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EVOLUTION OF RHEOLOGICAL PROPERTIES AND FALLING NUMBER OF WHEAT STORED OVER A LONGER PERIOD OF TIME

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Abstract: The quality of wheat is essential for the processing of flour in the bakery industry, this can be determined by several methods, one of which is alveographic properties. The problem of sprouting from a batch of stored wheat can lead to a sufficiently high enzymatic activity that compromises the functionality of the flour and the quality of the bread. The phenomenon is usually analysed using the Hagberg falling number method. Maintaining the quality of cereals and preventing large product losses is achieved with the help of efficient storage systems. This paper evaluates the link between the effects of long-term, more accurate wheat storage and alveographic properties, along with falling number (FN). The wheat from which the flour is obtained is stored for a period of at least three years, the purpose of this study being to observe the quality of the wheat over time. To obtain high quality doughs, the wheat must be conditioned 24 hours before being analysed. In this respect 12 samples of common wheat were analysed, from the area of the Curtea de Argeș, Romania provided by the deposits of the National Administration of State Reserves and Special Issues. From the values obtained for FN and Alveograph, it could be observed that analysed samples storage suffered quality loss after several years of storage compared to the moment they were collected. Factors leading to deterioration of these properties could be improper storage, humidity, and temperature of the product as well as the microclimate not being controlled or monitored daily, ventilation not provided by mechanical means, especially during the summertime, appropriate measures were not taken to keep these parameters within limits allowed, treatments against live pest infestation.

Keywords: wheat, Falling Number, alveographic properties, storage

Introduction

Wheat used in the bakery industry (*Triticum aestivum L.*) is one of the most important cereals for human beings. Unlike other cereal flours, wheat flour can generate single three-dimensional dough structure and viscoelasticity when water is added. The rheological properties of dough are essential during kneading, bread formation, leavened and some studies reported a high correlation between rheological properties and baking performance (Tronsmo *et al*., 2003; Noorfarahzilah *et al*., 2014).Starch, the important carbohydrate found in the wheat grain, accounts for approximately 70% of the grain and 75% of the flour weight, is capable of playing an essential role in the quality of the grains and functions of the dough, not only through its internal structure and physico-chemical properties, but also through its interaction with starch gluten (Wang *et al*., 2017).Wheat starch has been divided into amylose and amylopectin on the basis of their various polymerization of glucose and their degree of branching, and the amylose and amylopectin content often varies in different wheat varieties (Shevkani, *et al*., 2016). The falling number has a critical and direct level that has affected commercial wheat prices and has resulted in a significant economic loss for the wheat industry, in particular wheat growers. The determination of the drop index is a standard method for the assessment of cereals; α-amylase activity (AACC International, 2010). Drop index values should be between 300 and 450 s or above. A value of less than 300 s implies germination damage and poor end-use quality related to germination. The low fall number value often leads to a reduction in transaction prices (Delwiche *et al*., 2015; (Repeatabilityprecision of the falling number procedure under standard and modified methodologies), Idaho Wheel Commission, Boise, ID, 2017). The low falling number may indicate poor flour quality, as a low falling number wheat has a fast liquefaction during ripening. Wheat flour with a falling number between 200 s and 250 s can produce a good bread crumb with the ideal texture, colour and a good volume of bread can be obtained (Perten, 1964). Bread sticks become sticky when using flour with a falling number less than 150 s because the starch in question is strongly hydrolysed by α-amylase and cannot form a continuous starch-protein matrix of bread (Hug-Iten *et al*., 1999; Scanlon and Zghal, 2001). Although a low Falling number is associated with the unwanted texture, using a high falling number flour does not guarantee excellent baking quality. For example, bread crumbs made of flour with a high falling number, (i.e. more than 300 s) were proven to have an undesirable dry texture (Perten,1964). A result of falling number below 250 s for ground wheat creates difficulties, because as the fault of the quality of the product, especially for dough-based products, is growing as the falling number decreases. Cakes, donuts and similar products are likely to have poor quality characteristics due to amylase activity. Arab-style flat breads and some baguettes are the most resistant products when it comes to problems caused by amylase and can withstand lower jaw numbers than other products. Wheat acquisition specifications often include falling number values ranging from 300 s to, in some cases, 350 s, bakers prefer this slightly increased range. Above 300 s, and in particular 350 s, amylase and the falling number is admissible. In addition, the falling number does not always correlate well with the quality of the product. Even if the value of 200 s is decreased, an acceptable volume of cakes can be obtained depending on the wheat variety. Falling number values that are above 300 s do not guarantee any good performance of the tours. Clearly, other factors, in addition to the presence of amylase, are involved in the quality of wheat. Although the falling number provides information on the degree of degradation induced by starch amylase, it does not provide a concrete estimation of the functionality of the end-use (Bettge, 2018). Falling number is a decades-old method in wheat (*Triticum aestivum L.*) quality assessment measuring the robustness of the endosperm of seed, in particular as regards the integrity of starch and the α-amylase enzyme which hydrolyses starch (Hagberg, 1960; Perten, 1964; Ross and Kongraksawech, 2012).The method is a physical determination which measures the viscosity of a heated mass-water mixture, subject to gelatinisation and hydrolysis under strictly controlled conditions of preparation, mixing and heating of the mixture. Reported in units of seconds for a piston to descend through a heated gel, the high values indicate the integrity of intact starch, thus a low amylolitic activity. In contrast, high α-amylase activity material produces thin gels that lead to low falling number. Hagberg Method – Perten falling number is used to detect starch degradation due to α-amylase activity in wheat flour (Perten, 1964). The drop index was introduced in 1960 to measure α-amylase activity due to the deterioration of wheat germ. The germination damage is caused by α-amylase enzyme, which separates long chains of starch from the wheat endosperm into shorter pieces, resulting in poor quality of bread, cakes and pasta. A mixture of healthy wheat flour in the water will be gelatinized to the boil. Broken α-amylase starch chains fail to gelatinize well. In the falling number test, a flour/water suspension is agitated for 60 s and then the falling number tool measures the time stir rod takes to fall to the bottom of the tube. α-amylase in the sample will reduce the gelatinisation of the suspension, causing the stirrer to fall faster, resulting in lower falling number. Alveograph is a world standard method (ICC 121, AACC 54-30.02) for falling number determination. In its more recent version, the international standard ISO 27971-2015 introduces important information on the accuracy of the test at the start of analysis of wheat grains (and not of flour already manufactured). This standard includes important information on "how the grain is prepared and milled" and "what impact these operations have on the final repeatability and reproducibility of the test". Since compliance with the standard leads to the creation of a flour as repressive as possible for the wheat purchased, the method must include basic practice for milling wheat. ISO 27971-2015 emphasizes the importance of moistening cereals at 16% water and allowing all wheat samples to rest for 24 hours. Many studies show that laboratory milling of dry grain is not satisfactory. An important element for the moistened wheat is the equipment that is intended for the mixing of the grain with the corresponding amount of water. Every factory or laboratory in the world uses smooth wavy rollers to homogenize the humidified wheat, but also flour. In order to obtain conclusive results, the laboratory mill must include this equipment with these two types of rollers, the absence of these accessories may result in damage to the starch and the ash content to be affected, as well as the rheological properties. In this study was analysed the influence of the storage conditions on the quality parameters of the wheat, namely the falling number and the rheological properties of the flour. Wheat samples were analysed for three years 2019, 2020 and 2021. Storage conditions were recorded monthly during this period.

Materials and methods

Twelve samples of common wheat (*Triticum aestivum L.*) were considered for the present study. The samples were collected from Curtea de Argeș area. The samples were harvestedin2019.Two mills were used for grinding, the Perten LM 120 mill was used for falling number determination, and the CD1 Chopin technologies mill was used to determine the alveograme. The weighing of the samples was carried out by means of the metrological-verified technical libra scale. The methods used were in accordance with: SR EN ISO 3093:2010 and SR EN ISO 27971:2015.

The moisture of both cereals and flour was determined by quick method using Infraatic IM 9500 NIR grain analyser. Samples for the determination of alveolar properties was carried out with the Chopin rotary mixer (Chopin, Villeneuve-la-Garenne, France).

The falling number determination

The Falling Number values were obtained with using 1000 Falling Number instrument (Perten, Hägersten, Sweden) equipment with an attached recirculating cooling water tower. Approximately 300 g of wheat from each sample were ground with a hammer mill (Perten LM 120 model), after which a quantity of flour, grained according to the moisture of the wheat, was introduced into each of the two precision tubes and 25 ml of distilled water was added. The samples were mechanically shaken (Shakematic, Perten), and were introduced into the equipment to begin the determination. The method was carried out according to SR EN ISO 3093:2010. The samples were analysed in double.

Determination of rheological properties

Conditioning of the samples was carried out by adding a quantity of water to more than 800 g of sample mixed in a jar with the special wheat roller and let at rest for 24 h. After 24h, obtained flour was mixed for 20 min using a rotary mixer, equipped with the specific flour roller. The rheological properties were assessed with the NG alveograph, and an alveolink recorder (Chopin, Villeneuve-La-Garenne, France). The procedure consisted of weighing 250 g of flour, pouring it into the mixing chamber and adding the saline solution according to the moisture of the flour. The kneading process itself took eight minutes following the standard SR EN ISO 27971:2015. The dough strength (P), extensibility (L), deflection energy (W), the curve configuration report (P/L) and the inflation index (G) were determined. The analysis was realised according to SR EN ISO 27971:2015.

Results and discussions

The microclimate of the store where the wheat has been stored is shown in Table 1. The moisture content and temperature during wheat harvesting may be between 20-35% and 10-35°C respectively, but these conditions are not favourable for safe storage of wheat for long periods. Thus harvested wheat must be dried and cooled before storage. The moisture content and temperature of cereals are the essential parameters determining the length of storage of the cereals. In general, high temperature and high moisture grain will allow a short time for post-harvest actions. (Karunakaran *et al*., 2001). Moisture is one of the essential wheat storage parameters and its recommended value is 12,5% (Sisman and Ergin, 2011). In Table 1, recorded data of wheat deposits can be observed. The data was obtained using a storage room temperature and humidity monitoring device. In 2019 the summer temperature did not exceed 26°C and during the winter period the minimum value recorded was -5°C. In 2020 the peak in the summer was 27°C, and the minimum in winter was 4°C, and in 2021 the minimum in winter months was -5°C, and the maximum this summer was 24°C. The data recorded over the three years show that wheat samples taken into analysis were kept under compliant microclimatic conditions.

Falling number

The FN is important in the baking process and the recommended value for baking bread is 250 s. A lower value indicates higher amylase activity and vice versa. Falling number value above 350 s indicates healthy and stored wheat seeds (Buriro *et al*., 2012). From Table 1 falling number values can be observed, the graph of these results can be found in Figure 1. The first sample averaged 428 s in 2019 and over the next two years was 418 s and 415 s. In the last two years the first sample showed no significant differences, compared to the first year the difference was of circa 10 s, it is not a major difference, it may be due to storage conditions or climatic variations affecting humidity. Analyses carried out on sample 2 show that the lowest value obtained was in 2021 at 382 s, in 2020 and 2019 the values were very close, the difference between the two years and the last year. According to Hrušková *et al*., 2003 the storage conditions for the falling number are not taken into account as they do not influence this analysis, but only the qualitative properties of the wheat grain. The amylase activity of sample 3 in 2019 was 440 s, in 2020 435 s and in 2021 426 s, a decrease was observed over the three years in the case of sample 3. The falling number values for sample 4 over the three years are slightly increasing, in 2019 the average was 371 s, in 2020 379 s and in 2021 404 s. The fifth sample in the first two years was marked by an increase, 2019 seconds was obtained in 420 and 2020 seconds in 438, followed by a slight decrease in 2021, 415 s. Sample 6 measured the values: In 2019, 468 s, in 2020 432 s and in 2021 461 s. In this three-year sample, it can be seen that in 2020 the average figure of false number is decreasing, which is slightly significant, but in the year three it is close to the first year of harvesting. Alpha-amylase activity for sample 7 averaged 374 s in 2019, 383 s in 2020 and 2021 394, increased significantly. Sample 8 had a mean α-amylase value in the year 2019 399 s, in the year 2020 380 s and in the year 2021 412 s, the variation of the three values over the three years is not significant and does not exceed the repeatability limit according to SR EN ISO 3093:2010. The values obtained for the sample 9 were in the year 2019 451 s, in the year 2020 460 s and in 2021 445 s, no significant differences were observed. In 2019, 10 recorded 460 s in 2020 435 and 2021 484 s. In the case of this sample, slightly increased differences can be observed between the three years of storage. In 11, in the year 2019 534, in 2020 544 and 528 s in the last year, there are no significantly different values. For sample 12 the figures were given: 482 s in 2020, 445 s, and 2021 462 s. The values obtained are significantly different over the three years of storage. A-amylase activity can greatly reduce the quality of the flour. Flour is mostly starch and α-amylase reduces the important qualities of flour. Testing with falling number is performed by creating a suspension of flour and water in a tube. The time required for a piston to fall through the suspension shall be measured. Healthy, starchy grains produce a thick paste (and a higher number of falling number). Grains damaged by germs will result in a mixture of flour and water that is thinner or less viscous because α-amylase has started to break down starch. The faster the piston falls to the bottom of the tube, the lower the viscosity and the lower the phoning number. The lower figures indicate that there have been higher levels of α-amylase activity. Falling number is therefore an indirect but quite accurate measure. In general, the falling number less than 250 s to 300 s indicates poor quality flours for grinding and baking. Damaged wheat flour that produces flour with a small falling number, can affect the mixing, the resistance of the crumb, the slicing, the slicing ability and the loaf volume.

As can be seen during the three years, the values are close to each other, meaning that storage is done properly and safely.

Innovative Romanian Food Biotechnology Vol. 21, 2021
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RESEARCH ARTICLE

Table 1. Microclimate conditions wheat storage room for a period of three years

Month	Year 2019				Year 2020				Year 2021			
	Temperature °C		Moisture %		Temperature °C		Moisture %		Temperature °C		Moisture %	
	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.
January	-5	2	49	94	-4	5	48	83	-4	5	45	89
February	-2	5	51	91	-1	7	35	85	-5	4	47	90
March	2	9	42	85	-1	7	35	85	0	5	61	78
April	7	13	44	89	3	13	43	70	2	9	62	80
May	11	21	53	85	10	18	53	78	10	17	60	85
June	16	26	60	88	14	20	55	81	12	21	67	85
July	16	26	52	85	15	27	53	72	15	23	65	80
August	18	25	54	75	19	27	52	70	19	24	60	75
September	11	23	55	76	12	23	50	68				
October	11	18	55	78	10	18	50	70				
November	7	14	60	91	5	15	58	80				
December	-1	8	55	90	-2	5	54	80				

Table 2. Falling Number results (s)

Samples	Year 2019	Year 2020	Year 2021
S_1	428.00 ± 5.66	418 ± 9.90	415 ± 2.83
S_2	396.00 ± 5.66	394 ± 8.49	382 ± 1.41
S_3	440.00 ± 7.07	435 ± 2.83	426 ± 2.83
S_4	371.00 ± 9.90	379 ±4.24	404 ± 5.66
S_5	420.00 ± 5.66	438 ± 2.83	415 ± 5.66
S_6	468.00 ± 8.49	432 ± 5.66	461 ± 1.41
S_7	374.00 ± 8.49	383 ± 4.24	394 ± 7.07
S_8	399.00 ± 4.24	380 ± 2.83	412 ± 5.66
S_9	451.00 ± 5.66	460 ± 5.66	445 ± 4.24
S_{10}	460.00 ± 7.07	435 ± 8.49	484 ± 7.07
S_{11}	534.00 ± 8.49	548 ± 5.66	528 ± 4.24
S_{12}	482.00 ± 2.83	445 ± 7.07	462 ± 7.07

Innovative Romanian Food Biotechnology Vol. 21, 2021
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RESEARCH ARTICLE

Table 3. The results of the alveographic properties over the three years of storage

Samples	P (mm H_2O)			L (mm)			W (10^{-4} J)			Ie (%)		
	2019	2020	2021	2019	2020	2021	2019	2020	2021	2019	2020	2021
S_1	64 ± 2.49	60 ± 2.49	58 ± 2.49	96 ± 28.06	92 ± 28.06	90 ± 28.06	215± 65.37	200± 65.37	202± 65.37	59,6± 70.00	51,3± 70.00	55,3± 70.00
S_2	62 ± 1.63	64 ± 1.63	60 ± 1.63	104 ± 31.29	98 ± 31.29	101 ± 31.29	220 ± 69.32	215± 69.32	217± 69.32	59,3 ±71.80	60,1 ±71.80	60,8 ±71.80
S_3	68 ± 2.45	62 ± 2.45	65 ± 2.45	76 ± 23.98	80 ± 23.98	84 ± 23.98	186 ± 58.07	191± 58.07	184± 58.07	56,5 ±67.34	55,4 ±67.34	54,3 ±67.34
S_4	59 ± 2.36	64 ± 2.36	59 ± 2.36	114 ± 34.90	110 ± 34.90	106 ± 34.90	205 ± 66.13	218± 66.13	204± 66.13	53,8 ±67.91	52,6 ±67.91	53,2 ±67.91
S_5	77 ± 2.62	78 ± 2.62	72 ± 2.62	101 ± 32.34	109 ± 32.34	112 ± 32.34	267 ± 87.19	274± 87.19	268± 87.19	59,5 ±88.30	59,9 ±88.30	58,5 ±88.30
S_6	61 ± 2.16	66 ± 2.16	62 ± 2.16	112 ± 35.70	118 ± 35.70	108 ± 35.70	231± 73.77	225± 73.77	235± 73.77	59,9 ±73.59	58,3 ±73.59	58,6 ±73.59
S_7	70 ± 1.63	72 ± 1.63	68 ± 1.63	116 ± 36.15	120 ± 36.15	112 ± 36.15	252± 78.35	245± 78.35	240± 78.35	55,8 ±77.67	56,1 ±77.67	55,6 ±77.67
S_8	61 ± 2.05	63 ± 2.05	58 ± 2.05	113 ± 32.92	108 ± 32.92	90 ± 32.92	214± 67.57	220± 67.57	202± 67.57	55,2 ±69.64	54,7 ±69.64	55,3 ±69.64
S_9	53 ± 2.87	56 ± 2.87	60 ±2.87	124 ± 37.98	119 ± 37.98	101 ± 37.98	212± 70.68	227± 70.68	217± 70.68	58,8 ± 69.62	57,9 ± 69.62	60,8 ± 69.62
S_{10}	63 ± 2.05	60 ± 2.05	65 ± 2.05	137 ± 40.31	131 ± 40.31	84 ± 40.31	281 ±83.38	275± 83.38	184± 83.38	61,2 ± 81.94	60,4 ± 81.94	54,3 ± 81.94
S_{11}	58 ± 1.70	55 ± 1.70	59 ± 1.70	105 ± 34.33	110 ± 34.33	106 ± 34.33	203± 66.22	215± 66.22	204± 66.22	57,6 ± 68.05	56,6 ± 68.05	53,2 ± 68.05
S_{12}	63 ± 4.50	62 ± 4.50	72 ± 4.50	108 ± 32.92	104 ± 32.92	112 ± 32.92	226± 78.27	232± 78.27	268± 78.27	58,6 ± 79.42	58,3 ± 79.42	58,5 ± 79.42

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Table 4. The results of the alveographic properties over the three years of storage

Samples	P/L			G		
	2019	**2020**	**2021**	**2019**	**2020**	**2021**
S_1	0,67± 66.30	0,65± 66.30	0,64± 66.30	21,8± 63.13	19,8± 63.13	20,7± 63.13
S_2	0,6± 68.86	0,65± 68.86	0,59± 68.86	22,7± 62.77	22,5± 62.77	22,0± 62.77
S_3	0,89± 62.95	0,78± 62.95	0,77± 62.95	19,4± 71.65	20,1± 71.65	21± 71.65
S_4	0,52± 67.68	0,58± 67.68	0,55± 67.68	23,8± 65.12	23,2± 65.12	22,7± 65.12
S_5	0,76± 82.12	0,72± 82.12	0,64± 82.12	22,4± 58.73	22,8± 58.73	22,2± 58.73
S_6	0,54± 72.08	0,56± 72.08	0,57± 72.08	23,6± 62.23	23,1± 62.23	23,7± 62.23
S_7	0,6± 75.83	0,6± 75.83	0,56± 75.83	24± 69.12	23,8± 69.12	22,9± 69.12
S_8	0,54± 67.71	0,58± 67.71	0,64± 67.71	23,7± 62.83	23,2± 62.83	20,7± 62.83
S_9	0,43± 69.34	0,47± 69.34	0,59± 69.34	24,8± 63.02	23,9± 63.02	22,0± 63.02
S_{10}	0,46± 80.10	0,46± 80.10	0,77± 80.10	26,1± 69.39	25,8± 69.39	21± 69.39
S_{11}	0,55± 67.29	0,5± 67.29	0,55± 67.29	22,8± 71.82	23± 71.82	22,7± 71.82
S_{12}	0,58±75.77	0,59± 75.77	0,64± 75.77	23,1± 61.80	23,4± 61.80	22,2± 61.80

P- extension;
L-dough extensibility;
W-deformation energy;
I_e- elasticity index;
P/L- curve configuration ratio.
SD- standard deviation.

As can be seen from Table 3 to Table 4 the data obtained for alveographic properties do not have major differences between the three storage years. The obtained value of p used ANOVA test is greater than 0,05, meaning that the values have not changed significantly over the three years, the ANOVA test was performed using Microsoft Excel. The values are relatively close, with only some samples presenting a slight decrease between 2020 and 2021, only in some samples. Between the three years studied on these samples and the two types of analysis, no major differences were observed, the values were kept constant, only in the third year can small changes be specified, but it is not possible to say that these changes are due to storage conditions. From this study, we can conclude that storage was safe and carried out in good conditions. The alveographic parameters such as the elasticity of the dough (P), extensibility (L), and the dough deflection energy (W) obtained using an alveograph also describe the viscous properties of the dough. The tenacious AlvP (AlvP) measures the dough against the maximum pressure required for the dough deflection, while the alveograph extensibility (L) indicates the expandability of the curve and P/L is the configuration ratio of the curve. The inflation index (G) is the square root of the essential volume of air needed to break the bubble and is primarily a measure of the extensibility of the dough. The W value is taken as a measure of the resistance of flour (Faridi and Reper, 1987). Extensive research on durum wheat and soft wheat (Rasper *et al*., 1986) has shown that the processing behaviour of wheat flour can be determined by the alveograph and that the suitability for specific end-use can be assessed. The variation in L and W is more influenced by the environment than P, due to the influence of the protein content on L and W. Dubois *et al*., 2008, reported that high W and low L-values are characterized a standard quality wheat has values of elasticity of the alveograph (P) for the range 60-80 mm, very good quality wheat 80-100 mm, while extra hard wheat is characterized by a P value greater than 100 mm. Furthermore, the L of 100 mm is generally considered good, although some applications require higher values (e.g. biscuits production). Wheat suitable for the production of bread should have a P/L value of less than 0,80. For the interpretation of W, good quality wheat and wheat improvement are characterized by W in the range 220-300 and greater than 300 (Bordes *et al*., 2008).

Wheat bread flour with a W value higher than 300 is considered strong, flour with W >220 is considered flour with W higher, than 160 is usually recommended for bread production and more than 115 for biscuits obtaining (Chopin, 2001). However, in the case of the P/L ratio, wheat flour with more than 0,6 may be used to make bread. According to (Faridi *et al*., 1987) one of the basic factors for the classification of wheat is the alveograph parameter W. In Europe, W-value flour between 130 and 160 can be classified as useful for bread production, 160 to 250 as an improvement in baking properties and over 250 as high gluten flour. By compacting the data obtained with the data from literature, the wheat analysed is of superior quality and the obtained values indicate a good wheat for the bakery industry. The W values obtained in the three years are in most samples above 200 or close, have not varied greatly during these years, meaning that the wheat is good for bread and the conditions to be stored are effective.

Conclusions

The samples analysed do not vary widely over the three years of storage under the conditions they were kept in. The data recorded over the three years to date show that wheat was kept under microclimatic conditions. Even during summer, when temperatures can easily exceed the threshold of thermal discomfort, especially in July-September, the wheat stored in the store has not undergone any changes in quality. The values obtained in all three storage years were not be less than 350 s for all 12 samples analysed and the highest recorded value was 548 s in 2020 in sample 11. The values are relatively close, a slight decrease is observed between 2020 and 2021, only in some samples. Between the three years studied and the two types of analysis, no major differences were observed. From this study, we can conclude that storage is safe and carried out in good conditions. The results obtained varied from storage factors, climatic conditions, harvesting methods, the diseases which the wheat has taken over during its development to threshing, pesticide treatment and pest action.

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