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SEED AND GRAIN YIELD AND QUALITY OF WHEAT SUBJECTED TO ADVANCED HARVEST USING A PHYSIOLOGICAL RIPENING PROCESS

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ABSTRACT

This study aimed to evaluate the yield performance, physiological and nutritional quality of wheat seeds and grains subjected to times of application of a physiological ripening agent in pre-harvest. The experiment was arranged in a randomized block design and the treatments were six times of application of the physiological process of ripening in three replications. The applications were carried out at the ealy milk stage, milk stage, early dough stage, soft dough stage, hard dough stage and a control with no application. Yield, nutritional characteristics and the physiological quality of the seeds were evaluated. Analysis of variance and the Skott Knott test were performed at 5% probability. Linear correlation coefficients between pairs of traits were calculated. The application of the physiological process of ripening from the soft dough stage did not affect wheat grain yield. Wheat seed germination was not impacted when the physiological process of ripening was applied from the hard dough stage. The use of the ripening agent reduced the vigor of wheat seeds, regardless of the time of application. The presence of protein in grains was not influenced by the application of the physiological ripening agent. Starch had the greatest expression when the physiological process of ripening was applied between the milk stage and the early dough stage.

Palavras-chave:
Germinação
Peso hectolitro
Proteína
Dessecação

RENDIMENTO E QUALIDADE DE SEMENTES E GRÃOS DE TRIGO SUBMETIDO À COLHEITA ANTECIPADA POR MEIO DE PROCESSO DE AMADURECIMENTO FISIOLÓGICO

RESUMO

Este estudo teve como objetivo avaliar o desempenho produtivo, a qualidade fisiológica e nutricional de sementes e grãos de trigo submetidos a épocas de aplicação de um agente de maturação fisiológica na pré-colheita. O experimento foi disposto em blocos casualizados e os tratamentos foram seis épocas de aplicação do processo fisiológico de maturação em três repetições. As aplicações foram realizadas no estádio leite precoce, estádio leite, estádio massa precoce, estádio massa mole, estádio massa dura e uma testemunha sem aplicação. Foram avaliados o rendimento, as características nutricionais e a qualidade fisiológica das sementes. Foram realizados análise de variância e teste de Skott Knott a 5% de probabilidade. Foram calculados coeficientes de correlação linear entre pares de caracteres. A aplicação do processo fisiológico de maturação a partir do estádio massa mole não afetou o rendimento de grãos de trigo. A germinação das sementes de trigo não foi impactada quando o processo fisiológico de maturação foi aplicado a partir do estádio massa dura. O uso do agente de maturação reduziu o vigor das sementes de trigo, independentemente da época de aplicação. A presença de proteína nos grãos não foi influenciada pela aplicação do agente de maturação fisiológica. O amido teve a maior expressão quando o processo fisiológico de amadurecimento foi aplicado entre o estágio de leite e o estágio inicial da massa.

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INTRODUCTION

In wheat cultivation, one of the main management practices is the pre-harvest application of a physiological ripening agent to standardize the crop and accelerate harvest for an earlier soybean planting (BELLÉ *et al*., 2014). The use of physiological process of ripening allows the wheat harvest to be speeded up, because the herbicide accelerates the drydown of plants and seeds, reducing the period of exposure to deteriorating factors (EMBRAPA, 2020).

Wheat is sown according to the climate conditions at the planting time and its phenological growth stages to avoid critical periods coinciding with frost or excessive rainfall. This means that the crop harvest may delay the sowing of summer crops such as soybean and maize. Therefore, the application of a ripening agent is a strategy to accelerate the harvest and maintain the quality of the grain for industrial use or seed production. The demand for wheat grain is directly associated with the nutritional composition (LORO *et al*., 2023; SEGATTO *et al*., 2023). For this reason, it is essential to apply the physiological process of ripening at the appropriate time, since applications made before the crops reach physiological maturity affect grain development and seed quality (PERBONI *et al*., 2018).

Studies showed that the application of a physiological process of ripening to wheat did not interfere with yield but reduced the physiological quality of the seeds (BELLÉ *et al*., 2014). In white oats, the use of a physiological ripening agent did not affect grain yield and hectoliter weight (PRIETO *et al*., 2023). When glufosinate-ammonium was applied from the milk stage to the dough stage, there was reduction in wheat yield (PERBONI *et al*., 2018). The application of glufosinate-ammonium also reduced the weight of 100 seeds and the yield of wheat grains when applied at the milk to dough stage (KRENCHINSKI *et al*., 2017). Tavares *et al*. (2018) also observed a significant decrease in seed vigor when a physiological process of ripening was used before physiological maturity, particularly when seed moisture content was close to 35%.

These results highlight the importance of a well-managed application of physiological processes of ripening, which take into account the wheat development stages, seeking to optimize both yield and seed quality. Therefore, it is fundamental to understand and improve agricultural practices, consider the effects of these substances and their optimal times of application, aiming for a more efficient and sustainable crop. In this sense, the objective of this study was to evaluate the yield performance and the physiological and nutritional quality of grains of wheat subjected to pre-harvest applications of a physiological ripening agent.

MATERIAL AND METHODS

The experiment was conducted in the 2022 harvest, in the municipality of Catuípe (RS) located at a latitude of 28º07'46" South, longitude of 54º04'40" West and 282 m altitude. The soil of the experimental area is a typical dystroferric red latosol. This type of soil has good drainage, deep profile, dark reddish color, high clay content and for the most part, the presence of 1:1 clay minerals and iron and aluminum oxyhydroxides (SANTOS & ZARONI, 2021). The climate is classified as subtropical *Cfa*, with 4 well-defined seasons (ALVARES *et al*., 2014).

The experiment was installed on June 20, 2022, using 180 kg ha^{-1} of wheat seeds of cultivar ORS 1403, with the spacing of 0.17 m between rows. The basal fertilization was carried out using 150 kg ha^{-1} of MAP (monoammonium phosphate), containing 9% nitrogen (N) and 42% P_2O_5. Urea (45% N) was topdressed 40 days after sowing, , at the rate of 100 kg ha^{-1}, at the tillering stage of the crop.

The experiment was conducted in a randomized block design (RBD), with six treatments and three replications. The treatments consisted of times of application of the physiological ripening agent (glufosinate-ammonium), namely: 10 days after anthesis (early milk stage formation, T1); 15 days after anthesis (milk stage, T2); 20 days after at anthesis (early dough stage, T3); 25 days after anthesis (soft dough stage, T4); 30 days after anthesis (hard dough stage, T5); and no application (control, T6), based on the Zadoks´ phenological scale. The area of the plots was 35 m², totaling 630 m² of experimental area.

Earlier harvest took place with the application of the physiological process of ripening using Glufosinate-Ammonium Salt (GLA), at the dose of two liters ha^{-1} associated with 0.15 liters ha^{-1} of vegetable oil. The application started at anthesis (Table 1), approximately 105 days after the sowing of the experiment.

Table 1. Time after anthesis to accelerate harvest using physiological ripening agent (GLA) in wheat crops. Catuípe - RS, 2023

Treatment	Application date	Days after anthesis
T1– early milk stage formation	10/13/22	10
T2- milk stage	10/18/22	15
T3- early dough stage formation	10/23/22	20
T4- soft dough stage	10/28/22	25
T5- hard dough stage	10/02/22	30
T6- control.	-	No application

Only the center rows were harvested, discarding the borders of each plot to eliminate the border effect that leads to experimental error. A sample of approximately two kilograms of seeds was taken from each plot and stored for the vigor and germination tests to evaluate the physiological quality and tests to determine the content of starch and protein to evaluate the nutritional quality.

The variables analyzed in the plots were: plant height (PH, cm), number of tillers per plant (TILL, unit $plant^{-1}$), final population of plants per hectare (POP, unit ha^{-1}), number of spikes per square meter (NSSM, unit m^{2-1}), spike length (SL, cm), number of grains per spike (NGS, unit $spike^{-1}$), grain area (AR_G, cm²), grain perimeter (PE_G , cm), grain length (L_G, cm), grain width (W_G, cm), spike grain weight (SGW, g), thousand grain weight (TGW, g), hectoliter weight (HW, unit) , grain yield (GY, kg ha^{-1}), percentage of germination (G, %), percentage of abnormal seedlings in the germination test (A, %), percentage of dead seeds in the germination test (DEAD, %), percentage vigor (VIG, %), percentage of abnormal seedlings in the vigor test (A_VIG, %), percentage of dead seeds in the vigor test (DEA_V, %), protein content in the grain (PTN, %) and starch content in the grain (STARCH, %).

Plants were collected in one linear meter to evaluate the yield components and the variables above were subsequently measured. Quality tests took place with the two-kilogram sample taken at the time of harvest. To assess the spike grain weight, 10 spikes were sampled from each plot, threshed and weighed. Thousand seed weight (TSW) was calculated by weighing 2 replicates containing 100 grains and average multiplied by 10.

The grain yield was measured at the harvest by weighing the grains threshed from each plot, then the weight in grams in one square meter was determined and converted to kilograms per hectare (kg ha^{-1}). The specific weight (HW) was also determined using a specific weight scale for wheat (hectoliter weight), which is converted through of a specific weight table.

Germination and vigor tests were performed at the Seed Analysis Laboratory (SAL) of Unijui. Each sample was homogenized, and for the vigor test, the seeds were accelerated aging in a gerbox with a metal dividing screen, containing 40 ml of water. The boxes were covered and placed in a BOD-chamber for 60 hours at 41° C. Afterwards, 4 repetitions of 100 seeds were sown per roll of germitest paper, with the volume of water for imbibition of 2.5 times the weight of the substrate (MELO *et al*., 2015). The germitest paper rolls were placed in a sealed plastic bag to maintain moisture and were exposed to light and a constant temperature of 20° C for 4 to 7 days. The evaluation of germination is similar to that of vigor, however, there is no aging and the seeds are sown directly in the germitest. The results are given as percentage, by determining vigor and germination, which is done by subtracting the number of normal seeds from the number of abnormal and dead seeds.

The protein and starch content were measured using near-infrared spectroscopy (NIRS). This methodology uses radiation (light beam) of a specific wavelength in the near-infrared region, thus, the organic substances absorb through covalent bonds, making it possible to estimate the number and type of molecular bonds, which is measured by the NIRS light beam as well as the light reflected by the sample. Climatic data on minimum temperature (Tmin, ºC), mean temperature (Tmean, ºC), maximum temperature (Tmax, ºC), precipitation (Prec, mm), relative humidity (RH, g.kg^{-1}) and incident radiation

(Rad, MJ.m².day-¹) were obtained from NASA Prediction of Worldwide Energy Resources (NASA POWER, 2023).

Analysis of variance was performed at 5% probability using the F test. The variables that demonstrated significance were compared using the Scott Knott's grouping of means at 5% probability. Pearson's linear correlation coefficients were calculated between pairs of variables, with significance by the T test at 5% probability. The mean Euclidean algorithm and UPGMA clustering were applied to construct the genetic dissimilarity dendrogram, after which the biplot main components were used to identify the trend of association between variables and cultivars (R CORE TEAM, 2023).

RESULTS AND DISCUSSION

The times of application of the physiological process of ripening had a significant effect on the following variables: plant height (PH), degree of tillering per plant (TILL), grain area (AR_G), grain perimeter (PE_G), grain width (W_G), spike grain weight (SGW), thousand grain weight (TGW), hectoliter weight (HW), grain yield (GY), germination percentage (G), percentage of abnormal seedlings in the germination test (A) , percentage of dead seeds in the germination test (DEAD), percentage of vigor (VIG), percentage of abnormal seedlings in the vigor test (A_VIG), percentage of dead seeds in the vigor test (DEA_V) and starch content in the grain (STARCH) (Table 2).

Table 2. Analysis of variance for the variables plant height (PH), degree of tillering per plant (TILL), final population of plants per hectare (POP), number of spikes per square meter (NSSM), spike length (SL), number of grains per spike (NGS), grain area (AR_G, index), grain perimeter (PE_G, index), grain length (L_G), grain width (W_G), spike grain weight (SGW), thousand grain weight (TGW), hectoliter weight (HW), grain yield (GY), percentage of germination (G), percentage of abnormal seedlings in the germination test (A), percentage of dead seeds in the germination test (DEAD), percentage of vigor (VIG), percentage of abnormal seedlings in the vigor test (A_VIG), percentage of dead seeds in the vigor test (DEA_V), protein content in the grain (PTN) and starch content in the grain (STARCH), Catuípe, RS. 2023.

SV	DF	PH	TILL	POP	NSSM	SL
Treatment	5	0.013063*	0.018325*	0.15715	0.78483	0.37391
Block	2	0.056076	0.056674	0.23788	0.93596	0.73842
Residual	10					
CV (%)		1.98	24.1	5.14	6	4.39
FV	DF	NGS	NSS	AR_G	PE_G	L_G
Treatment	5	0.82012	0.31084	0.000003*	0.042367*	0.30838
Block	2	0.76646	0.80133	0.064427	0.066337	0.11441
Residual	10					
CV (%)		6.26	5.33	1.7	1.2	1.45
FV	DF	W_G	SGW	TGW	HW	GY
Treatment	5	0.000000*	0.00003*	0.00000*	0.00000*	0.0000*
Block	2	0.073963	0.95676	0.95373	0.29541	0.5301
Residual	10					
CV (%)		1.11	6.09	1.24	0.63	0.67
FV	DF	G	A	DEAD	VIG	A_VIG
Treatment	5	0.00000*	0.00000*	0.00000*	0.00000*	0.0000*
Block	2	0.17832	0.90008	0.40188	0.34765	0.2084
Residual	10					
CV (%)		0.12	4.49	8.19	0,24	3.14
FV	DF	DEA_V	PTN	STARCH		
Treatment	5	0.00000*	0.54024	0.00004*		
Block	2	0.13169	0.36589	0.34080		
Residual	10					
CV (%)		5.55	20.87	0.4		

FV: Factor of variation; DF: Degree of freedom; CV: Coefficient of variation. *Significant at 5% probability using the F test

The application of the physiological ripening agent at the stages early milk (T1), milk (T2) and early dough (T3) reduced the grain area, grain width, spike grain weight, thousand grain weight, hectoliter weight, grain yield and germination, while increased the percentage of seedlings being abnormal, dead, abnormal in vigor test and dead in vigor test (Table 3). This indicates that the treatment before the soft dough stage promotes a marked reduction in the physiological quality and yield performance of wheat genotypes. However, this response was not observed for nutritional traits, since the use of the ripening agent had no influence on protein content and the treatment at the stages of milk, early dough and dough promoted greater starch accumulation.

Application of glufosinate-ammonium from the milk to dough stages resulted in a decrease in wheat yield, as reported by Perboni *et al*. (2018). Furthermore, Krenchinski *et al*. (2017) found that the application of this herbicide during the same stage of wheat development also caused a reduction in hundred seed weight and grain yield. A number of studies demonstrated that the application of a physiological process of ripening to wheat had no impact on yield, but reduced the physiological quality of the seeds (BELLÉ *et al*., 2014). Studies carried out by Tavares *et al*. (2018) related to the physiological quality of seeds reported a marked reduction in vigor when the ripening agent was applied before the physiological maturity of the seeds (seed moisture close to 35%). On the other hand, in relation to white oats, the use of physiological ripening agent did not influence grain yield or hectoliter weight, as evinced by Prieto, Borsoi and Toledo (2023). These results indicate the importance of choosing the appropriate time to apply the herbicide in order to avoid damaging effects on the production and quality of wheat grains.

The principal components (PCA) scatter plot (Figure 1) shows the variables that had the highest affinity within each treatment. Some variables showed affinity with specific treatments, for

Table 3. Means for the Scott-Knott grouping of the variables analyzed based on the application of the physiological ripening agent (GLA) at different stages of grain formation, Catuípe, RS. 2023

Treatment	PH	AR_G	W_G	SGW	TGW	HW	DEA_V
T1	97.43 a	385.64 c	14.806 d	0.633 c	20.403 d	66.616 d	8.416 a
T2	98.36 a	410.21 b	15.493 c	0.828 b	26.033 c	73.050 c	2.916 b
T3	99.93 a	414.21 b	15.836 b	0.936 a	28.048 b	76.483 b	2.500 b
T4	99.70 a	452.00 a	17.018 a	1.018 a	32.545 a	79.156 a	2.666 b
T5	94.40 b	440.32 a	16.914 a	1.021 a	32.481 a	79.166 a	2.666 b
T6	94.13 b	448.71 a	17.232 a	1.049 a	32.701 a	79.466 a	2.166 c
CV (%)	1.98	1.7	1.11	6.09	1.24	0.63	5.55
Treatment	GY	G	A	DEAD	VIG	A_VIG	STARCH
T1	2581.2 d	89.083 e	7.583 a	3.333 a	80.41 f	10.91 a	69.40 c
T2	3278.9 c	93.583 d	4.583 b	2.000 b	88.91 e	8.16 b	71.50 a
T3	3932.1 b	94.250 c	3.750 c	1.833 b	90.91 d	6.58 c	71.30 a
T4	4262.3 a	95.416 b	3.083 d	1.500 c	92.08 c	5.25 d	71.30 a
T5	4245.4 a	96.000 a	2.583 e	1.416 c	93.25 b	4.08 e	70.66 b
T6	4235.9 a	96.083 a	2.583 e	1.333 c	94.83 a	3.00 f	70.90 b
CV (%)	0.67	0.12	4.49	8.19	0,24	3.14	0.4

Means followed by the same small letter in the column are not significantly differ by the Scott Knott test at 5% probability. SV: Source of variation; DF: Degree of freedom; CV: Coefficient of variation; T1: Early milk stage, application on 10/13/2022; T2: Milk stage, application on 10/18/2022; T3: Early dough stage, application on 10/23/2022; T4: Soft dough stage, application on 10/28/2022; T5: Hard dough stage, application on 02\11\2022; T6: No application; PH: Plant height (m); TILL: Degree of tillering per plant; POP: Final population of plants per hectare; NSSM: Number of spikes per square meter; SL: Spike length (cm); NGS: Number of grains per spike; AR_G: Grain area (index); PE_G: Grain perimeter (index); L_G: Grain length (index); W_G: Grain width (index); SGW: Spike grain weight (g); TGW: Thousand grain weight (g); HW: Hectoliter weight; GY: Grain yield (kg/ha); G: Germination percentage; A: Percentage of abnormal seedlings in germination test; DEAD: Percentage of dead seeds in the germination test; VIG: Percentage of vigor; A_VIG: Percentage of abnormal seedlings in vigor test; DEA_V: Percentage of dead seeds in the vigor test; PTN: Protein content in the grain; STARCH: Starch content in the grain. GLA: glufosinate-ammonium

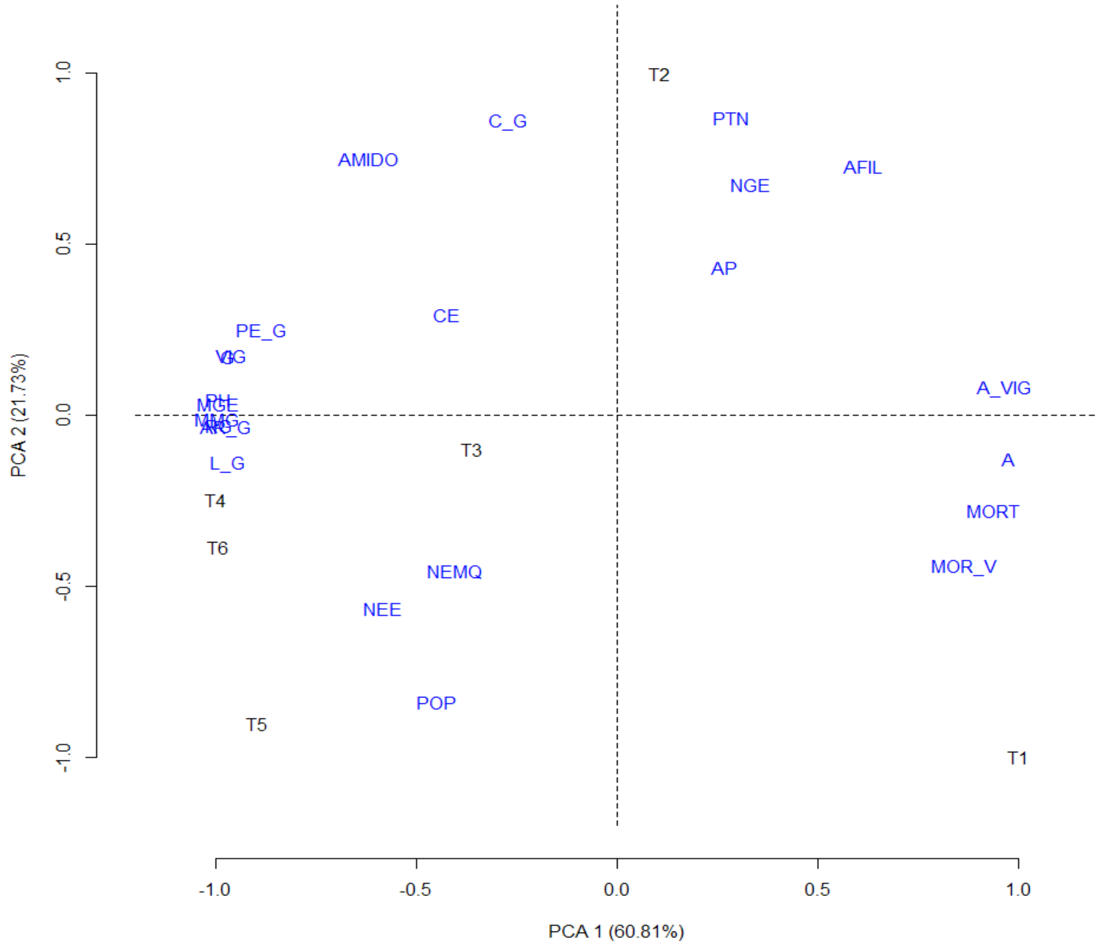

Figure 1. Scatter plot of the scores of the principal components (PCA) for 6 treatments: early milk stage formation (T1); milk stage (T2); early dough stage (T3); soft dough stage (T4); hard dough stage (T5); and no application (T6), with 23 variables evaluated. T1: Early milk stage, 10 days after anthesis; T2: Milk stage, 15 days after anthesis; T3: Early dough stage, 20 days after anthesis; T4: Soft dough stage, 25 days after anthesis; T5: Hard dough stage, 30 days after anthesis; T6: No application, control; PH: Plant height; TILL: Degree of tillering per plant; POP: Final population of plants per hectare; NSSM: Number of spikes per square meter; SL: Spike length; NGS: Number of grains per spike; AR_G: Grain area (index); PE_G: Grain perimeter (index); L_G: Grain length; W_G: Grain width; SGW: Spike grain weight; TGW: Thousand grain weight; HW: Hectoliter weight; GY: Grain yield (kg/ha); G: Germination percentage; A: Percentage of abnormal seedlings in germination test; DEAD: Percentage of dead seeds in the germination test; VIG: Percentage of vigor; A_VIG: Percentage of abnormal seedlings in vigor test; DEA_V: Percentage of dead seeds in the vigor test; PTN: Protein content in the grain; STARCH: Starch content in the grain

instance, the early milk stage treatment (T1) had affinity with the variables percentage of abnormal seedlings in germination test (A), percentage of dead seeds in the test germination rate (DEAD), and percentage of dead seeds in the vigor test (DEA_V). The milk stage treatment (T2), on the other hand, showed affinity with the variables protein content in the grain (PTN), number of grains per spike (NGS), degree of tillering per plant (TILL), plant height (PH) and percentage of abnormal seedlings in the vigor test (A_VIG).

The treatments beginning at the dough stage (T3), soft dough stage (T4), hard dough stage (T5) and no application (T6) showed similar affinities with the variables final population of plants per hectare (POP), number of spikelets per spike (NSS), number of spikes per square meter (NSSM), grain width (W_G), thousand grain weight (TGW), grain area (AR_G) and grain yield (GY). Finally, the variables grain perimeter (PE_G), spike grain weight (SGW), hectoliter weight (HW), germination percentage (G), vigor percentage (VIG), and starch content in the grain (STARCH), spike length (SL) and grain length (L_G) showed no affinity with any treatment.

The variable spike length (SL) had a high positive correlation with the number of spikelets per spike (NSS) and the number of grains per spike (NGS), with the same high positive correlations (0.68 and 0.64) (Figure 2), therefore, meaning that the longer the length of the spike, the greater the number of spikelets per spike and the number of grains per spike. Spike grain weight (SGW) was correlated with the percentage of vigor (VIG), percentage of germination (G), grain yield (GY), hectoliter weight (HW) and thousand grain weight (TGW), which were highly positive (0.94, 0.95, 0.95, 0.97 and 0.95), indicating that the increase in the spike grain weight causes a positive change in these traits.

High correlations were also found between the variable spike grain weight and the variables percentage of dead seeds in the vigor test (DEA_V), percentage of abnormal seedlings in the vigor test (A_VIG), percentage of dead seeds in the germination test (DEAD) and percentage of abnormal seedlings in the germination test (A), with negative correlations (-0.85, -0.93, -0.90 and -0.93, respectively), denoting that the greater the spike grain weight, the lower the percentage

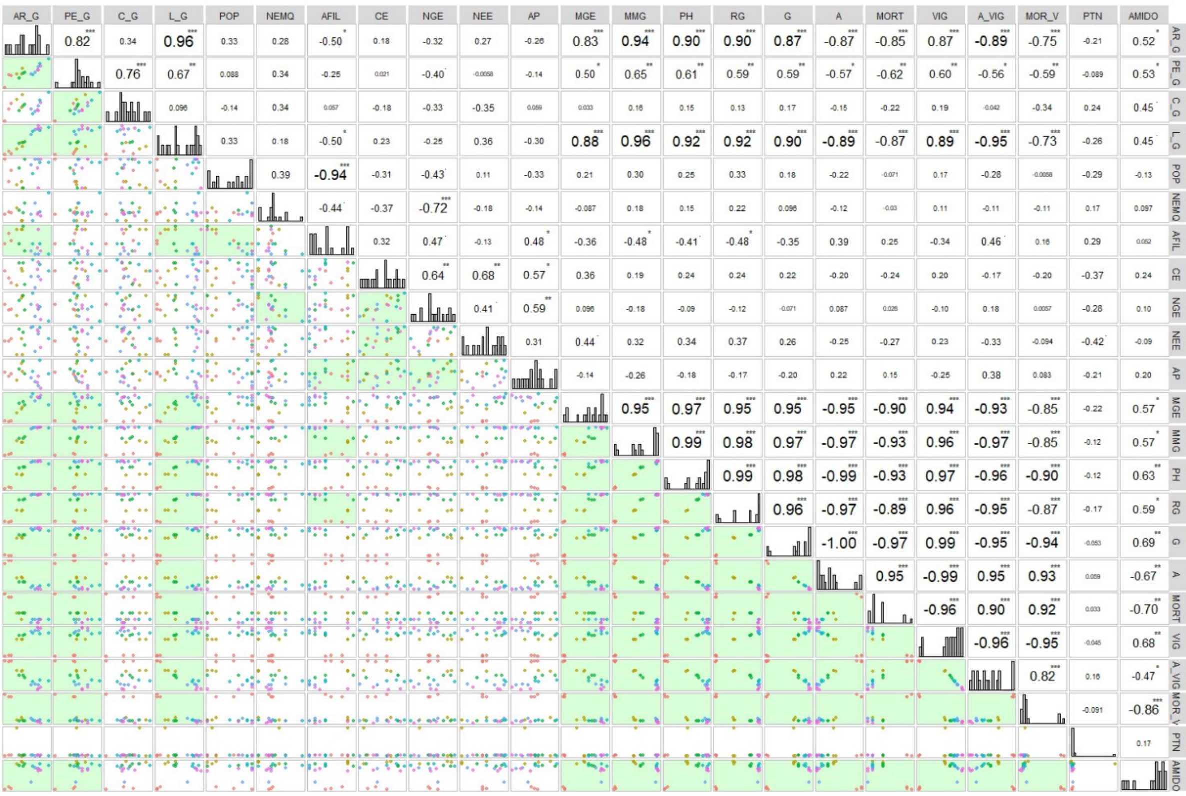

Figure 2. Linear correlation between the 23 variables of accelerating harvest using physiological processes of ripening in wheat. PH: Plant height; TILL: Degree of tillering per plant; POP: Final population of plants per hectare; NSSM: Number of spikes per square meter; SL: Spike length; NGS: Number of grains per spike; AR_G: Grain area (index); PE_G: Grain perimeter (index); L_G: Grain length; W_G: Grain width; SGW: Spike grain weight; TGW: Thousand grain weight; HW: Hectoliter weight; GY: Grain yield (kg/ha); G: Germination percentage; A: Percentage of abnormal seedlings in germination test; DEAD: Percentage of dead seeds in the germination test; VIG: Percentage of vigor; A_VIG: Percentage of abnormal seedlings in vigor test; DEA_V: Percentage of dead seeds in the vigor test; PTN: Protein content in the grain; STARCH: Starch content in the grain

of dead and abnormal plants in the vigor and/or germination test.

The variable thousand grain weight (TGW) presented high positive correlations with the percentage of vigor (VIG), percentage of germination (G), grain yield (GY) and hectoliter weight (HW) (0.96, 0.97, 0.98 and 0.99, respectively). The data show that the increase in the spike grain weight causes a positive change in these components. On the other hand, this variable showed high negative correlations with the percentage of dead seeds in the vigor test (DEA_V), percentage of abnormal seedlings in the vigor test (A_VIG), percentage of dead seeds in the germination test (DEAD) and percentage of abnormal seedlings in the germination test (A) with high negative values (-0.85, -0.97, -0.93, -0.97). Therefore, the greater the thousand grain weight, the lower the percentage of dead and abnormal plants will be in both the vigor and the germination tests.

High positive correlations occurred between the variable hectoliter weight (HW) and starch content (STARCH), vigor percentage (VIG), germination percentage (G) and grain yield (GY) (0.63, 0.97, 0.98 and 0.99), showing that the increase in hectoliter weight causes a positive change in starch content, vigor percentage, germination percentage and grain yield. However, the variables percentage of dead seeds in the vigor test (DEA_V), percentage of abnormal seedlings in the vigor test (A_VIG), percentage of dead seeds in the germination test (DEAD) and percentage of abnormal seedlings in the germination test (A) had high negative correlations (-0.90, -0.96, -0.93, -0.99), therefore showing that the greater the hectoliter weight, the lower the percentage of dead and abnormal plants in the vigor test and also in the germination test.

The variable grain yield (GY) showed correlations with the percentage of vigor (VIG) and percentage of germination (G), which were highly positive (0.96 and 0.96), meaning that the increase in grain yield causes a positive change in the percentage of vigor and germination. However, the variables percentage of dead seeds in the vigor test (DEA_V), percentage of abnormal seedlings in the vigor test (A_VIG), percentage of dead seeds in the germination test (DEAD) and percentage of abnormal seedlings in the germination test (A) had high negative correlations (-0.87, -0.95, -0.89, -0.97), indicating that the higher the grain yield, the lower the percentage of dead and abnormal plants in the vigor test as well as in the germination test.

Percentage of germination (G) presented correlations with the starch content (STARCH) and the percentage of vigor (VIG), both being highly positive (0.69 and 0.99), meaning that the increase in germination causes a positive change on starch content (STARCH) and germination percentage. However, the variables percentage of dead seeds in the vigor test (DEA_V), percentage of abnormal seedlings in the vigor test (A_VIG) and percentage of dead seeds in the germination test (DEAD) had high negative correlations (-0.94, -0.95 and - 0.97), while the percentage of abnormal seedlings in the germination test (A) presented a perfect correlation (1.00), meaning that the higher the grain yield, the lower the starch content, the lower the percentage of dead and/or abnormal plants in the test. vigor and in the germination test.

The variable percentage of abnormal seedlings in the germination test (A) showed correlations with the percentage of dead seeds in the vigor test (DEA_V), percentage of abnormal seedlings in the vigor test (A_VIG) and percentage of dead seeds in the germination test (DEAD), with highly positive correlations (0.93, 0.95 and 0.95), indicating that the higher the percentage of abnormal seedlings in the germination test, the higher the percentage of dead and abnormal seeds in the vigor test, as well as the percentage of dead seeds in the germination test. However, there were also correlations with the variables starch content (STARCH) and vigor percentage (VIG), with highly negative values (-0.67 and -0.99), such that the greater the number of abnormal seedlings in the germination test, the lower the germination percentage and starch content.

Percentage of dead seeds in the germination test (DEAD) presented correlations with the percentage of dead seeds in the vigor test (DEA_V) and the percentage of abnormal seedlings in the vigor test (A_VIG), which are highly positive (0.92 and 0.90), denoting that the higher the percentage of dead seeds in the germination test, the higher the percentage of dead seeds in the vigor test and the percentage of abnormal seedlings in the vigor test. However, there were also correlations with the variables starch content (STARCH) and vigor percentage (VIG), being both highly negative (-0.70 and -0.96), meaning that the higher the percentage of dead seeds in the germination test, the lower the germination percentage and starch content.

Percentage of vigor (VIG) is correlated with the starch content (STARCH), with a highly positive value (0.68), meaning that the higher the percentage of vigor, the higher the starch content, but, there are also correlations with the percentage of dead seeds in the vigor test (DEA_V) and percentage of abnormal seedlings in the vigor test (A_VIG), which are highly negative (-0.95 and -0.96), indicating that the higher the percentage of germination, the lower the percentage of dead and abnormal seeds in the vigor test.

A high positive correlation (0.82) was found between the variable percentage of abnormal seedlings in the vigor test (A_VIG) and the variable percentage of dead seeds in the vigor test (DEA_V), such that the higher the percentage of abnormal seedlings in the vigor test, the higher the percentage of dead seeds in the vigor test. Finally, the last variable, the percentage of dead seeds in the vigor test (DEA_V) is correlated with starch content (STARCH) with a highly negative value (-0.86), indicating that the higher the percentage of dead seeds in the vigor test, the lower the starch content.

The dendrogram of the dissimilarity analysis shows 1 group and 3 subgroups in addition to an isolated treatment, with the subgroup 1, the one with the smallest Euclidean distance, presenting the greatest similarity (Figure 3). Subgroup 1 consists of similar treatments at the early dough stage (T3) and the treatment without application (T6), which has similarity for the variables degree of tillering per plant (TILL), final population of plants per hectare (POP), number of spikes per square meter (NSSM), spike length (SL), number of grains per spike (NGS), number of spikes per spikelet (NSS), grain perimeter (PE_G), grain length (L_G), spike grain weight (SGW) and protein content in the grain (PTN).

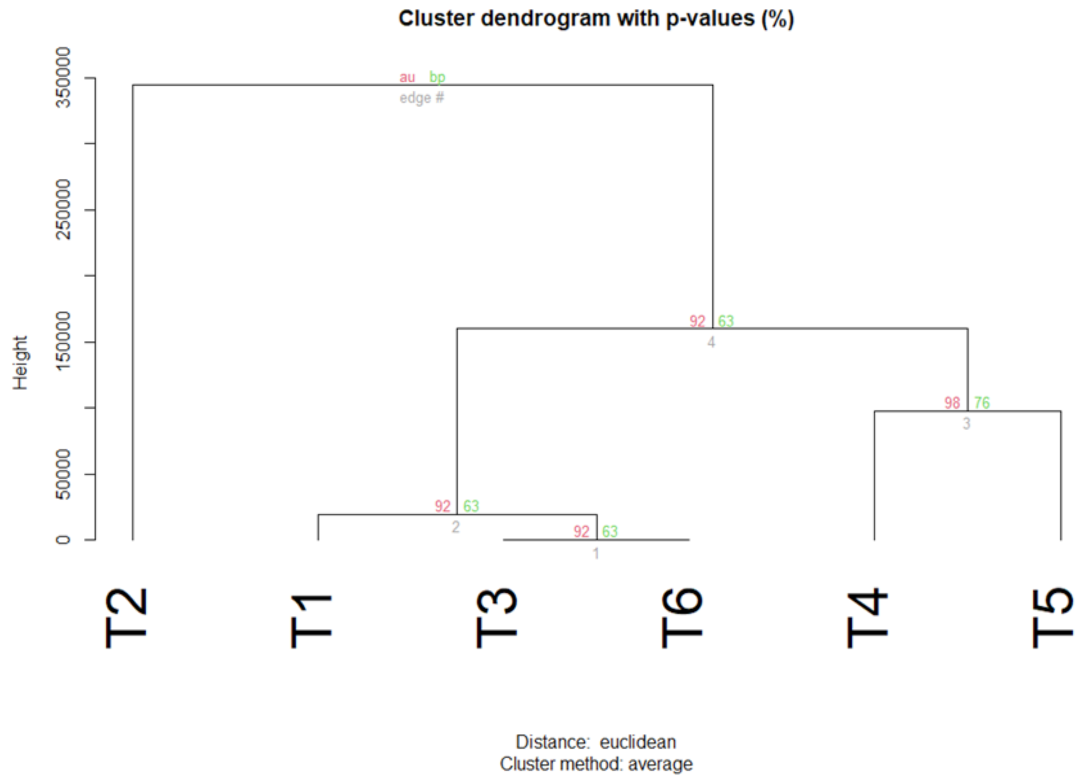

Figure 3. Cluster dendrogram of 6 different treatments, in the experiment to accelerate harvest using physiological processes of ripening in wheat, Catuípe, RS. 2023. T1: Early milk stage, application on 10/13/2022; T2: Milk stage, application on 10/18/2022; T3: Early dough stage, application on 10/23/2022; T4: Soft dough stage, application on 10/28/2022; T5: Hard dough stage, applied on 02\11\2022; T6: No application

Nevertheless, subgroup 1 (T3 and T6) also has similarity with subgroup 2, which is formed by the early milk stage treatment (T1), where there is similarity with the variables degree of tillering per plant (TILL), number of spikes per square meter (NSSM), spike length (SL), number of grains per spike (NGS), number of spikes per spikelet (NSS), grain perimeter (PE_G), grain length (L_G) and protein content in the grain (PTN).

Similar subgroup 3 consists of the treatments soft dough stage (T4) and hard dough stage (T5), which have similarity for the variables degree of tillering per plant (TILL), final population of plants per hectare (POP), number of spikes per square meter (NSSM), spike length (SL), number of grains per spike (NGS), number of spikes per spikelet (NSS), grain area (AR_G), grain perimeter (PE_G), grain length (L_G), grain width (W_G), spike grain weight (SGW), hectoliter weight (HW), grain yield (GY), percentage of dead seeds in the germination test (DEAD), percentage of dead seeds in the vigor test (DEA_V) and grain protein content (PTN).

Similar group 4 is formed by the similarity between subgroup 2 (T1 (T3 and T6)) and subgroup 3 (T4 and T5), which have similarity for the variables degree of tillering per plant (TILL), number of spikes per square meter (NSSM), spike length (SL), number of grains per spike (NGS), number of spikes per spikelet (NSS), grain perimeter (PE_G), grain length (L_G) and grain protein content (PTN).

The milk stage treatment (T2) showed no similarity with the others, had the greatest Euclidean distance and remained isolated. In subgroup T2, the variables plant population per hectare (POP), grain width (W_G), spike grain weight (SGW), thousand grain weight (TGW), hectoliter weight (HW), grain yield (GY), germination percentage (G), percentage of abnormal seedlings in the germination test (A), percentage of vigor (VIG) and percentage of abnormal seedlings in the vigor test (A_VIG) had no similar results to the other treatments (T1, T3, T4, T5 and T6).

Therefore, it becomes clear that wheat productivity results from the expression of a number of yield components, mainly the number of spikes per m², number of grains per spike and thousand grain weight (CAMPONOGARA *et al*., 2016). The period of grain formation, from anthesis to grain filling, is one of the most important in defining the productivity of this crop, as highlighted by Rodrigues, Teixeira and Costenaro (2011). Furthermore, the use of a ripening process at the recommended time is a critical management to avoid losses in yield and physiological and nutritional quality of the grains.

CONCLUSIONS

- The application of the physiological process of ripening from the soft dough stage does not affect wheat grain yield.
- Wheat seed germination is not impacted when the physiological process of ripening is applied from the hard dough stage.
- The use of this ripening process reduces the vigor of wheat seeds, regardless of the time of application.
- The presence of protein in grains is not influenced by the application of a physiological ripening agent to wheat.
- Starch demonstrates the greatest expression when the physiological process of ripening is applied at the stage between the milk stage and the early dough stage.

AUTHORSHIP CONTRIBUTION STATEMENT

RIGOTTI, E. J.: Conceptualization, Data curation, Software, Validation, Writing – review & editing; **CARVALHO, I. R.:** Formal Analysis, Investigation, Methodology, Project administration, Resources; **LORO, M. V.:** Formal Analysis, Funding acquisition, Investigation, Visualization, Writing – original draft; **PRADEBON, L. C.:** Investigation, Writing – review & editing; **ROZA, J. P. D.:** Investigation, Writing – review & editing; **SANGIOVO, J. P.:** Formal Analysis, Writing – review & editing.

DECLARATION OF INTEREST

The authors declare that they have no financial or personal interests that could influence the work reported in this article.

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