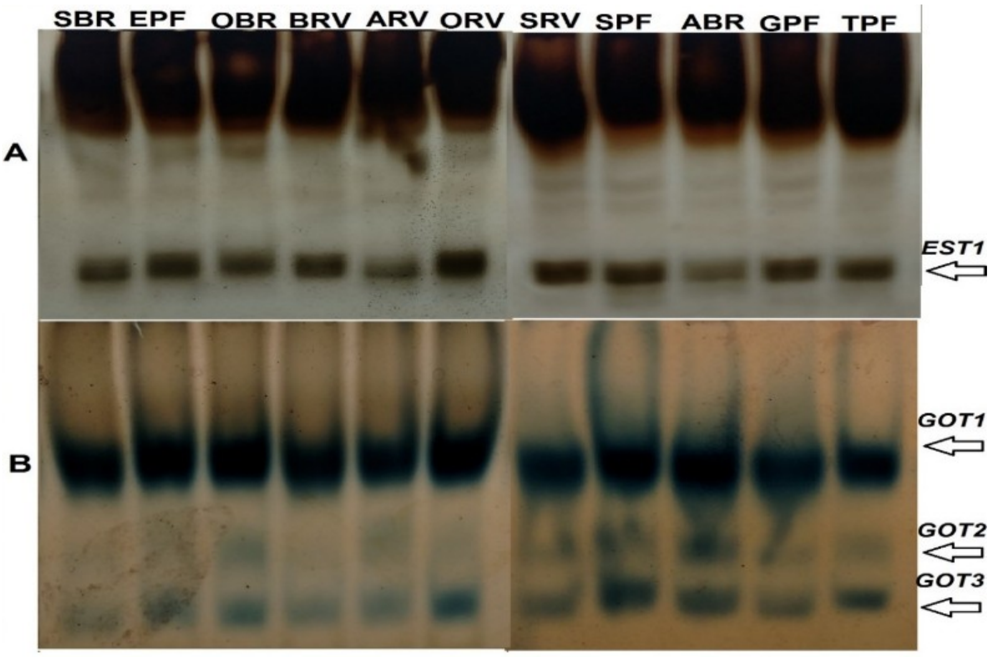
Table 7 - Estimated canonical correlations between primary components of physical attributes: 1000 seed mass and hectoliter and secondary weight of physiological quality parameters: Germination, accelerated aging, seedling dry mass, shoot length, and root length. In the municipality of Capão do Leão/RS, 2017 harvest season.

Variables	**Physical quality**
Mass of one thousand seeds	0.03132
Hectoliter weight	-0.485
	Physiological quality
Germination	-0.1602
Accelerated aging	0.5406
Seedling dry mass	-0.1149
Shoot Length	0.1563
Root Length	0.0278
r:	0.5826
LRT:	<0.0001

* r: Canonical correlation coefficient; LRT: maximum likelihood ratio.

Font: Authors.

Figure 1 – Isoenzymatic expression, A: Esterase (EST), B: Glutamate oxalacetate transaminase (GOT), from wheat seeds, from different cultivars and production sites; SBR (Tbio Sintonia; Brasilia), EPF (Tbio Energia; Passo Fundo), OBR (Tbio Sonic; Brasília), BRV (BRS-264; Rio Verde); ARV (Tbio Audaz; Rio Verde), ORV (Tbio Sonic; Rio Verde), SRV (Tbio Sintonia; Rio Verde), SPF (Tbio Sintonia; Passo Fundo), ABR (Tbio Audaz; Brasilia), GPF (Tbio Sossego; Passo Fundo), TPF (Tbio Toruk; Passo Fundo).



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4. CONCLUSIONS

The seeds of the cultivar TBIO Audaz originated from Brasília presented superior quality, with higher vigor after the accelerated ageing test, shoot length, and emergence speed, also being the cultivar with the highest starch content.

Among the studied materials, it is verified that independently of the cultivar and the local of wheat seeds production there is a positive association between the biochemical and physical attributes that influence the physiological quality of wheat, standing out the starch, fiber, and mineral content, as well as the thousand seeds mass, germination, vigor, and seedling length.

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