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Quality Profiling of Wheat Flour from Commercial Cultivars Grown in Brazil

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HIGHLIGHTS

- Comprehensive evaluation of wheat flour quality through physicochemical and rheological properties.
- Damaged starch granules increase susceptibility to α -amylase, impacting flour functionality.
- Climatic conditions play a critical role in determining wheat grain quality.

Abstract: Wheat is one of the most important cereal crops worldwide, and its flour quality is directly related to grain characteristics, which are influenced by genetics, environmental conditions, and geographical factors. Understanding the technological properties of wheat flour is essential for defining its suitability for different food applications. This study aimed to evaluate the physicochemical and rheological parameters of wheat flours produced from varieties cultivated in Paraná State, Brazil. Wheat samples were collected from three municipalities (Arapoti, Paulo Frontin, and Ponta Grossa), and physical properties of the grains (test weight and thousand kernel weight) were determined. Flours were produced using a laboratory mill (Chopin CD-1) to simulate industrial processing. Analyses included moisture, ash, protein, gluten content, granulometry, damaged starch, color, and rheological properties (alveography, farinography, pasting properties, falling number, and stirring number). Significant differences were observed among the flours for most evaluated parameters. Under the same milling conditions, the samples resulted in different flour types, which could be classified as type I, type II, and whole flour, according to Brazilian legislation. The varieties 'Audaz', 'Calibri', and 'Feroz', cultivated in Arapoti, exhibited superior rheological properties, especially for breadmaking purposes. These findings contribute to a better understanding of the quality profile of wheat flours from different varieties and highlight the influence of environmental conditions on technological performance. This knowledge can support both producers and the milling industry in improving wheat flour classification and optimizing its commercial value.

Keywords: cereal; physicochemical and rheological parameters; alveography; farinography; technological application.

INTRODUCTION

The cultivation of wheat (*Triticum aestivum* L.) is increasingly significant, positioning Brazil among the world's leading producers of this cereal [1]. Wheat production is one of the most critical sectors in agriculture due to the essential role of wheat flour, which is extensively utilized in the food industry [2]. In 2022, Brazil's wheat production reached 10.3 million tons, with cultivated areas primarily concentrated in the South, Southeast, and Mid-West regions. The South region alone accounts for approximately 90% of the national harvest [1].

Wheat flour is produced by milling cleaned and sound kernels, separating the morphological fractions (external layers, embryo, and endosperm) through sieving, and reducing endosperm particles into flour of high economic value [3]. This flour is crucial for manufacturing bread, biscuits, cakes, pasta, and various other food products [4]. The use of flour in these products necessitates specific physical, chemical, and rheological properties, as these characteristics significantly influence the final quality of the food items [5].

One of the primary factors determining flour quality is the structure of the wheat endosperm [5]. For instance, endosperm hardness is closely linked to milling performance, affecting the levels of damaged starch, particle size distribution, process yield, and the physicochemical and rheological properties of the resulting flour [3, 6, 7].

The production of high-quality flour is heavily dependent on the quality of harvested wheat, which is influenced by numerous field-related challenges such as weather conditions, sowing periods, cultivation regions, and varieties cultivated. Understanding these variables is essential for the success of the wheat industry, as it requires the provision of suitable flours for diverse applications in the food sector [8]. Climate change is one of the main challenges facing humanity and has the potential to significantly impact wheat cultivation worldwide. In this context, Brazil must prepare to address these challenges. Therefore, gaining deeper insights into genotype - environment interactions is crucial for improving wheat production [9, 10].

Understanding the technological quality and its range is essential for determining the appropriate applications of flours derived from various wheat varieties and those cultivated in different geographical locations. The primary objective of this study was to evaluate selected wheat varieties harvested in the principal wheat-producing region of Brazil (the State of Paraná) by analyzing the physicochemical and rheological properties of flours obtained from a laboratory mill.

MATERIAL AND METHODS

Reagents, enzymes and wheat samples

All reagents used in the present study were of analytical grade. The fungi α -amylase (EC 3.2.1.1) used in the analysis was from *Aspergillus oryzae* (E-ANAAM, 120 U/mg), obtained from Megazyme (Wicklow, Ireland). The wheat samples were donated by farmers and by an agricultural cooperative from the state of Paraná. In this study, 13 samples were available, and they differ between their genetic background and region of cultivation. The samples were harvested in the year 2022 in three different cities of Paraná state (Table 1).

Table 1. Wheat varieties and regions of cultivation.

Variety	Regions of cultivation	Codification
Ágile	Paulo Frontin – PR	Ágile PF
Audaz	Paulo Frontin – PR	Audaz PF
Bela Jóia	Paulo Frontin – PR	Bela Jóia PF
Destaque	Paulo Frontin – PR	Destaque PF
Sena	Paulo Frontin – PR	Sena PF
Sonic	Paulo Frontin – PR	Sonic PF
Audaz	Ponta Grossa – PR	Audaz PG
Audaz	Arapoti – PR	Audaz AP
Calibri	Arapoti – PR	Calibri AP
Ello	Arapoti – PR	Ello AP
Feroz	Arapoti – PR	Feroz AP
ORS 1405	Arapoti – PR	ORS 1405 AP
Madre Pérola	Arapoti – PR	Madre Pérola AP

Meteorological data were collected from all regions included in this study, both directly from farmers and from a regional research foundation [11]. The variation in rainfall throughout the entire crop cycle, including at harvest period, was taken into consideration.

Physical Characterization of wheat kernels

Test Weight (TW) and Thousand kernel weight (TKW)

Test weight was determined following the methodology reported in the Rules for Seed Analyses from the Brazilian Ministry of Agriculture [12]. TW values were obtained by using a specific scale (Dalle Molle, Caxias do Sul, RS, Brazil) and expressed as kg hL⁻¹. Calculations followed the equivalence table from the State of Paraná Cooperative Organization (Ocepar) system. The TKW was determined following the methodology reported in the Rules for Seed Analyses from the Brazilian Ministry of Agriculture [12].

Wheat milling

The wheat grains were processed using a laboratory mill (Chopin CD1, Villeneuve-la-Garenne, France), following the AACC 26-10 method [13]. Immediately prior to milling, the moisture contents of the grains were adjusted to between 12% and 14%, after which the milling process was conducted.

Color

The color was measured by a portable colorimeter (Mini Scan EZ, Hunter Lab, Reston VA, USA) using the CIEL*a*b* system. The color parameters L* (luminosity), a* and b*, chromaticity (chroma), and hue angle (°H) were taken into consideration [14].

Moisture, protein and ash contents

The compositional analyses followed the methods previously described [15]. Protein determination was made considering the value of 5.83 as a conversion factor. All results were expressed in dry basis (except for moisture content) as percentage (m m⁻¹).

Granulometry

Granulometry of the produced flours was evaluated by sequential sieving 50 g through 250 µm opening [16]. The results were expressed as the percentage of flour that passed through the 250 µm opening sieve.

Damaged starch

The level of damaged starch was measured following the method of Boyaci, Williams e Koksel [17] and Farrand [18] with slight modifications, by hydrating the flour samples, following enzymatic hydrolysis (fungi α-amylase). After that, the samples were passed through paper filter, and total soluble solids were measured by refractometry (°Brix). Damaged starch content was calculated according to Equation 1.

$$\text{Damaged starch} = ((B2-B1)*V/M)*F \quad (1)$$

Where: B1: °Brix blank; B2: °Brix sample; V: total volume (50mL); M: mass of wheat flour (g); F: conversion factor: 1.64. The results were expressed in percentage (m m⁻¹) in relation to the initial wheat flour.

Rheology of the flours

Farinography

This analysis was made with a Perten DoughLAB 2500 (Perkin-Elmer, Shelton, CT, USA) as described by the AACC 54-21 and AACC 54-70 methods [13]. The water absorption (% m/m), development time (min), stability (min), and degree of softening (UF) were registered in a farinogram.

Alveography

The wheat flour samples were analyzed in a calibrated Chopin Alveolab alveograph (Chopin, Villeneuve-la-Garenne, France), following the AACC 54-30 official method [13], with obtention of the parameters: dough deformation (W - 10⁻⁴ J), dough tenacity (P - mmH₂O), extensibility (L-ext - mm) and the P/L ratio.

Pasting properties

The pasting properties were analyzed by using a Rapid Visco Analyzer (RVA-4, Newport Scientific, Australia), with the STD-2 profile from Thermocline for Windows software. Each sample was suspended in distilled water (10 %, m m⁻¹, dry basis) (28 g, total mass) and exposed to continuous heating followed by a cooling step, down to 50°C until the end of the analysis [19].

Falling Number

The Falling Number was measured in a Perten Falling Number 1000 device, following the official method from AACC International [20].

Stirring Number

The Stirring Number is an alternative method to estimate the α – amylase activity using the Rapid Visco Analyzer (RVA - 4, Newport Scientific, Australia). The wheat flour samples were suspended in distilled water (10%, m m⁻¹, dry basis) (28 g, total mass), and continuously stirring (160 rpm), heating to 95°C, keeping at that temperature for 3 min [19].

Gluten content

The gluten content was determined by using the Glutomatic 2000, according to the official AACC method [21].

Statistical analysis

The results were submitted to analysis of variance (ANOVA) and Tukey test to discriminate the mean values at 95 % ($p < 0.05$) confidence level, with the use of Statistica v. 13.3 software (Statsoft South America, São Caetano do Sul, SP, Brazil).

RESULTS AND DISCUSSION

Physical characterization of wheat kernels

Test weight (TW)

The test weight values of all samples (Table 2) showed variations of 17.02% when comparing the varieties Sena PF with Audaz AP and Calibri AP. Each determination was repeated three times, but there was no variation between them. According to legislation of the Brazilian Ministry of Agriculture (IN n° 38, from November 30th, 2010) [22], which defines the official standards for wheat classification, it can be divided into two groups. Group I: wheat for human consumption, and Group II: wheat for other uses.

Table 1. Test weight (TW), thousand kernel weight (TKW) values and flour yield from the different wheat grains.

Variety	TW (kg hL ⁻¹)	TKW (g)	Flour yield (%)
Ágile PF	76.35	30.08±0.38 ^h	62.01
Audaz PF	77.90	30.75±0.25 ^h	62.44
Bela Jóia PF	79.25	27.87±0.31 ⁱ	ND*
Destaque PF	79.70	26.61±0.07 ^j	ND*
Sena PF	71.40	44.45±0.20 ^a	54.05
Sonic PF	76.35	40.86±0.10 ^b	ND*
Audaz PG	79.25	34.00±0.35 ^g	83.18
Audaz AP	83.55	36.45±0.20 ^d	70.95
Calibri AP	83.55	39.04±0.64 ^c	72.77
Ello AP	82.40	35.14±0.87 ^{ef}	ND*
Feroz AP	81.50	38.54±0.13 ^c	65.00
ORS 1405 AP	79.45	34.72±0.22 ^{fg}	66.51
Madre Pérola AP	81.70	35.83±0.28 ^{de}	66.83

Means followed by different low case letters in the same column differed significantly ($p < 0.05$) by the Tukey.

*ND: Not determined due to technical issues.

TW classifies wheat inside those two groups in Types I, II and III (minimum TW values of 78 kg hL⁻¹, 75 kg hL⁻¹ and 72 kg hL⁻¹, respectively). According to that IN n° 38, TW values lower than 72 kg hL⁻¹ indicate wheat without the minimum quality to be milled [22]. In a previous agronomic evaluation of six wheat varieties cultivated in the West region of Paraná state in the year 2021 were studied. TW values for varieties Bela

Jóia, Madre Pérola and Audaz were, respectively, 77.7 kg hL⁻¹, 74.1 kg hL⁻¹ and 75.5 kg hL⁻¹. The relatively low TW values were attributed to climatic issues, mainly low levels of moisture in the soil [23]. TW is a very important indicator of wheat kernel soundness and is directly related to milling yield [24].

The pluviometry data for the wheat cultivation regions throughout the crop cycle is available (Figure 1). As observed, rainfall increased significantly during August, corresponding to the final development period of wheat. This climatic condition contributes to the reduction of test weight (TW) values due to weight loss occurring close to harvest time. Figure 1 shows that rainfall levels were relatively proportional in the three geographic regions. By analyzing the TW values for each sample, it was possible to note that wheat grown in the municipality of Arapoti had the highest values. The explanation may reside in the fact that sowing in that region occurred in different periods and the varieties from Arapoti were less exposed to excess rain, not resulting in TW dropping. Arapoti is in a northern geographical position in Paraná State with warmer weather that accelerates wheat harvesting around 50 days before the harvest of the region of Paulo Frontin, where harvesting is done in late October.

Rainfall distribution across the days of each month (Table S1, Supplementary Material) indicates that Paulo Frontin experienced a high volume of rainfall over a short period, coinciding with the beginning of the harvest. This likely contributed to the observed decrease in TW values. In contrast, Arapoti, which was less affected by rainfall during the harvest period (late August to early September), recorded the highest TW values. The Paulo Frontin region experienced extremely dry conditions in July, followed by heavy rainfall in August. In Ponta Grossa, rainfall patterns were more like those in Arapoti, with a more uniform distribution throughout the crop cycle.

Thousand kernel weight (TKW)

TKW results are shown (Table 2) and differed by 67.04 % when comparing the varieties Destaque PF and Sena PF. TKW is a relevant quality indicator for wheat, proportional to the size of the kernel. The grains are classified as very small, small, medium, big, and very big (15 – 25 g, 26 – 35 g, 36 – 45 g, 46 – 54 g and ≥ 55 g, respectively) [25]. Our results showed small and medium kernels for all the varieties. The samples classified as medium size kernels were Sena PF, Sonic PF, Audaz AP, Calibri AP, Feroz AP and Madre Pérola AP. All others had small size kernels. In general, medium and small kernels have a better performance during milling when compared to the extremes (very large and very small) [25].

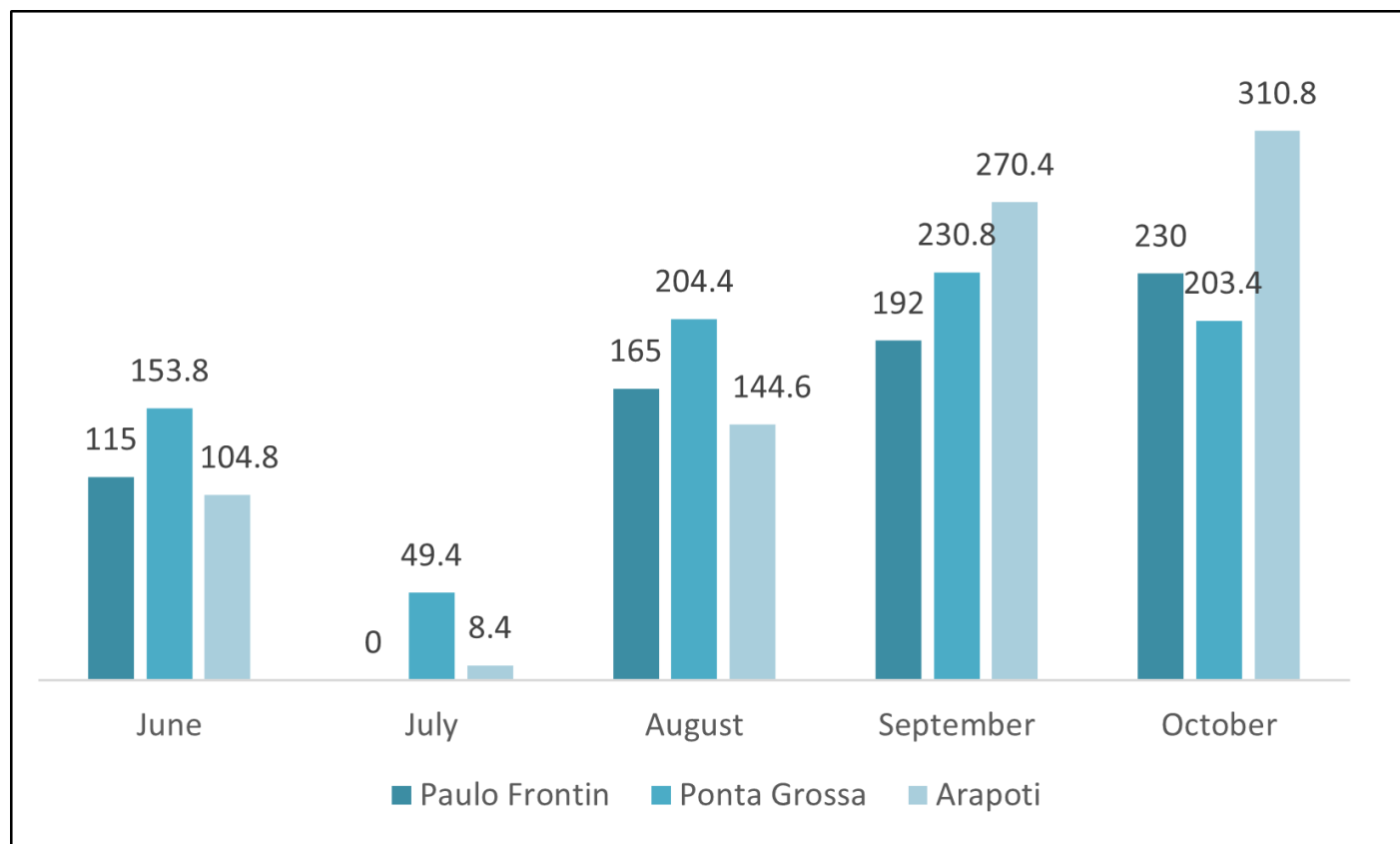


Figure 1. Rainfall (mm) during wheat crop (year 2022) in the regions of the study.

Wheat flour extraction

In commercial wheat milling, the objective is to produce the maximum amount of white and fine flour, with low ash content, without contamination with bran. Flour yield is one of the most important factors that drive the selection of desired wheat varieties for milling. This is a big challenge to millers, i.e., increasing flour yield without compromising its color, ash content, rheological and general quality to reach the consumers' needs [26]. Laboratory milling was carried out, and the flours were produced of the desired quality. Results from process yield are presented in Table 2. The results showed that yield varied considerably among the samples, with the lowest and highest values found for the samples Sena PF and Audaz PG. Yield is directly related to TW, because high TW means high percentage of endosperm in the grain that will give large amount of flour [25]. Based on the test weight (TW) and milling yield results observed in the present study, it was noted that the wheat cultivar with the lowest TW value - Sena PF - resulted in the lowest extraction yield. However, the cultivar with the highest yield - Audaz PG - did not exhibit the highest TW value. The cultivars Audaz AP and Calibri AP showed TW values of 83.55 kg hL⁻¹, with extraction yields of 70.95% and 72.77%, respectively. The remaining cultivars presented yields ranging from 62.01% to 66.83%.

As shown in Table 2, extraction percentages were not determined for some cultivars. This was due to operational failures in the laboratory mill during the processing of those specific varieties, which led to substantial mixing of flour with bran and, consequently, compromised the accurate determination of extraction yield. Wheat can be classified according to its flour extraction yield as follows: good extraction yield (66 - 68%), low milling potential (63 - 65%), and very low milling potential (<62%). In the present study, the only cultivar classified as having very low milling potential was Sena PF, which notably was also categorized as "off-type" based on its test weight (TW) [25].

Physicochemical characterization of wheat flours

Physicochemical characteristics of wheat flour are shown in Table 3. All the characteristics have limits established by the Brazilian rules, i.e, maximum of 15% and 0.8%, for moisture and ash, respectively (type I), ash between 0.81 and 1.4% (type II) and ash ranging from 1.41 to 2.5% for whole wheat flour. In the case of protein content, the minimum acceptable is 7.5% for type I and 8% for type II and whole wheat flour [27].

The results showed that all flours had protein levels in line with the type I product, with a minimum of 10.50 % (Madre Pérola AP) and a maximum of 14.98 g 100 g⁻¹ (Sena PF). The ash contents, on the other hand, varied from 0.52 to 1.20 %, resulting in different classifications. Considering ash levels, the varieties Madre Pérola AP, ORS 1405 AP, Feroz AP, Ello AP, Calibri AP, Sonic PF, Audaz AP, and Audaz PF were classified as type I, whereas Audaz PG, Sena PF, Destaque PF, Bela Jóia PF, and Ágile PF, as type II [27].

In a previous study, particle size distribution was correlated with ash content. In general, the larger the particle size, the higher ash contents are present. For flour fractions with particles ranging from 0.15 - 0.30 mm, ash contents ranged from 1.50 to 2.29 % (m m⁻¹), higher than the values found in our work [28]. High ash content can also be related to the presence of aleurone layers [29]. This presence of aleurone layer seems to be associated with our results for ash contents, which were a little higher than those reported for commercial flours [30]. All the studied varieties had high protein contents with the highest levels present in the samples from the Paulo Frontin region. These values are generally related to the gluten contents and though, to the breadmaking potential of the varieties. There are, however, great gluten quality differences and the quantitative aspect alone cannot be attributed to the flour technological performance [31].

Color

Wheat flour color is one of the most important properties for application is different food products [32]. The color parameters (L*, a* and b*) are shown in Table 3. From these parameters, it was possible to calculate Chroma* and °H values. There were differences in all analyzed parameters and varieties. The L* value ranged from 86.38 to 93.80 for Destaque and Madre Pérola varieties, respectively. From our data, the varieties produced in Arapoti were the whitest (higher L*), followed by those from Ponta Grossa. The least white ones were those produced in the Paulo Frontin region (L* below 90.20). The highest L* value from all samples was that from the Madre Pérola AP variety that also had the lowest a* and b* values. This variety was classified as whitening wheat for breadmaking [33]. On the other hand, Sena PF and Destaque PF varieties had the lowest L* values as well as the highest a* values, indicating the most yellow-orange color.

The thirteen wheat flour samples analyzed exhibited similar values for hue angle (°H). However, a significant variation was observed for this parameter, ranging from 83.04 to 88.31, indicating that the samples' color varied between red and yellow, with a stronger tendency toward yellow. Significant differences were also found in Chroma* values among the samples, ranging from 7.41 for the cultivar Madre Pérola AP to

13.24 for Bela Jóia PF. This parameter reflects the degree of color saturation, where higher Chroma* values correspond to a greater color saturation. Moreover, higher values of a* and b* are associated with increased Chroma*, consistent with the findings reported in this study [34].

Ash contents correlated negatively to the L* values for the same varieties cultivated in different regions, i.e., those cultivated in Arapoti (AP) were whiter and had the lowest ash contents, in line with previously published data [35, 36]. One exception to this logical was the variety Bela Jóia PF with L* value 90.17 but a high level of ash content (1.17 %, m m⁻¹). For other varieties with L* close to this one, ash contents were lower. This behavior can be related to the presence of the aleurone layer, which could be milled together with the wheat endosperm, incorporated into the flour [37].

Granulometry

Flour granulometry corresponds to the particle size distribution, and the product can be classified as type I, type II or whole wheat flour. The 95 percent must pass through a 250 µm opening sieve [27]. The granulometry results are shown in Table 3. The percentage of sieved product ranged from 99.59% to 99.95%; however, no significant differences were observed among the cultivars. These results are partially consistent with those reported by a previous study that evaluated three commercial wheat flour cultivars in the local market of Belém, PA, where particle size distribution ranged from 94.33% to 98.86%. In that case, one of the samples did not meet the requirements established by the MAPA Normative Instruction, as it presented a percentage below the legal threshold. The authors attributed this variation to the high standard deviation observed in their results [38].

Wheat flour granulometry is very important for food applications and depends on the quality of raw material as well as on the process adopted [39]. Reaching homogeneous and appropriate granulometry is crucial, especially in breadmaking because the gluten network can be easily affected. In a previous study in which coarser wheat flour was used, bread with limited volume was obtained and the undesirable effect of the fiber fraction on the gluten network was used to discuss the results [40].

Damaged starch (DS)

Damaged starch appears due to mechanical stress during the roll-milling process. The level of damaged starch depends on various factors, including breaking rolls pression, gaps between the rolls, time of milling, grain hardness, among others [6]. The results for damaged starch are presented in Table 3. The levels of damaged starch differed significantly ($p < 0.05$) among samples. The highest levels of DS were found in varieties cultivated in the Paulo Frontin region, followed by those from the Ponta Grossa region, and finally, from Arapoti region. In the case of the Paulo Frontin region, the DS levels ranged from 4.67 to 15.94%, for the varieties Audaz PF and Sena PF, respectively. In the Ponta Grossa region, the value 7.79% was found for the variety Audaz PG. In the Arapoti region, the values ranged from 1.17 - 5.45% for the varieties ORS 1405 AP and Ello AP, respectively.

Differences in the grain hardness may be the cause for the distinct levels of DS [6]. The higher levels of DS can result in higher water absorption levels and that can result in some technological issues [41].

With the different levels of damaged starch in the flours, distinct pasting property parameters are expected to be confirmed [42]. This behavior is also possible to note when comparing results presented on Tables 3 and S2 (Supplementary Material). DS levels not too high in wheat flour can be desirable, in some respects. Higher water absorption is one of the effects, and the availability of soluble sugar to yeast favors fermentation and gas production. If the level of DS is excessive, above 8%, the possible benefits disappear, and the dough becomes excessively sticky resulting in low quality breads and biscuits [43]. Soft wheat varieties are easier to mill and result in low levels of DS due to weak protein – starch interaction inside the endosperm [43]. In the present study, the sample with the lowest protein content had also the lowest level of DS when milled (Madre Pérola AP). On the other hand, the variety with the highest protein content resulted in the flour with the highest DS level (Sena PF).

Rheological characterization of the flours

Farinography

The farinography gives important measurements that are essential to wheat flour quality check [44]. In Table 4, the results of farinography are presented. Absorption, stability and dough development time (DDT) have values ranging from 52.1 to 70.3 %, 4.1 to 18.4 min and 1.9 to 14.5 min, respectively. The farinograph results help to anticipate flour industrial performance. A long development time is related to high protein content, in the same way that greater stability, indicating a stronger gluten. Absorption and degree of softening may be related to gluten composition and damaged starch content [45].

Table 3. Physicochemical characteristics, color parameters, granulometry and damaged starch of wheat flours.

Variety	L*	a*	b*	Chroma*	°H	Moisture %	Ash %	Protein %	% sieved	Damaged starch (%, m m ⁻¹)
Ágile PF	88.74±0.17 ^d	1.20±0.04 ^a	12.59±0.10 ^{ab}	12.64±0.10 ^{ab}	84.54±0.22 ^e	11.72±0.24 ^{ef}	0.92±0.001 ^b	13.51±0.14 ^{bc}	99.86±0.04 ^a	10.89±1.78 ^b
Audaz PF	89.76±0.37 ^d	0.98±0.04 ^b	13.15±0.16 ^a	13.19±0.16 ^a	85.74±0.17 ^{bcd}	12.37±0.14 ^c	0.75±0.010 ^{bc}	12.07±0.16 ^{de}	99.71±0.09 ^a	4.67±1.16 ^{efg}
Bela Jóia PF	90.17±0.23 ^{cd}	1.19±0.09 ^a	13.19±0.36 ^a	13.24±0.37 ^a	84.86±0.32 ^{de}	11.83±0.08 ^{def}	1.17±0.105 ^a	14.04±0.63 ^{abc}	99.88±0.04 ^a	9.72±1.34 ^{bc}
Destaque PF	86.38±1.24 ^e	1.26±0.05 ^a	12.99±0.20 ^a	13.05±0.20 ^a	84.45±0.12 ^e	11.12±0.07 ^g	0.85±0.119 ^{bc}	13.46±0.05 ^{bc}	99.59±0.47 ^a	5.17±0.68 ^{def}
Sena PF	86.45±0.50 ^e	1.37±0.02 ^a	11.22±0.08 ^{cd}	11.31±0.08 ^c	83.04±0.05 ^f	10.39±0.16 ^h	1.20±0.021 ^a	14.65±0.03 ^a	99.89±0.05 ^a	15.94±0.67 ^a
Sonic PF	90.20±0.58 ^{cd}	0.91±0.07 ^b	10.75±0.28 ^{cde}	10.79±0.28 ^{cd}	85.17±0.31 ^{cde}	11.50±0.23 ^{fg}	0.78±0.202 ^{bc}	11.48±0.99 ^{ef}	99.90±0.11 ^a	12.08±1.34 ^b
Audaz PG	91.53±0.37 ^{bc}	0.87±0.06 ^b	12.35±0.13 ^b	12.38±0.13 ^b	85.99±0.26 ^{bc}	12.11±0.03 ^{cde}	0.96±0.158 ^b	14.25±0.24 ^{ab}	99.92±0.12 ^a	7.79±1.36 ^{cd}
Audaz AP	92.27±0.18 ^{ab}	0.95±0.12 ^b	11.35±0.31 ^c	11.39±0.31 ^c	85.22±0.52 ^{cde}	12.47±0.20 ^c	0.68±0.024 ^{cd}	12.26±0.20 ^{de}	99.93±0.05 ^a	2.34±0.00 ^{fgh}
Calibri AP	91.45±0.56 ^{bc}	0.92±0.02 ^b	12.22±0.20 ^b	12.25±0.20 ^b	85.69±0.04 ^{bcd}	13.08±0.20 ^b	0.74±0.02 ^{bc}	12.05±0.04 ^e	99.79±0.05 ^a	1.56±0.67 ^h
Ello AP	91.53±0.37 ^{bc}	0.87±0.06 ^b	12.35±0.13 ^b	12.38±0.13 ^b	85.99±0.26 ^{bc}	13.93±0.23 ^a	0.71±0.013 ^{cd}	13.01±0.01 ^{cd}	99.84±0.07 ^a	5.45±0.68 ^{de}
Feroz AP	92.61±0.42 ^{ab}	0.64±0.04 ^c	10.62±0.04 ^{de}	10.64±0.03 ^d	86.57±0.23 ^b	12.27±0.13 ^{cd}	0.60±0.040 ^{cde}	12.22±0.13 ^{de}	99.95±0.04 ^a	4.68±1.17 ^{efg}
ORS 1405 AP	89.94±0.63 ^d	0.97±0.08 ^b	10.38±0.25 ^e	10.43±0.25 ^d	84.65±0.40 ^e	12.42±0.13 ^c	0.52±0.089 ^{cdef}	10.74±0.09 ^{fg}	99.80±0.03 ^a	1.17±0.00 ^h
Madre Pérola AP	93.80±0.25 ^a	0.22±0.08 ^d	7.40±0.29 ^f	7.41±0.29 ^e	88.31±0.58 ^a	12.48±0.03 ^c	0.61±0.052 ^{cde}	10.27±0.41 ^g	99.78±0.61 ^a	1.95±0.67 ^{gh}

Means followed by different low case letters in the same column indicate significant difference (p<0.05) by the Tukey test.

Table 4. Farinography of wheat flour samples.

Variety	Absorption (%)	Stability (min)	Dough development time (min)	Degree of softening (FU)
Ágile PF	66.2	7.5	5.9	110.5
Audaz PF	61.2	11.2	7.4	63.3
Bela Jóia PF	66.7	4.7	4.2	104.1
Destaque PF	62.8	5.2	3.1	153.9
Sena PF	ND	ND	ND	ND
Sonic PF	70.3	4.1	3.3	205.9
Audaz PG	63.4	6.2	4.7	-
Audaz AP	66.2	18.0	14.5	94.1
Calibri AP	63.1	18.4	2.5	12.5
Ello AP	63.4	5.8	5.3	91.4
Feroz AP	64.8	14.0	10.1	-
ORS 1405 AP	52.1	16.7	1.9	32.0
Madre Pérola AP	65.7	10.4	6.9	32.0

*ND: Not determined. FU = farinographic units

Our results showed dough development times for the samples Audaz AP, Feroz AP and Audaz PF of 14.5 min, 10.1 min and 7.4 min, respectively. When associating DDT with protein contents, it was possible to note that the samples with the highest DDT values presented intermediary protein contents, roughly 12% when compared to the others. Some samples presented low DDT values but high protein levels, not aligned with other studies [43], but such behavior can be related with differences in the quality of protein that in some cases will not produce a high-quality gluten network for the desired dough performance.

When considering the water absorption level, sample Sonic PF ranked first and was the flour with the second highest damaged starch content (12.08%), after the sample Sena PF. Due to the very low amount of this last sample, it was not possible to make its farinograph analysis. It is well established that high DS levels will be related to high absorption of the flours [41]. In this study, the samples with the best results for stability were Calibri AP, Audaz AP, ORS 1405 AP, Feroz AP, Audaz PF and Madre Pérola AP. Strong flours have superior DDT and stability [46]. This was the case of these samples, which were also analyzed by the alveograph.

Another important parameter that the farinograph provides is the degree of softening, which means a way of evaluating gluten's strength. Weak flours have high values due to the protein network degradation during mechanical stress [47]. In this work, the samples that presented the lowest degree of softening were Sonic PF, Destaque PF, Ágile PF and Bela Jóia PF. These same samples had relatively low values of the alveographic parameter W. The samples Audaz PG and Calibri AP had a different behavior and did not show detectable degree of softening, suggesting that they were stable, i.e., their gluten network did not lose consistency with the mechanical stress.

A strong wheat flour has certain attributes, including water absorption higher than 59 %, dough development time higher than 3 min and degree of softening lower than 40 FU. In the case of weak flours, the degree of softening is above 150 FU, indicating that dough will not resist the necessary mechanical work to develop a desirable gluten network [44].

Alveography

The most used technique to test gluten quality nowadays is alveography [31]. These rheological parameters are essential to understand the potential of the flours to their best uses [48]. The results showed that some samples had high W values, i.e., Feroz AP, Calibri AP and Audaz AP, with values of $273 \cdot 10^{-4} \text{ J}$, $291 \cdot 10^{-4} \text{ J}$ and $366 \cdot 10^{-4} \text{ J}$, respectively (Table 5). For breadmaking, the values of P/L must be close to 1 and W must range from $170 - 275 \cdot 10^{-4} \text{ J}$ [49].

Wheat can be grouped into three kinds, depending on its destination: a) Bread flour, which produces elastic and resistant dough, with high P value and big L (L-ext) value for bubble rupture, with typical P/L of 0.9 and W higher than $170 \cdot 10^{-4}$ J; b) Flours for biscuit or mixtures, which generate extensible dough with low P and big L; P/L in general low (0.55) and W ranging from 80 to $120 \cdot 10^{-4}$ J; c) Flours apt only for animal nutrition, with hard dough due to big P and short L for bubble rupture, with P/L from 0.3 to 1.5 and W ranging from 60 to $140 \cdot 10^{-4}$ J [50].

Table 2. Results from the alveograph analysis of wheat flours.

Variety	P	L-ext	W	P/ L-ext
Ágile PF	85	81	201	1.05
Audaz PF	73	80	186	0.91
Bela Jóia PF	68	48	92	1.42
Destaque PF	76	51	110	1.49
Sena PF	61	87	61	0.70
Sonic PF	108	47	157	2.30
Audaz PG	55	90	183	0.61
Audaz AP	102	109	366	0.94
Calibri AP	77	126	291	0.61
Ello AP	63	58	110	1.09
Feroz AP	96	100	273	0.96
ORS 1405 AP	101	68	226	1.49
Madre Pérola AP	38	95	138	0.40

* P (elasticity). L-ext (extensibility), W (deformation energy from the dough) and P/L (ratio between elasticity and extensibility); the results from these parameters are expressed as mmH₂O, mm and 10^{-4} J, respectively.

Based on our results, the samples that showed the highest potential as bread flour were: Ágile PF, Audaz AP, Feroz AP and ORS 1405 AP. It was also evident that the samples from Paulo Frontin region had similar results for elasticity (P), however, extensibility varied considerably, ranging from 47 to 81 mm. In the case of samples from the region of Arapoti, the same behavior was noted but with their P and L-ext parameters ranging from 38 to 102 mmH₂O and from 58 to 126 mm, respectively. The sample from the region of Ponta Grossa presented values in between those of the other two regions. The highest P and the lowest L-ext values, i.e., the highest P/L ratio was found for the sample Sonic PF.

The results of dough deformation (W) ranged from 61 to $366 \cdot 10^{-4}$ J, with four samples from the region of Arapoti those with the highest values: Audaz AP, Calibri AP, Feroz AP and ORS 1405 AP ($366 \cdot 10^{-4}$ J, $291 \cdot 10^{-4}$ J, $273 \cdot 10^{-4}$ J and $226 \cdot 10^{-4}$ J, respectively). All other samples had W values below $201 \cdot 10^{-4}$ J. Sena PF was the sample with the lowest W ($61 \cdot 10^{-4}$ J), despite its high content of moist gluten (Table 6). This fact shows that high gluten content does not ensure high gluten quality. It depends on the interaction among other parameters. When considered together with other rheological analyses, the results for this sample were not favorable.

The alveography results from flours of the samples Ágile PF, Audaz PF, Sena PF, Audaz PG, Feroz AP and Madre Pérola AP showed L values that were similar, but for the value P, they differed. The maximum deformation capacity of the dough differed depending on the origin of the flour. Dough that resists high tension has a superior gluten network, as well as high concentrations of protein [51]. But not only the amount of protein (gluten) reflects the resistance to deformation; molecular mass of the protein and its interaction with starch during the network formation is very important [52]. In general, our findings showed that most wheat

samples analyzed had low resistance to tension whilst high extensibility with low deformation energy. Such behavior signs for flours that do not perform well in breadmaking due to poor gluten network development and, consequently, poor gas retention during dough fermentation. A poor oven spring is also expected with this rheological profile of the studied flours [53]. Therefore, rheological data indicates flours for other uses that do not require a strong gluten network. Testing in practical scenarios, however, is essential for defining the best uses of the ingredients.

Pasting properties

The Rapid Visco Analyzer (RVA) was chosen for evaluating flour's pasting properties [54], and the results are shown in Table S2 (Supplementary Material) and Figure 2.

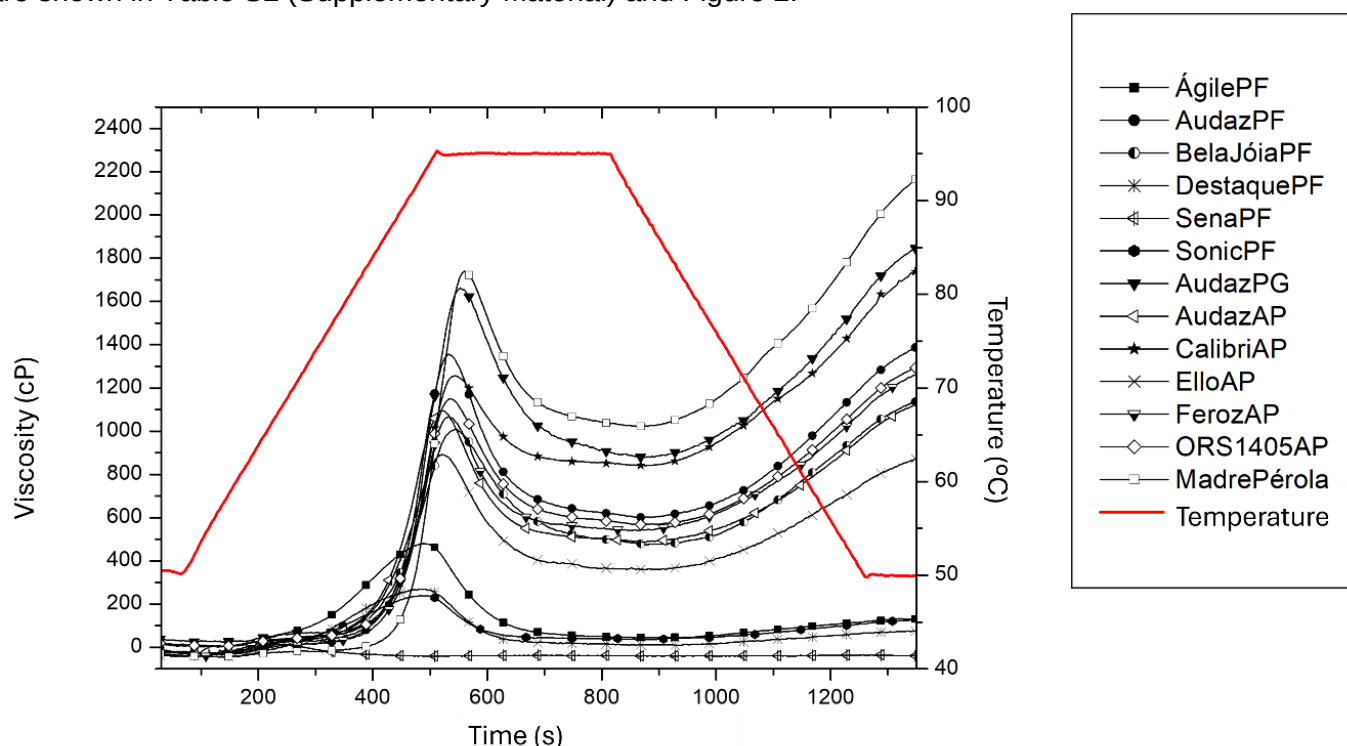


Figure 2. Pasting properties of wheat flours.

Peak viscosities varied greatly (16 to 1739.5 cP), for Sena PF and Madre Pérola AP samples, respectively. These results agree with those of falling number and stirring number (Table 6), indicating different α -amylase activity in the flours. In RVA analysis, PV is directly related to the water absorption capacity of starch, and one of the important factors for this behavior is the amylose – amylopectin ratio [55]. Low PV values are linked to low swelling of the starch granules due to higher amylose contents [56, 57]. If we were considering isolated starch, free of amylases, we would rank the samples with higher amylose contents as follows: Sena PF, Sonic PF, Destaque PF and Ágile PF, which presented the lowest PV values. All these samples were harvested in the same region (Paulo Frontin), which was reached by high rainfall levels at harvest. Therefore, RVA analysis is an important tool to evaluate wheat quality, especially if it faced any adverse event at the end of crop cycle that could stimulate amylases to be synthesized [58]. Besides this physiological issue, at pre-harvest, other climatic events (high temperatures, excess of rain during the crop development) can result in undesirable changes in pasting properties [59].

In this study, the wheat flour samples that may indicate a higher amylose content due to their lower viscosity are Sena PF, Sonic PF, Destaque PF, Ágile PF, Ello AP, Feroz AP, Bela Jóia PF, and Audaz AP. The highest PV values were found for the samples Audaz PG and Madre Pérola AP, 1662.0 and 1739.5 cP, respectively.

Falling Number (FN) and Stirring Number (SN)

FN is the most accepted and used method for estimating α -amylase activity in both wheat and white flour [20]. SN, on the other hand, can also be used for the same estimation of α -amylase activity. Starch paste liquefaction will be evaluated comparatively and gives a correspondent result [62]. The FN and SN results are presented in Table 6. Our results showed important variation between the samples, with FN ranging from

62 to 334 s, for Sena PF and Audaz PF, respectively. For the SN analysis, the values ranged from 8 to 2144 cP. for samples Sena PF and Madre Pérola AP, respectively. This last sample had a FN that did not differ from sample Audaz PF.

The lowest FN values for samples Sena PF, Sonic PF, Destaque PF and Ágile PF can be associated with intense rainfall during harvest at the region of Paulo Frontin and reflect physiological signs for germination of the seeds [60]. Oppositely, the region of Arapoti was not affected by intense rainfall at harvest and the samples identified as "AP" had the highest values for FN. It is important to mention that FN is one key quality parameter for accepting or not the grains at the mill [61].

In the case of breadmaking, the best values of FN are in the range 200 - 350 s. Values below 150 s mean high enzymatic activity whereas values over 350 s represent low activity. In both cases, bread will present lower quality when compared to that made with flour with FN into the right range [62].

Although SN can be very precise in also estimating the amylase activity in wheat flour, it is still rarely used. In one previous study, the correlation between FN and SN was established ($r = 0.70$) [63]. In our study, the Pearson correlation coefficient for the value was higher ($r = 0.81$). As expected, SN values are comparable to those of the RVA pasting properties (Table S2, Supplementary Material), mainly the parameter PV.

Table 6. FN and SN values, and moist gluten contents of the flours.

Variety	Falling Number	Stirring Number*	Moist Gluten %
Ágile PF	253±7.34 ^c	717±9.90 ^d	37.61±1.03 ^{bcd}
Audaz PF	334±11.93 ^a	1385±46.67 ^{bc}	31.69±1.01 ^{def}
Bela Jóia PF	322±2.52 ^a	1415±36.77 ^{bc}	37.61±1.03 ^b
Destaque PF	239±5.69 ^c	439±19.80 ^d	36.14±0.30 ^{bc}
Sena PF	62±0.00 ^d	8±1.41 ^e	43.62±2.02 ^a
Sonic PF	242±5.97 ^c	459±9.90 ^d	34.13±1.92 ^{bcde}
Audaz PG	329±6.37 ^a	1345±45.96 ^{bc}	38.86±0.45 ^{bc}
Audaz AP	310±13.52 ^{ab}	1323±14.85 ^c	30.98±0.22 ^{ef}
Calibri AP	327±11.96 ^a	1633±3.54 ^{bc}	30.18±2.10 ^f
Ello AP	288±1.53 ^b	1372±16.26 ^{bc}	31.44±0.28 ^{def}
Feroz AP	325±15.13 ^a	1675±309.01 ^b	33.93±1.23 ^{cde}
ORS 1405 AP	327±12.62 ^a	1377±118.09 ^{bc}	30.18±1.76 ^f
Madre Pérola AP	333±5.46 ^a	2144±173.95 ^a	25.33±0.42 ^g

*Stirring Number refers to viscosity of flour aqueous suspension after three min at 95 °C, expressed in cP; FN is expressed in s. Means with distinct low letters at the same column indicate significant differences ($p < 0.05$) among samples, by the Tukey.

Moist Gluten

Gluten network development is possible after complete hydration and mechanical homogenization of the dough. Gluten proteins, named glutenin and gliadin, are responsible for the desired extensibility and elasticity of the dough [64]. Table 6 shows the results for moist gluten in the samples, varying from 25.33 to 43.62 %, for samples Madre Pérola AP and Sena PF, respectively.

The amount of gluten is an indicative of flour quality, but it is not absolutely linked with the gluten strength [31]. One good example of disconnection between gluten/protein level and flour quality is the sample Sena PF, which had the highest crude protein and moist gluten contents but performed very poorly in the other analyses. In the case of the sample Audaz AP, on the other hand, the results were all consistent and positive for all analyses. It had 30.98 % gluten, 12.54 % protein, and W value of $366 \cdot 10^{-4}$ J, being the sample with the best overall gluten quality [48].

The samples from Paulo Frontin presented the highest moist gluten contents, but in terms of gluten quality, especially the W value, they did not perform well [31]. Destaque PF and Ello AP had close values for W and similar contents of crude protein. Destaque PF had a higher moist gluten level when compared to the sample Ello AP.

The sample Madre Pérola AP was the one that had the lowest value for moist gluten (25.33 %), as well as the lowest crude protein content (10.50 %) and an intermediary W value, when compared to the other samples. This variety is known as bleaching and is blended during milling to improve the color of produced flour. In this case, a W value not so adequate would not interfere in final use of the flour that is produced by blending different wheats and the proportion of this bleaching flour is low [33]. In some cases, the high gluten levels found could be associated with the presence of bran in certain flours (that also had high levels of ash), which make it difficult to wash completely the gluten network. The contamination of flour with bran particles makes its water absorption higher than expected and affects negatively dough stability as well as dough development time [65].

General characteristics of wheat samples

Table S3, Supplementary Material, presents the Pearson correlation coefficients considering the main variables of the present study. It is possible to note that several variables presented high correlation coefficients. Test weight, for example, is positively correlated with flour extraction yield. If climatic conditions are not appropriate for the complete development of sound grains, negative impact shall reach the milling process. Another point that is interesting to report was the highly correlated contents of crude protein and gluten in the flours, but this fact did not correlate with gluten quality. Damaged starch correlated negatively with FN, an expected result, as these damaged granules are more susceptible to the α -amylase.

In general, our results showed that the samples have a broad range of potential applications, other than breadmaking. All possible uses must be tested previously to any action that would be based exclusively in the physicochemical and rheological analyses. Crop year shall pose a big difference between wheat grains due to climatic changes during the years. Testing flours is a challenging task and must consider many variables to solve technological issues in the wheat milling market.

CONCLUSION

Our results made it possible to visualize the impact of physicochemical and rheological characteristics on the quality of wheat flour, which can be designed for specific products and processes. Varieties produced in different regions from Paraná State showed completely different results for the selected quality analyses.

The varieties from Paulo Frontin region, located in the south of Paraná state, showed results that are not so good for industrial uses that need high quality flours. The opposite was noted for the other two regions (Ponta Grossa and Arapoti), which did not suffer the high volumes of rain during the crop cultivation, including the final period, very close to harvest time.

From the varieties that were studied, Audaz AP, Calibri AP and Feroz AP showed the best general results. Therefore, these three samples were very promising for producing high quality breads. All the samples, except one (Sena PF) have met the legal standard from the Brazilian Ministry of Agriculture, in the same manner as the produced flours.

Finally, it was concluded that the samples gave results in line with those reported on previous studies. Our results also showed that climatic conditions are crucial for producing sound wheat grains that will result in well succeeded milling and high-quality products.

Author Contributions:

Conceptualization: Marina Fernanda da Silva Junges and Ivo Mottin Demiate; methodology: Marina Fernanda da Silva Junges, Daniele Bach and José Pedro Wojeicchowski; resources, Alessandro Nogueira and Ivo Mottin Demiate; data curation, Daniele Bach and José Pedro Wojeicchowski; writing—original draft preparation, Marina Fernanda da Silva Junges; writing—review and editing, Daniele Bach, José Pedro Wojeicchowski and Ivo Mottin Demiate; supervision, Ivo Mottin Demiate; project administration, Ivo Mottin Demiate and Alessandro Nogueira; funding acquisition, Ivo Mottin Demiate and Alessandro Nogueira. All authors have read and agreed to the published version of the manuscript.

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Data availability statement: Research data are available in the repository (<https://doi.org/10.5281/zenodo.17363373>).

Supplementary Material: Table S1: Raining distribution in the cultivation regions on the 2022 harvest; Table S2: Pasting properties of wheat samples; Table S3: Pearson correlation coefficients. The file is available here: <https://doi.org/10.5281/zenodo.17363373>

REFERENCES

1. FAOSTAT. Wheat. 2024. Available from: <https://www.fao.org/faostat/en/#data/QCL>
2. Sharma A, Garg S, Sheikh I, Vyas P, x Dhaliwal HS. Effect of wheat grain protein composition on end-use quality. *J Food Sci Technol*. 2020; 57: 2771–85.
3. Scheuer P, de Francisco A, Miranda M, Limberger VM. [Wheat: characteristics and use in baking]. *Rev Bras Prod Agroindustriais*. 2011; 13: 211–22.
4. Wang J, Hasanalieva G, Wood L, Markellou E, Iversen PO, Bernhoft A, et al. Effect of wheat species (*Triticum aestivum* vs *T. spelta*), farming system (organic vs conventional) and flour type (wholegrain vs white) on composition of wheat flour; results of a retail survey in the UK and Germany - 1. Mycotoxin content. *Food Chem*. 2020; 327: 127011.
5. Nuttall JG, O'Leary GJ, Panozzo JF, Walker CK, Barlow KM, Fitzgerald GJ. Models of grain quality in wheat—A review. *Field Crops Res*. 2017 202: 136–45.
6. Jukić M, Komlenić D, Mastanjević K, Habschied K, Lučan Čolić M, Popovici C, et al. Influence of damaged starch on the quality parameters of wheat dough and bread. *Ukr Food J*. 201; 8: 512–21.
7. Perseguelo FM, Coelho AR, Seibel NF. [Determination of physical, chemical, microscopic contaminants and microbiological quality of wheat used for the preparation of whole flour]. *Braz J Dev*. 202; 6: 52473–82.
8. Guttieri MJ, Stark JC, O'Brien K, Souza E. Relative Sensitivity of Spring Wheat Grain Yield and Quality Parameters to Moisture Deficit. *Crop Sci*. 2001; 41: 327–35.
9. Casagrande CR, Mezzomo HC, de Sousa DJP, Santos CV, Yamanaka CH, Olivoto T, et al. Envirotypes applied to evaluate the adaptability and stability of wheat genotypes in the tropical region in Brazil. *Euphytica*. 2024; 220-7.
10. Bornhofen E, Todeschini MH, Stoco MG, Madureira A, Marchioro VS, Storck L, et al. Wheat Yield Improvements in Brazil: Roles of Genetics and Environment. *Crop Sci*. 2018; 58: 1082–93.
11. Tsukahara RY. [Agrometeorological Monitoring System of the ABC Group: Climate Analysis of the 2022/2022 Crop Season]. Available in: <https://sma.fundacaoabc.org>
12. BRASIL. [MAPA-Regulamentation for seed analysis]. 2009.
13. AACC. International Approved Method of Analysis. 2000.
14. Hunterlab. Insight on Color: CIE L*a*b* Color Scale. 2008.
15. Zenebon O, Sadocco Pascuet N, Tiglea P. [Physicochemical Methods for Food Analysis]. São Paulo: Instituto Adolfo Lutz, 2008.
16. AOAC. Official Methods of Analysis of AOAC International. 2016.
17. Boyacı İH, Williams PC, Köksel H. A rapid method for the estimation of damaged starch in wheat flours. *J Cereal Sci*. 2004; 39: 139–45.
18. Farrand EA. Flour properties in relation to the modern bread processes in the United Kingdom. with special reference to alpha-amylase and starch damage. *Cereal Chem*. 1964; 41: 99–111.
19. ICC. International Association for Cereal Science and Technology. 161, 1996.
20. AACC. International Approved Method of Analysis. Method 56-81.03: Determination of Falling Number. 1999.
21. AACC. International Approved Method of Analysis. Method 38-12-02: Wet Gluten. Dry Gluten. Water-Binding Capacity. and Gluten Index. 2000.
22. BRASIL. MAPA - [Normative Instruction No. 38, of November 2010]. 2010.
23. Seidel EP, Fey E, Souza Junior JB, Augusto J, Costa NVN, Barilli D. Wheat cultivars with agroecological management in the West of Paraná State: Organic wheat. *Sci Agrar Parana*. 2022; 230–6.
24. Dunăreanu IC, Bonea D. Grain Yield and Hectolitre Weight of Some Wheat Cultivars in Organic and Conventional Production Systems. *Romanian Agric Res*. 2022; 39: 229–37.
25. Guarieenti EM. [Industrial Quality of Wheat]. 2nd ed. EMBRAPA - Centro Nacional de Pesquisa de Trigo, 1996.
26. Kalitsis J, Minasny B, Quail K, McBratney A. Application of response surface methodology for optimization of wheat flour milling process. *Cereal Chem*. 2021; 98: 1215–26.
27. BRASIL. MAPA - [Normative Instruction No. 8, of June 2, 2005]. 2005.
28. Memon AA, Mahar I, Memon R, Soomro S, Harnly J, Memon N, et al. Impact of flour particle size on nutrient and phenolic acid composition of commercial wheat varieties. *J Food Compos Anal*. 2020; 86: 103358.

29. Li X, Hu H, Xu F, Liu Z, Zhang L, Zhang H. Effects of aleurone-rich fraction on the hydration and rheological properties attributes of wheat dough. *Int J Food Sci Technol*. 2019; 54: 1777–86.
30. Lebert L, Buche F, Sorin A, Aussenac T. The Wheat Aleurone Layer: Optimisation of Its Benefits and Application to Bakery Products. *Foods*. 2022; 11: 3552.
31. Schuster C, Huen J, Scherf KA. Comprehensive study on gluten composition and baking quality of winter wheat. *Cereal Chem*. 2023; 100: 142–55.
32. Popovska O. Determination of Some Flour Characteristics. *Eur J Agric Food Sci*. 2023; 5: 8–12.
33. Mittelstadt JV. [Germination and Seedling Growth of Wheat Genotypes Under Simulated Water Deficit]. Graduation, Universidade Federal da Fronteira Sul, 2023.
34. Cazzaniga A, Brousse MM, Linares RA. Variation of color with baking time in snacks made with pregelatinized cassava. *J Food Sci*. 2021; 86: 4100-9.
35. Cankurtaran T, Ceylan H, Bilgiçli N. Effect of partial replacement of wheat flour by taro and Jerusalem artichoke flours on chemical and sensory properties of tarhana soup. *J Food Process Preserv*. 2020; 44: e14826.
36. Wen Y, Lin S, Li X, Zhang J, Zhao Y, Ma D, et al. Relationship between wheat flour's quality characteristics and color of fresh wet noodles. *Int J Food Prop* 2023; 26: 290–300.
37. Ji T, Ma F, Baik B-K. Biochemical characteristics of soft wheat grain associated with endosperm separation from bran and flour yield. *Cereal Chem*. 2020; 97: 566–72.
38. Pinheiro AR. [Application of the 6W3H Method to Improve Efficiency in a Wheat Flour Production Line]. Graduation, Universidade Federal do Ceará, 2021.
39. Protonotariou S, Ritzoulis C, Mandala I. Jet milling conditions impact on wheat flour particle size. *J Food Eng*. 2021; 294:110418.
40. Bressiani J, Oro T, Santetti GS, Almeida JL, Bertolin TE, Gómez M, et al. Properties of whole grain wheat flour and performance in bakery products as a function of particle size. *J Cereal Sci*. 2017; 75: 269–77.
41. Abo-Dief M, Abo-Bakr T, Youssef M, Moustafa A. Quality of wheat flour and pan bread as influenced by the tempering time and milling system. *Cereal Chem*. 2019; 96: 429–38.
42. Wu F, Li J, Yang N, Chen Y, Jin Y, Xu X. The Roles of Starch Structures in the Pasting Properties of Wheat Starch with Different Degrees of Damage. *Starch – Stärke*. 2018; 70: 1700190.
43. Barak S, Mudgil D, Khatkar BS. Effect of flour particle size and damaged starch on the quality of cookies. *J Food Sci Technol*. 2014; 51: 1342–8.
44. Biel W, Jaroszevska A, Stankowski S, Sobolewska M, Kępińska-Pacelik J. Comparison of yield, chemical composition and farinograph properties of common and ancient wheat grains. *Eur Food Res Technol*. 2021; 247: 1525–38.
45. Cui C, Caporaso N, Chen J, Fearn T. Farinograph characteristics of wheat flour predicted by near infrared spectroscopy with an ensemble modelling method. *J Food Eng*. 2023; 359: 111689.
46. Saraswath R, Hameed RS. Farinograph as a Rheological Tool to Predict the Quality Characteristics for Blend of Wheat with Pulse Flour. *Int J Adv Agric Sci Technol*. 2018; 5: 146–53.
47. Mirza Alizadeh A, Peivasteh Roudsari L, Tajdar Oranj B, Beikzadeh S, Barani-bonab H, Jazaeri S. Effect of Flour Particle Size on Chemical and Rheological Properties of Wheat Flour Dough. *Iran J Chem Chem Eng*. 2022; 41: 682–94.
48. Jødal ASS, Larsen KL. Investigation of the relationships between the alveograph parameters. *Sci Rep*. 2021.
49. Nitzke JA, Thys RCS. [Assessment of the Technological/Industrial Quality of Wheat Flour]. 2010.
50. Zhygunov D, Toporash I, Barkovska Y, Yehorshyn Y. Comparison of alveograph characteristic of flour obtained from different types of common wheat and spelt wheat. *Grain Prod Mix Fodder's*. 2020; 20: 23–30.
51. Dufour M, Chaunier L, Hugon F, Dugué A, Kansou K, Saulnier L, et al. From Alveograph test to extensional behavior of wheat flour dough. *Rheol Acta*. 2024; 63: 179–190.
52. Gao X, Tong J, Guo L, Yu L, Li S, Yang B. Influence of gluten and starch granules interactions on dough mixing properties in wheat (*Triticum aestivum* L.). *Food Hydrocoll*. 2020; 106: 105885.
53. Sun X, Koksel F, Scanlon MG, Michael T, Nickerson MT. Effects of water, salt, and mixing on the rheological properties of bread dough at large and small deformations: A review. *Cereal Chem*. 2022; 99: 709–23.
54. Balet S, Guelpa A, Fox G, Manley M. Rapid Visco Analyser (RVA) as a Tool for Measuring Starch-Related Physicochemical Properties in Cereals: a Review. *Food Anal Methods*. 2019; 12: 2344–60.
55. Asiyani-Hammed TT, Simsek S. Comparison of physical and chemical properties of wheat flour, fermented yam flour, and unfermented yam flour. *J Food Process Preserv*. 2018; 42: e13844.
56. Li C, Dhital S, Gilbert RG, Gidley MJ. High-amylose wheat starch: Structural basis for water absorption and pasting properties. *Carbohydr Polym*. 2020; 245: 116557.
57. Yuan TZ, Liu S, Reimer M, Isaak C, Ai Y. Evaluation of pasting and gelling properties of commercial flours under high heating temperatures using Rapid Visco Analyzer 4800. *Food Chem*. 2021; 344: 128616.
58. Singh A, Bobade H, Sharma S, Singh B, Gupta A. Enhancement of Digestibility of Nutrients (In vitro), Antioxidant Potential and Functional Attributes of Wheat Flour Through Grain Germination. *Plant Foods Hum Nutr Dordr Neth*. 2021; 76: 118–24.
59. Moiraghi M, Sciarini LS, Paesani C, León AE, Pérez GT. Flour and starch characteristics of soft wheat cultivars and their effect on cookie quality. *J Food Sci Technol*. 2019; 56: 4474–81.

60. He Y, Lin Y-L, Chen C, Tsai MH, Hui-Mei Lin A. Impacts of Starch and the Interactions Between Starch and Other Macromolecules on Wheat Falling Number. *Compr Rev Food Sci Food Saf.* 2019; 18: 641–54.
61. Shao Y, Tsai M-H, He Y, Chen J, Wilson C, Hui-Mei Lin A. Reduction of falling number in soft white spring wheat caused by an increased proportion of spherical B-type starch granules. *Food Chem.* 2019; 284: 140–8.
62. Lanzarini DP, Martins RC, Rauhen TG, Bravo CEC, Pinto EP. [Quality control applied to bread-making wheat flour produced in mills in the state of Paraná]. *Braz J Dev.* 2020; 6: 16919–29.
63. Kiszonas AM, Engle DA, Pierantoni LA, Morris CF. Relationships between Falling Number, α -amylase activity, milling, cookie, and sponge cake quality of soft white wheat. *Cereal Chem.* 2018; 95: 373–385.
64. Shewry P. What Is Gluten-Why Is It Special? *Front Nutr.* 2019; 6: 101.
65. Liu N, Ma S, Wang Z, Zheng X, Wang X. Influence of wheat bran dietary fiber on gluten protein structure during dough fermentation. *J Food Process Preserv.* 2021; 45: e15035.



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