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Brazilian Cerrado wheat: Technological quality of genotypes grown in tropical locations

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Abstract

Brazilian Cerrado wheat has emerged as an alternative to expand a new agricultural frontier in tropical areas. In this study, technological quality of 34 samples grown in five locations situated in the *Cerrado Mineiro* was evaluated in terms of their grain, flour, and starch properties. Damaged starch was positively ($p < .05$) correlated with Single Kernel Characterization System parameters ($r = 0.578$) and pasting properties ($r = 0.761$), and negatively ($p < .05$) correlated with enthalpy ($r = -0.400$) and relative crystallinity ($r = -0.379$). The irrigation system strongly influenced the starch characteristics, rheological, and pasting properties. *Piumhi* location showed the highest mean of resistant starch (0.80 g/100g), bringing an interesting prebiotic appeal to these samples. Gluten index (mean = 90.6) and damaged starch (mean = 5.0%) values showed that genotypes present suitable standards for bakery products. This pioneering study highlights promising agronomic materials for cultivation in the *Brazilian Cerrado* region, which has great potential to produce tropical wheat.

Practical applications

Wheat is the second most significant staple grain after maize, constituting a strategic role in food security to the world economy. In Brazil, more than 90% of wheat is grown in traditional areas that include subtropical climates. In this scenario, *Brazilian Cerrado* has been standing out as a potential region for wheat cultivation to produce improver wheat class that is the main consumer-driven market. Wheat culture has been adapted under *Cerrado* conditions after massive investments regarding genetic improvement and integrated soil–water–nutrient–plant practices that allow high grain productivity. Thus, the characterization of wheat grain associated with flour rheological evaluation and starch profile is effective in predicting processing behavior and applicability in different bakery products. The results showed that irrigation system strongly influenced the rheological and pasting properties of starch. These samples showed suitable contents of dry gluten (11%–14%) and damaged starch (4.5%) for bakery products development.

1 | INTRODUCTION

Wheat is the second most significant staple grain after maize, with worldwide production of 734 million tons according to the most recent survey (FAOSTAT, 2020). Wheat production plays a strategic role in food security and in the world economy (Mutwali et al., 2015). In Brazil, more than 90% of wheat is grown in traditional areas that include the southern states (Paraná, Santa Catarina, and Rio Grande do Sul), region with the most severe winter of the country and occurrence of frosts. In recent years, wheat has also been cultivated in the *Central Brazilian* region (*Goiás*, *Distrito Federal*, *Minas Gerais*, *Mato Grosso*, *Mato Grosso do Sul*, *Bahia* and *São Paulo* States), characterized by the *Cerrado* biome (open Brazilian Savannah), which comprises an area of 2 million km^2 (CONAB, 2017).

New wheat cultivars are required to increase yield and contribute to a sustainable production (Johansson, Henriksson, et al., 2020). Wheat production in *Cerrado* has advantages such as (a) proximity to the southeast region, the main consumer of wheat in Brazil; (b) wheat cultivation in the off-season; (c) upland wheat cultivation; (d) bread wheat classification; and (e) higher profits for wheat producers (Pasinato et al., 2018). Moreover, wheat from the Brazilian *Cerrado* cultivated in rainfed or irrigated crops presents a great potential and an alternative to produce wheat with high standard for bread making.

Brazilian research institutions have developed wheat seeds adapted to the Central Brazilian region, allowing high grain productivity (Madeira et al., 2015). In this region, wheat culture has been adapted under *Cerrado* conditions after massive research investments in terms of genetic improvement and integrated soil–water–nutrient–plant practices. In the 2020–2021 crop, the states of *Mato Grosso do Sul*, *Goiás*, and the *Distrito Federal* produced 186 thousand tons of harvested wheat (CONAB, 2020).

Environmental conditions, genotype, agronomic characteristics, crop management practices, and their interactions influence quality, processing, performance, end-use products, and nutritional characteristics of both wheat grain and flours (Bhatta et al., 2017; Tozatti et al., 2020). Concerning technological properties, wheat genotype has a stronger effect on grain hardness and gluten proteins composition, while environmental conditions have a stronger influence on protein and mineral contents (Johansson, Branlard, et al., 2020; Johansson et al., 2013; Malik et al., 2013).

Due to its unique gluten proteins, wheat flour is the only among cereals able to form a three-dimensional viscoelastic dough when mixed with water. Thus, wheat grain characterization and the rheological evaluation of wheat flour can be effective in predicting processing behavior, controlling the quality of end products, and providing practical information to supply chain management (Song & Zheng, 2007). Wheat genotypes also differ in starch functionality in terms of sizing, thermal properties, retrogradation performance, and nutritional characteristics. In addition, starch properties are also fundamental to assess technological quality and applicability in bakery products (Shevkani et al., 2017).

In recent scientific literature, there is no detailed study of the technological quality of wheat genotypes grown in the Brazilian *Cerrado*, especially focusing on starch characterization. Therefore, the aim of this study was to evaluate the wheat grain and flour qualities, focusing on the starch properties of 12 different wheat genotypes cultivated in five locations in the Brazilian *Cerrado*.

2 | MATERIAL AND METHODS

2.1 | Material

Thirty four samples were harvested in 2017 situated in five different locations (Table 1) in the *Cerrado Mineiro*: *Madre de Deus de Minas* (M) (21°28′58′′ S, 44°19′58′′ W), *Coromandel* (C) (18°28′22′′ S, 44°19′49′′ W), *Piumhi* (P) (20°27′54′′ S, 45°56′45′′ W), *Uberaba* (U) (19°44′52′′ S; 47°55′55′′ W), and *Iraí de Minas* (I) (18°59′02′′ S, 53°15′6′′ W). Wheat genotypes samples were supplied by *Embrapa Trigo*, Passo Fundo, RS, Brazil.

2.2 | Crop management

Wheat genotypes were planted and harvested at different times in 2017 as follows: *M* (March 31 to August 10), C (March 22 to July 10), P (April 1 to August 15), U (May 4 to September 6), and I (April 28 to August 28). The average temperature and the average rainfall at different locations were monitored during the period by Meteorological Database (BDMEP) of the National Institute of Meteorology (INMET) and Agrometeorological Monitoring System (Agritempo), Brazil (Figure 1). Except for *Iraí de Minas*, all the other genotypes were cultivated in a rainfed system.

2.3 | Grain quality evaluation

The test weight (TW) was determined on a DalleMolle scale (Type 40, DalleMolle, Caxias do Sul, Brazil), according to method 55–10.01 (AACC, 2010), and expressed in (kg/hl). Grain physical characteristics were analyzed on 300 kernels per sample using the Single Kernel Characterization System (SK) (SKCS 4100, Perten Instruments, Huddinge, Sweden), according to method 55–31.01 (AACC, 2010), considering the averages of SK weight (in mg), SK hardness index (HI), and SK diameter (in mm) of single kernels.

The grain falling number (GFN) test was conducted using a Falling Number apparatus (1800, Perten Intruments, Huddinge, Sweden), according to method 56–81.03 (AACC, 2010). Wheat grains from the Brazilian *Cerrado* were conditioned up to 14% of moisture during 16–24 hr and milled in a Quadrumat Senior experimental mill (Brabender, Duisburg, Germany) according to method 26–10.02 (AACC, 2010) to obtain the wheat flours (white flours).

2.4 | Wheat flour quality

2.4.1 | Rheological evaluation

Previously, the moisture content of flours was determined according to method 44–15.02 (AACC, 2010). The rheological profile of flours was measured using a farinograph equipped with a 50 g mixing bowl

TABLE 1 Wheat genotypes and locations in the Brazilian *Cerrado*

Growth location				
Madre de Deus de Minas (M)	**Coromandel (C)**	**Piumhí (P)**	**Uberaba (U)**	**Iraí de Minas (I)**
Wheat genotypes				
BRS 264	BRS 264	BRS 264	BRS 264	NA
BRS 404	BRS 404	BRS 404	BRS 404	NA
BRS 394	BRS 394	BRS 394	BRS 394	NA
CPAC 09208	CPAC 09208	CPAC09208	CPAC 09208	
CPAC 09236	NA	CPAC 09236	CPAC 09236	NA
PF 100368	PF 100368	PF 100368	PF 100368	NA
PF 120212	PF 120212	PF 120212	PF 120212	NA
PF 120337	PF 120337	PF 120337	NA	NA
NA	NA	NA	NA	CPAC 0841
NA	NA	NA	NA	CPAC 0872
NA	NA	NA	NA	CPAC 0886
				CPAC 0891

NA, not available.

(C.W. Brabender, Duisburg, Germany) and an alveograph (NG, Chopin, Villeneuve-la-Garenne, France), according to methods 54–21.02 and 54–30.02 (AACC, 2010), respectively, considering a 14% moisture basis (d.b.).

2.4.2 | Gluten evaluation

Wet gluten (WG), dry gluten (DG), and gluten index (GI) of wheat flours were determined using a Glutomatic System (model 2200, Perten Instruments, Huddinge, Sweden), according to method 38–12.02 (AACC, 2010).

2.4.3 | Damaged starch

Damaged starch content was determined by SDMatic device (Chopin, France), according to method 76–33.01 (AACC, 2010).

2.5 | Physical properties

2.5.1 | Pasting properties

Pasting properties were determined using a Rapid Visco Analyzer (RVA series 4; Newport Scientific Pty. Ltd, Warriewood, Australia) according to method 76–21.01 (AACC, 2010).

2.5.2 | Flour color measurement

Color measurements were determined using a CR-400 colorimeter (Minolta, Hino, Japan), calibrated using the reflectance mode and observer/illuminant 10° and D_{65} in a CIEL*a*b system. Runnings were taken in triplicate for each sample. Color of wheat flour was expressed as whiteness index (WI) using the formula: $WI = 100 - [(100 - L^*)^2 + a*^2 + b*^2]^{1/2}$. In addition, yellowness index (YI) was also calculated according to the relation: $YI = 142.86 \times (b^*/L^*)$.

2.5.3 | Starch and characterization

Starch was extracted from flour according to Knight and Olson (1984), with modifications. A total of 100 g of flour was used to obtain a dough using 50 ml of NaCl solution (2%, v/v), which was washed in current water, and the starches were recovered by centrifugation using a universal centrifuge (320R, Hettich, Tuttlingen, Germany) at 9,000 rpm for 10 min at 25°C and then dried in a convection oven at 55°C for 4 hr. After dried, each one of wheat starch was milled in a laboratory hammer mill (Mill 3600, Perten Instruments, Huddinge, Sweden) to pass through a 212 mm sieve to break up any lumps and stored in a sealed plastic container.

2.5.4 | Particle size distribution

Particle size distribution was measured using a laser diffraction particle size analyzer (SDC S3500, Microtrac, Montgomeryville, USA). Samples were dispersed in distilled water in triplicate. Particle sizes were expressed in terms of mean particle size of D [4,3] (volume or mass moment mean) calculated by the Flex Software, version 11.0.0.3 (Microtrac, USA).

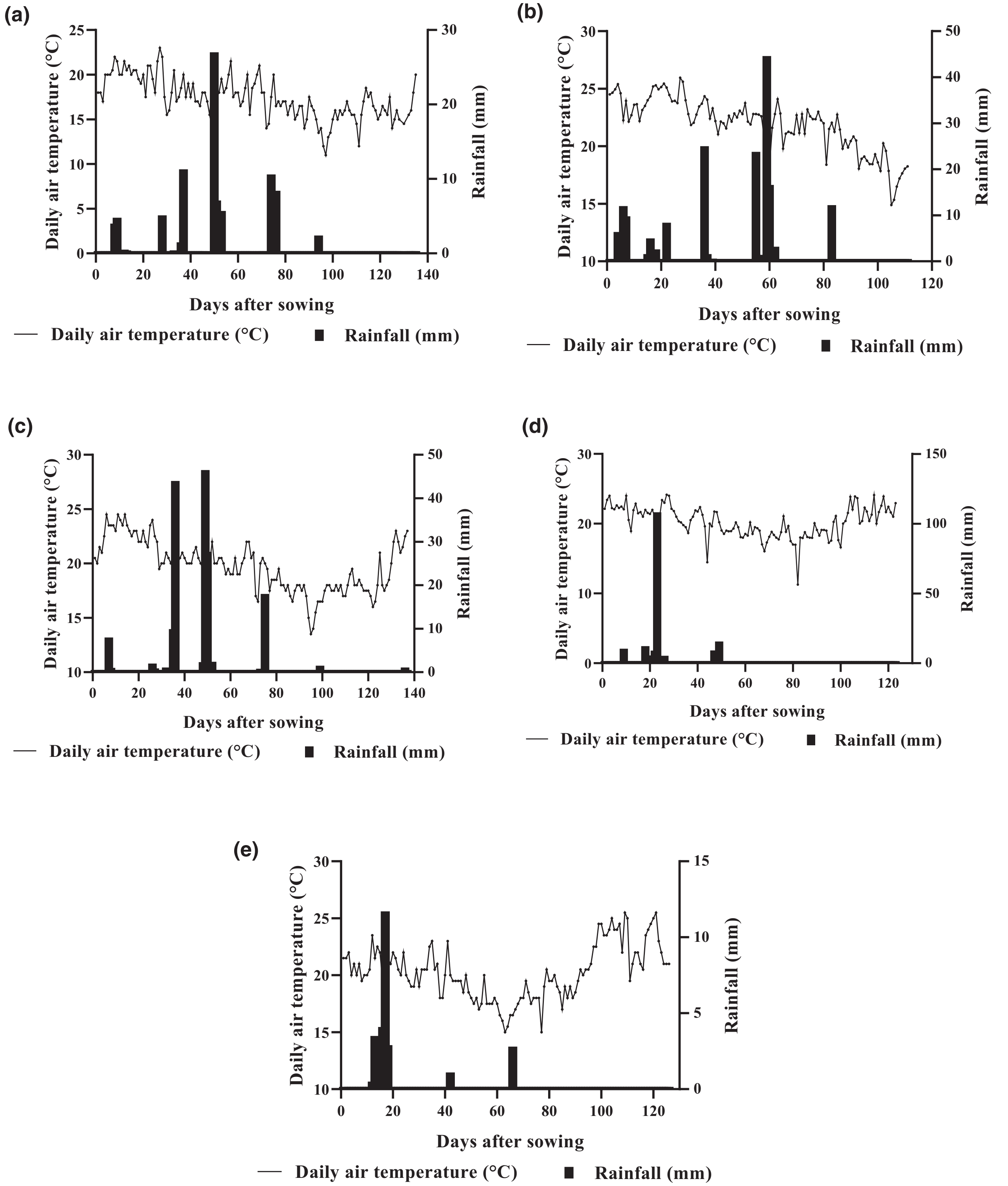

FIGURE 1 Daily air temperature and rainfall regime during experimental period at *Madre de Deus de Minas* (a), *Coromandel* (b), *Piumhi* (c), *Uberaba* (d), and *Iraí de Minas* (e)

2.5.5 | Thermal properties

Thermal properties were measured in three replicates using a differential scanning calorimeter (DSC Q200, TA instruments, New Castle, USA) fitted with a thermal analysis data station. Starch samples were weighed (~ 3 mg, d.b.) accurately into an aluminum sample pan. Distilled water was added to obtain a starch:water ratio of 1:2 (w/w) in the DSC pans then sealed and equilibrated overnight at 7°C. An empty pan was used as reference. The sample pans were heated from 20°C to 110°C at a constant heating rate of 10°C min^{-1}, using nitrogen gas at a flow rate of 50 ml min^{-1}. The onset (To), peak (Tp), endset temperature (Tc), and enthalpy (ΔH) of gelatinization were calculated by the Universal Analyses Software, version 4.5.05 (DSC Q200, TA instruments, New Castle, USA).

2.5.6 | X-ray diffraction pattern

X-ray diffraction analysis (XDS) was performed using a D2 Phaser X-ray diffractometer (Bruker, Karlsruhe, Germany), operating at Cu-K wavelength with 0.154 nm, target voltage and current of 30 kV and 10 mA, respectively. The samples were scanned in a 2θ range, varying from 2 to 32° at the rate of 0.15°min^{-1}, with a step size of 0.02°, a divergence slit width of 0.6 mm, a scatter slit width of 0.6 mm and a receiving slit width of 0.2 mm. Relative crystallinity (RC) was estimated as described by Lacerda et al. (2014), using the Diffract Evaluation v3 software (Bruker, Karlsruhe, Germany). The area under the main peaks from 2 to 32° (2θ angle) correspond to the crystalline region, whereas the amorphous area is characterized as the difference of the total area (baseline from 2 to 32°) minus the crystalline region.

2.5.7 | Starch characteristics

Amylopectin (AP) and amylose (AM) contents and resistant starch (RS) were determined using a K-AMYL and K-TSTA-100A 06/17 standard kits, respectively (Megazyme International, Bray, Ireland).

2.6 | Statistical analysis

Statistical analyses were performed using the R software (version 1.2.5042, RStudio, Boston, USA) and XLSTAT software (Addinsoft, Paris, France). A correlogram for correlation analysis and the significance test were generated in the R package "*corrplot*," and principal component analysis (PCA) was generated in R package "*FactoShiny*." After PCA, a hierarchical clustering on principal components (HCPC) was carried out in order to cluster similar samples.

3 | RESULTS AND DISCUSSION

3.1 | Grain quality

Related to test weight (TW), values ranged from 79.25 to 89.05 kg/hl; BRS 264, grown in *Coromandel*, had the lowest weight, and CPAC 09236, grown in *Uberaba*, showed the highest value, respectively (Table 2). The test weight is an indicator of wheat quality and can be influenced by crop year, growth location, genotype (shape and size of grains), and endosperm texture (Hook, 1984; Maphosa et al., 2014; Samaan et al., 2006). It is an important aspect, considering flour commercialization and marketing, since it can indicate wheat flour yield in the milling process (Troccoli et al., 2000).

However, there is no consensus on the influence of genotype and/or environment on the TW. There are reports in the literature describing genotype effect as predominant (Taghouti et al., 2010), whereas other authors have stated that the location of growing area was dominant (Subira et al., 2014) or similar (Kaplan Evlice et al., 2020). TW values were higher (79.25–89.05) than those found in wheat genotypes grown in different locations in Southern of Brazil (Rio Grande do Sul State), that ranged between 73.75 and 79.83 kg/hl for TBIO Sintonia and CD 1,303 genotypes, respectively (Miranda et al., 2020). However, Gutkoski et al. (2007) reported similar TW values (79.45–83.55 kg/hl) for wheat genotypes grown in the Brazilian *Cerrado*, classified as Type 1 according to Brazilian Wheat Legislation (Brasil, 2010). The Ônix cultivar presented significantly higher TW (83.55), followed by Fundacep 27 (81.30) and Taurum (81.60).

Regarding the SKCS values, grain diameter ranged from 2.73 to 3.32 mm and grain weight from 35.5 to 53.9 mg, in both cases CPAC 09208 grown in *Madre de Deus de Minas*, an upland wheat, presented the highest values. The grain hardness index ranged from 30.83 to 90.08. Highest hardness was found in PF 120.212 grown in *Piumhí*, while CPAC 09236 grown in *Uberaba* showed the lowest index of hardness. The CPAC 09236 genotype showed lower hardness values regardless of growing location. All genotypes were classified as hard or very hard wheat using SKCS (below 54, soft; 55–74, medium hard; 75–89, hard; and above 90; very hard) according to method 55–31.01 (AACC, 2010), except for the CPAC09236 genotype, which was classified as soft wheat in all growing locations. This parameter is used by the food industry to drive the different end-uses of wheat. Soft wheat flour is often used for cakes and cookies, while hard wheat flour for bread, and durum wheat (semolina) for pasta making (Pauly et al., 2013).

Grain hardness depends on the relationship of protein matrix and starch granules and influences damaged starch content. Generally, the higher the level of grain hardness, the higher of damaged starch content (Kundu et al., 2017). Hence, hard grains lead to a great amount of damaged starch during the milling step and, therefore, increasing water absorption in the flour. Moreover, the relationship between kernel texture and wheat protein content is useful to estimate power consumption during milling operation. The flour produced from hard wheat has a medium to high protein content and contains stronger gluten-forming proteins than the soft wheat flour, making suitable for the bread production (Szabó et al., 2016).

Grain Falling Number values (GFN) ranged from 184 to 450 s (Table 2). The genotypes grown in *Piumhí* (except BRS 264) had the lowest values, in contrast to those from *Iraí de Minas* location (irrigated cultivation) that had the highest. GFN values ranging between 300 and 450 s or higher than that are desired, while

TABLE 2 Values of grain quality evaluation, wheat flour rheology, and gluten parameters of wheat from the Brazilian *Cerrado*

Samples[a]	TW (kg/hl)	SK weight (mg)	SK diameter (mm)	SK hardness index	GFN	W ($\times 10^{-4}$)	P (mm H_2O)	L (mm)
BRS 264 M	83.35	44.1	3.00	63	427	195	55	109
BRS 404 M	84.70	43.7	2.99	73	384	338	110	91
BRS 394 M	82.40	47.9	3.00	68	370	314	104	99
CPAC 09208 M	84.95	53.9	3.32	68	411	258	78	118
CPAC 09236 M	84.25	44.6	2.97	34	394	223	64	114
PF 100.368 M	84.05	51.8	3.29	67	426	313	89	126
PF 120.212 M	84.25	45.9	2.97	81	363	225	76	96
PF 120.337 M	84.25	53.7	3.28	72	377	230	122	51
BRS 264 C	79.25	35.5	2.73	69	423	170	41	121
BRS 404 C	80.80	37.0	2.84	77	299	158	46	90
BRS 394 C	79.45	41.0	2.94	74	364	297	64	119
CPAC 09208 C	79.90	45.9	3.12	69	345	247	55	132
PF 100.368 C	81.05	44.3	3.08	73	407	269	63	120
PF 120.212 C	79.70	38.6	2.91	86	390	290	85	116
PF 120.337 C	80.15	47.6	3.10	75	302	277	76	112
BRS 264 P	81.70	41.1	2.93	73	436	190	49	115
BRS 404 P	84.05	41.2	2.93	77	253	244	69	105
BRS 394 P	81.25	45.1	2.97	80	213	279	95	94
CPAC 09208 P	82.40	47.6	3.12	74	300	138	46	102
CPAC 09236 P	82.90	43.7	2.95	33	184	161	39	138
PF 100.368 P	82.15	46.7	3.14	75	346	244	73	117
PF 120.212 P	81.95	41.4	2.91	90	383	192	67	105
PF 120.337 P	83.35	49.1	3.17	81	318	203	78	82
BRS 264 U	84.70	43.2	2.92	74	406	204	51	102
BRS 404 U	86.35	43.8	2.96	74	375	212	58	103
BRS 394 U	83.35	44.5	2.82	81	337	217	84	71
CPAC 09208 U	83.55	50.5	3.11	69	380	162	53	89
CPAC 09236 U	89.05	44.3	2.90	31	330	98	27	106
PF 100.368 U	85.20	52.9	3.27	74	415	305	82	109
PF 120.212 U	84.05	46.5	2.98	85	387	256	82	94
CPAC 0841 I	83.10	39.2	2.86	78	421	219	71	100
CPAC 0872 I	81.25	39.2	2.75	75	450	247	76	96
CPAC 0886 I	83.55	43.6	2.96	82	416	299	105	103
CPAC 0891 I	82.40	38.9	2.84	82	336	245	73	116
Minimum	79.25	35.52	2.73	30.83	184.00	98.00	27.00	51.00
Maximum	89.05	53.86	3.32	90.08	450.00	338.00	122.00	138.00
Mean value	82.91	44.65	3.00	71.71	363.76	232.91	70.76	104.74
CV (%)	2.53	10.34	4.97	19.06	17.04	23.99	30.36	16.22

Abbreviations: DG, dry gluten; EI, alveograph elasticity index; FBD, farinograph breakdown; FDDT, farinograph dough development time; FDST, farinograph dough stability; G, alveograph swelling index; GFN, grain falling number; GI, gluten index; grain SKCS, SK weight, SK diameter, SK hardness index; L, alveograph extensibility; MTI, farinograph mixing tolerance index; P, alveograph tenacity or resistance; TW, test weight; W, alveograph gluten strength; WA, farinograph water absorption; WG, wet gluten.

[a]Genotypes grown in five locations in the Brazilian *Cerrado: Madre de Deus de Minas* (M), *Coromandel* (C), *Piumhi* (P), *Uberaba* (U), and *Iraí de Minas* (I).

values below 300 s imply damage to germination viability and can cause poor quality in some wheat end-uses products (He et al., 2019). There are two major causes of high levels of alpha-amylase accumulation in grains: (a) late-maturity alpha-amylase (LMA) and (b) preharvest sprouting (PHS); independent but genetically controlled traits (Mares & Mrva, 2014). In addition to these factors,

P/L	G (mm)	P/G	EI (%)	WA (%)	FDDT (min)	FDST (min)	MTI (min)	FBD (min)	GI	WG (%)	DG (%)
0.50	23.2	2.1	56.0	55.6	7.3	11.4	28	13.0	99	26.40	9.32
1.21	21.2	5.1	57.6	61.8	8.2	11.6	18	16.6	95	32.46	11.26
1.05	22.1	4.7	52.3	60.4	28.5	37.0	6	43.9	99	25.42	9.27
0.66	24.2	3.2	50.9	60.6	7.5	8.1	29	13.5	98	30.09	10.38
0.56	23.8	2.6	53.9	53.9	6.5	12.6	19	13.8	97	26.76	9.06
0.71	25.0	3.5	52.6	63.0	9.8	13.0	14	19.5	87	35.51	12.13
0.79	21.8	3.4	52.4	61.4	4.0	5.5	35	7.7	85	32.23	11.91
2.39	15.9	7.6	46.8	64.5	6.7	8.0	28	14.0	89	33.12	11.51
0.34	24.5	1.6	60.8	53.9	14.0	31.9	5	38.1	100	28.55	10.67
0.51	21.1	2.1	59.9	59.8	6.5	8.8	21	12.8	111	30.43	14.04
0.54	24.3	2.6	67.2	59.6	17.3	23.2	12	27.0	99	35.95	13.07
0.42	25.6	2.1	62.2	60.8	9.0	10.3	24	15.6	94	42.00	14.22
0.52	24.4	2.5	64.8	61.5	8.8	10.9	22	16.1	85	45.05	14.95
0.73	24.0	3.5	53.7	60.2	5.5	6.1	28	11.3	75	42.55	14.00
0.68	23.6	3.2	58.7	61.8	7.2	16.1	8	21.8	73	41.77	13.78
0.43	23.9	2.0	57.4	57.6	7.7	9.7	24	14.5	89	33.80	11.33
0.66	22.8	3.0	59.9	60.3	5.9	7.1	27	11.3	90	35.88	12.16
1.01	21.6	4.3	52.3	60.4	10.7	19.3	10	25.4	100	30.76	10.99
0.45	22.5	2.0	48.7	60.6	5.7	4.3	52	8.6	84	36.83	12.04
0.28	26.1	1.4	55.4	53.8	6.0	9.9	20	12.5	96	29.47	10.19
0.62	24.1	3.0	51.3	62.7	5.8	5.5	32	10.8	79	37.37	12.50
0.64	22.8	2.9	46.5	60.4	4.2	5.0	41	7.5	78	32.70	10.86
0.95	20.2	3.8	50.5	61.5	6.0	10.2	17	17.3	83	31.77	10.90
0.50	22.5	2.2	66.3	55.3	10.5	18.1	20	20.2	100	27.10	9.72
0.56	22.6	2.5	62.0	60.5	7.2	9.6	29	12.6	95	32.31	11.02
1.18	18.8	4.4	56.5	58.3	8.2	12.7	22	16.2	98	24.30	8.36
0.60	21.0	2.5	56.2	58.0	5.2	5.1	42	8.9	92	30.58	10.19
0.25	22.9	1.1	57.5	53.1	3.5	4.6	59	5.9	82	32.21	10.76
0.75	23.2	3.5	61.8	64.2	7.9	10.4	9	16.6	80	36.46	12.12
0.87	21.6	3.7	55.7	61.2	7.3	11.9	23	17.8	95	29.43	9.82
0.71	22.3	3.1	52.1	62.5	7.7	8.8	15	16.6	74	40.58	14.01
0.79	21.8	3.8	57.6	60.9	20.2	23.4	8	34.5	95	32.45	10.88
1.02	22.6	4.6	47.8	61.00	17.8	24.3	8	33.2	94	33.16	11.22
0.63	24.0	3.0	51.9	59.8	9.7	12.1	16	18.1	93	33.16	11.26
0.25	15.90	1.10	46.50	53.10	3.50	4.30	5.00	5.90	72.57	24.30	8.36
2.39	26.10	7.60	67.20	64.50	28.50	37.00	59.00	43.90	111.08	45.05	14.95
0.72	22.71	3.14	55.80	59.73	8.94	12.54	22.68	17.45	90.59	33.19	11.47
52.51	8.59	39.69	9.64	4.97	57.59	61.41	55.77	50.85	10.00	15.25	14.24

location, climatic conditions during grain development, planting, or ripening can influence endogenous alpha-amylase (Delwiche et al., 2020). For instance, Flumignan et al. (2013) found no statistical difference in falling number test for genotype IPR 118 that grown under an irrigation system (534 s) and nonirrigated system (584 s).

3.2 | Wheat flour quality

Rheological properties evaluated by the alveograph and the farinograph besides the gluten indexes are presented in the Table 2. The official Brazilian standard for wheat classification regarding quality parameters includes gluten strength, W (alveograph), dough stability, and farinograph dough development time (FDDT) and farinograph dough stability (FDST) into five classes: improver (W ≥ 300 and FDST ≥ 14 min); bread (W ≥ 220 or FDST ≥ 10 min); domestic (W ≥ 160 or FDST ≥ 6 min); basic (W ≥ 100 or FDST ≥ 3 min); and other uses (any value of W or FDST) (Brasil, 2010). According to this classification, only genotypes BRS 404, BRS 394, and PF 100.368 grown in Madre de Deus de Minas, and PF 100.368 grown in Uberaba, can be classified as improver wheat class. In general, the average values were similar to wheat grown in the south and southeast regions of Brazil (Castro et al., 2016; Montagner Souza et al., 2019). Genotype BRS 394, grown in Madre de Deus de Minas, presented the highest values for FDDT (28.50 min), FDST (37.00 min), and farinograph breakdown (FBD) (43.90 min). Water absorption (WA) presented slight variation between samples (CV < 5%) and ranged from 53.10 (PF 120.337 M) to 64.50% (CPA 09236 U).

Generally, wheat grown in an irrigation system tends to have a lower W due to the percentage of protein that will influence the rheological behavior of the flour (Flumignan et al., 2013). Vázquez et al. (2012) investigated the influence of cultivar and environment on quality in 23 genotypes of wheat from Latin American: Argentina (4), Brazil (7), Chile (2), Mexico (4), Paraguay (4), and Uruguay (2). According to these authors, it was not clear whether the environment could have a positive or negative impact on flour quality and rheological characteristics of wheat. They attributed this result to the diversity of factors such as temperature, rain, soil nutrients, etc.

Gluten is a complex mixture of related but distinct proteins; in wheat, the covalent linkage of gliadin and glutenin forms this protein network. Each wheat genotype presents distinguished subunits composition with different amounts of gliadin and glutenin. Gluten proteins (i.e., composition, amount, polymerization degree) are especially affected by the environment and cultivation conditions, but genotypes can respond differently as reviewed by Dupont and Altenbach, (2003). In this work, the gluten indexes (GI) found ranged from 72.57 (PF 120.337 C) to 111 (BRS 404 C); dry gluten (DG) from 24.30 (BRS 404 U) to 45.05% (PF 100.368 C); and wet gluten (WG) from 8.36 (BRS 404 U) to 14.95% (PF 100.368 C). In general, the ranking of the different genotypes remained the same regardless of the locations, especially for the genotypes PF 100.368 and BRS 404 that consistently held the highest wet and dry gluten content (Table 2). These results found in the present work were higher than those found by Tozatti et al. (2020) who studied 25 western Canadian wheat cultivars (GI varied from 59.8 to 99), and results are in agreement with those presented by Siddiqi et al. (2020), who evaluated different wheat cultivars from north India (DG ranged from 23.46% to 43.04% and WG ranged from 8.28% to 15.00%).

3.3 | Physical properties

3.3.1 | Pasting properties

Table 3 presents the pasting profiles of genotypes determined by the RVA. Pasting temperature (PT) ranged from 82.20°C (BRS 264 C) to 94.63°C (BRS 404 U) showing a small variation (3%) as expected for wheat starch samples. Peak viscosity (PV) ranged from 850.50 (PF 120.212 C) to 3,285.00 cP (CPAC 09236 U); break down viscosity (BDV) ranged from 76.50 (PF 120.337 M) to 1,555.50 cP (BRS 264 M); setback (S) ranged from 595.00 (PF 120.337 C) to 1,815.00 cP (CPAC 0886 I); and final viscosity (FV) ranged from 1,228.50 (PF 120.337 C) to 3,831.00 cP (CPAC 0872 I), showing a great variation between samples, therefore a wide range of applications as end products. The genotypes grown in *Iraí de Minas* (irrigated wheat system) showed the highest values of PV, with an average (2,823.5 cP) 20% greater than the mean value of all samples (2,363.84 cP). Grouping samples by locations, the genotypes cultivated in the irrigated system also presented the highest mean of S and FV. These results suggest that the environment had great impact on pasting properties. On the other hand, when grouping the same genotypes cultivated in different locations, some parameters such as FV presented a small variation (~10%) for the most part of genotypes, suggesting a pronounced genotype effect. For some genotypes (i.e. CPAC 09236 and BRS 264), setback values or PV (BRS 394) varied slightly.

Indeed, flour pasting characteristics can be affected by adverse environmental conditions (heat or water stress) during grain development (Singh et al., 2010) but also by genotype and crop year conditions (Moiraghi et al., 2019). Corroborating our results, Nhan and Copeland (2016) reported that peak, holding, and final viscosities were all influenced significantly by genotype but also by growing location. In the same way, previous reports concluded that the environment could significantly affect functional properties of starch that are important in foods and other applications (Nhan & Copeland, 2016; Vignola et al., 2016).

Pasting properties are controlled to a significant extent by the starch chain-length distribution (CLD). Higher amylose content (<40%) can significantly suppress the RVA peak viscosity while increase the RVA setback viscosities. The proportion of short amylopectin chains plays a role in promoting retrogradation of wheat starch. Shorter amylopectin long chains and longer amylopectin internal chain segments can interact with amylose retrograded during the RVA cooling and affect the setback viscosity (Li, Wu, et al., 2020; Li, Zhou, et al., 2020). In this study, the genotype BRS 264 presented higher setback viscosity values and also higher amylose contents, regardless of the harvested location (Tables 3 and 4).

Dai et al. (2016) reported that wheat grown under an adequate irrigation system has better end-use quality as wheat flour. Wheat grown under the water-saving irrigation and rainfed conditions showed lower PV and FV compared with those grown under normal irrigation treatment. These results were attributed to the contents

TABLE 3 Physical properties of wheat flours from the Brazilian *Cerrado*

Samples[a]	Pasting temperature (°C)	Peak viscosity (cP)	Break down viscosity (cP)	Setback (cP)	Final viscosity (cP)	Flour color measurement (Minolta)			White index	Yellowness index
						L^*	a^*	b^*		
BRS 264 M	87.15	3272.00	1555.50	1629.00	3743.00	93.96	−0.40	9.11	89.06	13.85
BRS 404 M	89.23	2631.50	810.00	1491.00	3312.50	93.29	−0.75	11.35	86.79	17.38
BRS 394 M	88.47	2101.50	618.00	815.00	2959.00	93.63	−0.46	9.87	88.24	15.06
CPAC 09208 M	87.10	1969.00	482.50	790.00	2908.50	93.28	0.21	7.81	89.69	11.96
CPAC 09236 M	86.78	2347.00	547.50	1581.00	3380.50	95.69	−0.32	5.97	92.63	8.91
PF 100.368 M	91.95	1603.00	226.00	976.00	2353.00	93.63	0.12	7.84	89.90	11.96
PF 120.212 M	89.60	951.00	107.00	970.00	1814.00	93.53	−0.11	8.54	89.29	13.04
PF 120.337 M	91.98	963.00	76.50	751.50	1731.50	93.21	0.29	7.40	89.95	11.34
BRS 264 C	82.20	3213.00	1325.00	1619.50	3507.50	93.41	−0.25	9.86	88.14	15.08
BRS 404 C	89.48	2958.50	1050.00	1514.00	3422.50	92.63	−0.27	11.47	86.36	17.69
BRS 394 C	87.25	2658.50	966.00	1657.50	3350.00	92.54	0.06	9.48	87.94	14.63
CPAC 09208 C	88.80	2981.50	1241.50	1712.00	3452.00	92.61	0.46	7.86	89.20	12.12
PF 100.368 C	89.30	2423.50	804.50	1527.00	3146.00	93.30	0.29	8.07	89.51	12.36
PF 120.212 C	84.35	2799.98	1090.62	1503.11	3231.88	92.85	0.18	8.73	88.71	13.43
PF 120.337 C	89.70	850.50	217.00	595.00	1228.50	92.97	0.46	8.10	89.26	12.45
BRS 264 P	93.53	2053.00	496.50	1371.50	2928.00	93.29	−0.17	10.26	87.74	15.71
BRS 404 P	94.30	1709.50	385.50	1097.50	2421.50	93.21	−0.51	12.00	86.20	18.39
BRS 394 P	88.25	2426.50	941.00	1610.00	3095.50	93.58	−0.20	10.07	88.06	15.37
CPAC 09208 P	86.78	2281.00	907.50	1519.00	2892.50	93.62	0.32	8.13	89.66	12.41
CPAC 09236 P	86.78	2420.00	961.00	1481.50	2940.50	95.99	−0.20	6.30	92.53	9.38
PF 100.368 P	87.25	2621.00	781.00	1469.00	3309.00	93.57	0.18	8.38	89.44	12.79
PF 120.212 P	90.03	2740.00	853.00	1494.50	3381.50	93.66	−0.08	9.09	88.92	13.87
PF 120.337 P	91.20	2061.50	567.00	1370.50	2865.00	93.96	0.22	7.88	90.07	11.98
BRS 264 U	87.62	2788.50	917.50	1775.00	3646.00	94.01	−0.32	10.30	88.08	15.65
BRS 404 U	94.63	2699.50	805.00	882.50	3525.50	93.45	−0.68	12.63	85.76	19.31
BRS 394 U	87.63	2186.00	736.00	994.00	3126.00	93.65	−0.43	11.02	87.27	16.81
CPAC 09208 U	86.30	2514.00	802.00	1595.00	3307.00	93.77	−0.24	8.60	89.38	13.10
CPAC 09236 U	84.70	3285.00	1004.50	1474.50	3755.00	95.99	−0.18	6.41	92.44	9.54
PF 100.368 U	89.28	2190.00	528.50	1543.00	3204.50	93.57	0.31	8.44	89.39	12.89
PF 120.212 U	88.90	1377.50	378.00	779.00	1778.50	93.06	0.49	8.56	88.97	13.14
CPAC 0841 I	89.60	2732.50	798.50	1602.00	3536.00	93.88	−0.51	11.93	86.58	18.15

(Continues)

TABLE 3 (Continued)

Samples[a]	Pasting temperature (°C)	Peak viscosity (cP)	Break down viscosity (cP)	Setback (cP)	Final viscosity (cP)	Flour color measurement (Minolta)			White index	Yellowness index
						*L**	*a**	*b**		
CPAC 0872 I	86.78	3047.50	1019.50	1803.00	3831.00	94.45	−0.49	10.37	88.23	15.69
CPAC 0886 I	86.80	2924.00	1048.00	1815.00	3691.00	94.19	−0.01	9.35	88.99	14.18
CPAC 0891 I	88.85	2590.00	843.50	1641.50	3388.00	93.75	−0.12	10.19	88.05	15.53
Minimum	82.20	850.50	76.50	595.00	1228.50	92.54	−0.75	5.97	85.76	8.91
Maximum	94.63	3285.00	1555.50	1815.00	3831.00	95.99	0.49	12.63	92.63	19.31
Mean value	88.60	2363.84	761.50	1366.17	3063.60	93.68	−0.09	9.16	88.84	13.98
CV (%)	3.02	27.25	44.79	25.74	20.66	0.88	372.67	18.04	1.83	18.32

Abbreviation: D [4,3], particle size.

[a]Genotypes grown in five locations in the Brazilian *Cerrado: Madre de Deus de Minas* (M), *Coromandel* (C), *Piumhi* (P), *Uberaba* (U), and *Iraí de Minas* (I).

of amylose, starch, and protein and glutenin macropolymer. Our results indicated that irrigated system demonstrated the highest values for S (1,815.00 cP) and FV (3,831.00 cP) for CPAC 0806 I and CPAC 0872 I, respectively. In addition, comparing normal irrigation with the water-saving irrigation and/or rainfed conditions led to an increase of B-type starch granules, protein content, FV and PV, while A-type starch granules, amylose, and starch contents were decreased.

3.4 | Flour color measurement

The *L** values of the flours ranged from 92.54 to 95.99; the *a** values, ranged from 0.75 to 0.49; and the *b** values, varied from 5.97 to 12.63, respectively (Table 3). The CPAC 09236 had the highest WI regardless of growing location (92.63; 92.53; 92.44) that consisting in a suitable characteristic of flour to use for baking in order to obtain light bread crumbs. In contrast, the BRS 404 showed the highest value for the YI (17.38; 17.69; 18.39; 19.31) suggesting the use of this genotype to produce pastas. In fact, consumers in many countries prefer whiter flour, but different products may require different levels of whiteness. The Japanese and Chinese prefer yellowish-pigmented flours to produce yellow alkaline noodles (ramen) and Italians for pasta and couscous. Contrary, flours with a higher WI are desirable for Chinese steamed and baked bread (He et al., 2004).

Wheat flour color depends on some factors, such as the presence of bran, xanthophylls (Miskelly, 2010), carotenoids, protein content, particle size (Hidalgo et al., 2014), and can be affected by genotype, crop season, and location (Hidalgo et al., 2009).

3.5 | Starch characterization

3.5.1 | Starch granular size distribution

Wheat genotypes cultivated in Madre de Deus de Minas showed the largest mean value of particle sizes (62.42 μm), and particularly the genotype PF 100.368 showed the largest particle size (88.64 μm) (Table 4), while samples harvested in Uberaba presented the lowest mean value (34.81 μm). In addition, the genotype BRS 264 presented lower values (30.24 μm) in all planting locations. According to Sasaki and Matsuki (1998), wheat starch presents a bimodal profile and can be separated into A and B granule fractions based on granule size: (i) large A-granule range is ≈15–40 μm and (ii) small B-granule range is ≈1–10 μm. Thus, our results indicated that all genotypes cultivated in five different locations presented A-type granule, i.e. higher than 27.46 μm.

Li et al. (2016) investigated the particle size characteristics of 12 wheat cultivars grown in east China's Huanghuai region and found a positive correlation between amylose content and particle diameter >22 μm, and a significant negatively correlation between amylose content and particle diameter of granule <10 μm. These authors

TABLE 4 Starch characteristics of wheat grown in the Brazilian *Cerrado*

Samples[a]	D [4,3]	Resistant starch (g/100g)	To (°C)	Tp (°C)	Tc (°C)	ΔH J/g	Damaged starch (%)	Amylose (%)	Amylopectin (%)	Relative crystallinity (%)
BRS 264 M	27.68	1.52	56.12	61.57	78.33	11.05	4.15	**30.22**	69.17	16.1
BRS 404 M	43.42	0.41	55.6	62.15	79.6	9.94	4.71	28.03	49.26	21.2
BRS 394 M	34.03	0.66	55.59	62.58	81.73	9.09	4.99	28.34	50.42	17.9
CPAC 09208 M	54.86	0.14	55	62.35	80.18	8.53	4.83	25.85	62.8	19.6
CPAC 09236 M	77.41	0.76	56.58	66.12	81.27	8.62	3.81	25.89	62.82	16
PF 100.368 M	88.64	0.45	57.93	66.28	84.92	5.48	4.17	27.13	42.03	13
PF 120.212 M	70.05	0.22	58.7	68.7	83.32	4.36	5.18	24.81	82.4	13.8
PF 120.337 M	82.08	1.29	55.75	64.13	79.71	2.18	5.49	27.09	85.88	10.6
BRS 264 C	29.06	0.13	61.57	64.97	82.74	12.41	3.37	29.48	84.25	18.6
BRS 404 C	29.53	0	60.78	65.26	85.28	10.54	3.74	27.36	78.33	25.6
BRS 394 C	47.52	0.21	59.38	66.19	82.34	10.76	3.64	28.3	89.8	22.4
CPAC 09208 C	33.83	0.74	60.12	65.24	82.6	10.03	3.71	26.39	80.44	27.3
PF 100.368 C	33.86	0.72	64.91	68.68	83.2	8.89	3.42	27.83	76.14	26.5
PF 120.212 C	44.09	0	62.65	67.31	81.93	9.64	3.98	27.8	49.59	15.1
PF 120.337 C	33.39	0.49	61.69	66.79	80.51	4.72	4.39	28.2	79.73	18.5
BRS 264 P	36.76	0.45	62.1	67.17	81.24	10.15	4.12	26.02	77.84	27.2
BRS 404 P	42.91	0.89	62.57	67.38	81.51	7.86	4.34	26.42	76.24	28.8
BRS 394 P	40.86	1.45	59.8	65.03	83.73	11.92	4.65	26.52	82.4	26.5
CPAC 09208 P	33.39	0.62	58.96	63.97	80.2	11.82	4.38	26.15	76.46	20.9
CPAC 09236 P	46.66	0.92	62.37	66.46	80.88	12.54	3.32	24.24	75.65	36.3
PF 100.368 P	43.49	0.79	59.37	64.74	81.62	12.01	3.99	26.83	78.72	29.8
PF 120.212 P	47.90	0	59.1	63.89	82.53	11.75	4.91	27.87	76.13	20.7
PF 120.337 P	38.79	1.31	55.29	61	83.95	10.93	5.05	28.64	74.67	17.2
BRS 264 U	27.46	0.87	57.82	65.11	82.61	10.88	4.16	28.91	66.27	20.8
BRS 404 U	42.68	0.11	61.33	67.78	87.8	11.5	4.40	29.38	69.58	19.4
BRS 394 U	32.49	1.17	59.59	67.6	83.87	9.71	5.00	28.97	67.77	21.3
CPAC 09208 U	30.59	1.7	59.69	64.38	80.77	9.69	4.26	28.34	70.41	21.7
CPAC 09236 U	33.89	0.47	61.5	67.9	82.83	13.38	2.95	27.56	66.77	20.3
PF 100.368 U	28.88	1.15	57.03	65.01	77.5	7.99	4.26	28.5	67.44	18.3
PF 120.212 U	47.72	0.03	59.71	66.46	80.44	11.66	5.33	27.46	69.86	22.4
CPAC 0841 I	50.67	0.6	58.48	64.96	79.11	9.81	4.25	29.91	60.96	20.8
CPAC 0872 I	33.70	0.76	58.74	64.72	81.4	9.64	4.19	28.87	68.99	25.6
CPAC 0886 I	43.89	1.01	59.53	65.25	79.84	12.87	4.53	28.84	71.52	22
CPAC 0891 I	54.62	0	59.08	65.68	79.83	9.64	4.55	28.2	67.12	29
Minimum	27.46	0	55	61	77.5	2.18	3.32	24.24	42.03	10.6
Maximum	88.64	1.70	64.91	68.7	87.8	13.38	5.49	30.22	89.80	36.3
Mean value	43.73	0.65	59.25	65.38	81.74	9.76	4.95	27.66	70.82	21.51
CV (%)	35.39	74.54	4.12	2.99	2.56	25.80	17.68	5.07	15.54	25.22

Abbreviations: To, gelatinization onset; Tc, gelatinization conclusion; Tp, gelatinization peak; ΔH J/g, enthalpy.

[a]Genotypes grown in five locations in the Brazilian *Cerrado: Madre de Deus de Minas* (M), *Coromandel* (C), *Piumhi* (P), *Uberaba* (U), and *Iraí de Minas* (I).

concluded that large granules (>22 μm) have higher amylose content compared with small granules (<10 μm). However, our findings only indicated a significant ($p < .05$) negatively correlation (−0.410) between amylose content and particle diameter.

Hong et al. (2021) evaluated how the addition of A- or B-type starch could impact on pasting quality of wheat flour. The addition of 20% B-type increased solubility and gluten polymerization on noodles, enhancing its texture and yield. On the other hand, the addition of 20% A-type caused the contrary effects on noodles. Therefore, it is concluded that changes in starch quality have great influence on pasting properties, suggesting that the quality of the final product can be predicted by wheat quality.

Wheat flour with larger particle size is more resistant to short-range rupture molecular ordering due to heating (Guo et al., 2017). Hard wheat produces flours with particle sizes over 40 μm. Larger granules occupy a larger volume fraction than the swelling of small granules, causing greater friction and peak viscosity (Blanchard et al., 2012). Guan et al. (2020) found significant increases in peak viscosity, trough viscosity, breakdown viscosity, final viscosity, and setback as flour particle size decreased from 43.07 to 25.81 μm. Our results showed a significant negative correlation ($p < .05$) between particle size and breakdown viscosity (−0.590).

3.6 | Molecular structure

Amylose (AM) contents ranged from 24.24% to 30.22%; amylopectin (AP) content varied from 42.03% to 89.80%; and relative crystallinity (RC), from 10.60% to 36.30% (Table 4). Wheat starch has amylose and amylopectin ratios ranging from 25%–28% to 72%–75%, respectively, and differences in the proportions between the polymer chains will influence the characteristics of starch, e.g., gelatinization (Hung, 2008).

Environmental, agronomic conditions, and wheat genotype will influence the morphology, structure, composition, thermal and technological properties of starches. While common wheat starches have lower paste viscosity, durum wheat cultivars contain a high proportion of amylose, but lower gelatinization temperature and enthalpy (Shevkani et al., 2017). Gelatinization can be understood as an irreversible change in which the rupture of granules in the presence of water reflects the loss of molecular (double-helical) order (Cooke & Gidley, 1992), and it is determined by AP and AM contents (Nivelle et al., 2019). The amylose content of starch affects granule structure and starch polymorphism, which can affect the falling number (He et al., 2019). Moisture and AM presence also have a great impact in promoting the complex starch–lipid formation (Li et al., 2021).

Liang et al. (2021) concluded that wheat cultivated in supplemental irrigation system had minor effect on starch molecular structure, promoted the swelling of starch granules, decreased both the relative crystallinity, amylose content, and the content of amylopectin chains but increased the resistant starch content. In our study, the effect of genotype was more pronounced than the environmental conditions. This may be related to rainfall regime, season of the year, humidity and ambient temperature that were not controlled and were different in the five locations. The genotypes grown in *Piumhí* had a high mean value of enthalpy (11.79 J/g) suggesting that they require greater energy input for the occurrence of gelatinization phenomena, in which granule disruption occurs. Moreover, as expected, *Piumhí* genotypes showed higher resistant starch (RS) (0.84%) and relative crystallinity (RC) (26.85%), but lower levels of damaged starch (DS). *Madre de Deus de Minas* presented the highest mean values of DS (4.77%) and particle size D [4,3] (62.46 μm). Samples grown in *Uberaba* had the highest RS (0.87%), especially the genotype CPAC 09208 (1.70%), followed by samples from *Piumhí* (0.84%). The genotype CPAC 09236 presented the highest mean enthalpy (11.51 J/g) and crystallinity (24.20%) in all locations. The genotypes PF 120337 and PF 120212 showed the highest DS (4.93%).

DS is produced during milling of wheat and depends on environmental conditions, genotype, type of kernel, hardness, protein content, and milling conditions. It is an important component in wheat flour, as it can change the rheological properties of and the final quality of products, such as bread, pasta, and biscuits (Ali et al., 2014). DS content plays an important role in the formulation of bakery products, especially in the fermentation and gassing power of the dough, cooking quality, specific volume, color and crumb structure, and texture characteristics. DS achieves greater hydration than nondamaged starch and is more susceptible to enzymatic hydrolysis (Horstmann et al., 2017; Jane, 2009; Liu et al., 2013).

However, high levels of DS in wheat flour are correlated with increased acrylamide content in the bread crust and crumb. Thus, reducing damaged starch in flour is an option to mitigate acrylamide formation (Wang et al., 2017). Liu et al. (2013) observed that the falling number, sedimentation value, viscosity of starch pastes, and dough proofing stability were negatively correlated, while water absorption, pastes thermal stability, degree of starch pastes, and dough level were positively correlated with DS content but not significantly correlated with both the external and internal color of steamed bread.

DS content is also significantly affected by the thermal behavior of wheat starch. Wheat flour with higher levels of DS requires less energy for gelatinization (Barrera et al., 2012), which may explain the negative correlation found in the present study. Higher levels

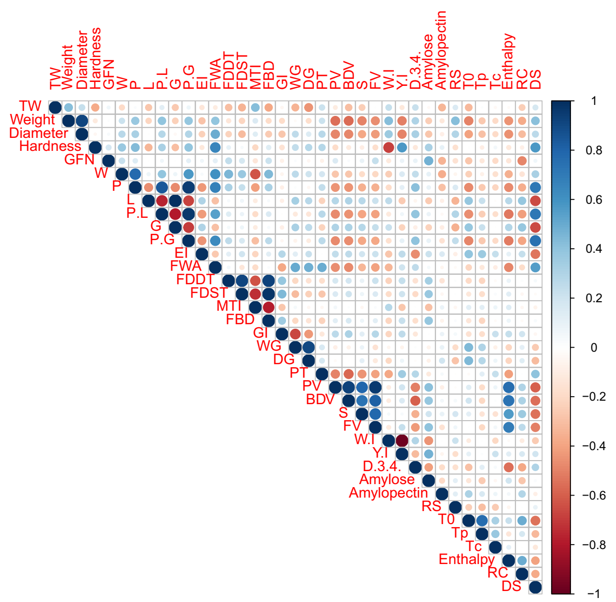

FIGURE 2 Correlogram for quality parameters and pasting and starch properties for wheat grown in the Brazilian *Cerrado*

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of DS significantly decrease the starch-gelatinization enthalpy and favor the formation of amylose–lipid complexes (León et al., 2006). Mechanical damage of starch structure disrupts the crystalline structure and increases the surface area. As a result, the shape is more irregular, and the relative crystallinity of starch is significantly decreased (Wu et al., 2017).

In the present study, relative crystallinity and enthalpy showed to be more influenced by genotype than by location, especially for the genotypes BRS264 and CPAC 09236. In contrast, Labuschagne et al. (2007) reported that specific genotypes interacted with specific environments, making the environment the determining factor of amylose:amylopectin ratio. Vignola et al. (2016) also noted that the environment had a greater impact on wheat starch properties than genotype for all pasting property parameters, except for pasting temperature.

3.7 | Pairwise correlation coefficient (*r*), principal component analysis (PCA), and clustering of different Brazilian *Cerrado* wheat quality parameters

A correlation-focused approach was undertaken to understand the relationship between grain quality, physical properties, and starch of wheats from Brazilian *Cerrado*. The correlogram indicates a positive relationship between damaged starch and SKCS parameters, P/G, WA, but a negative correlation with pasting properties (PT, PV, S,

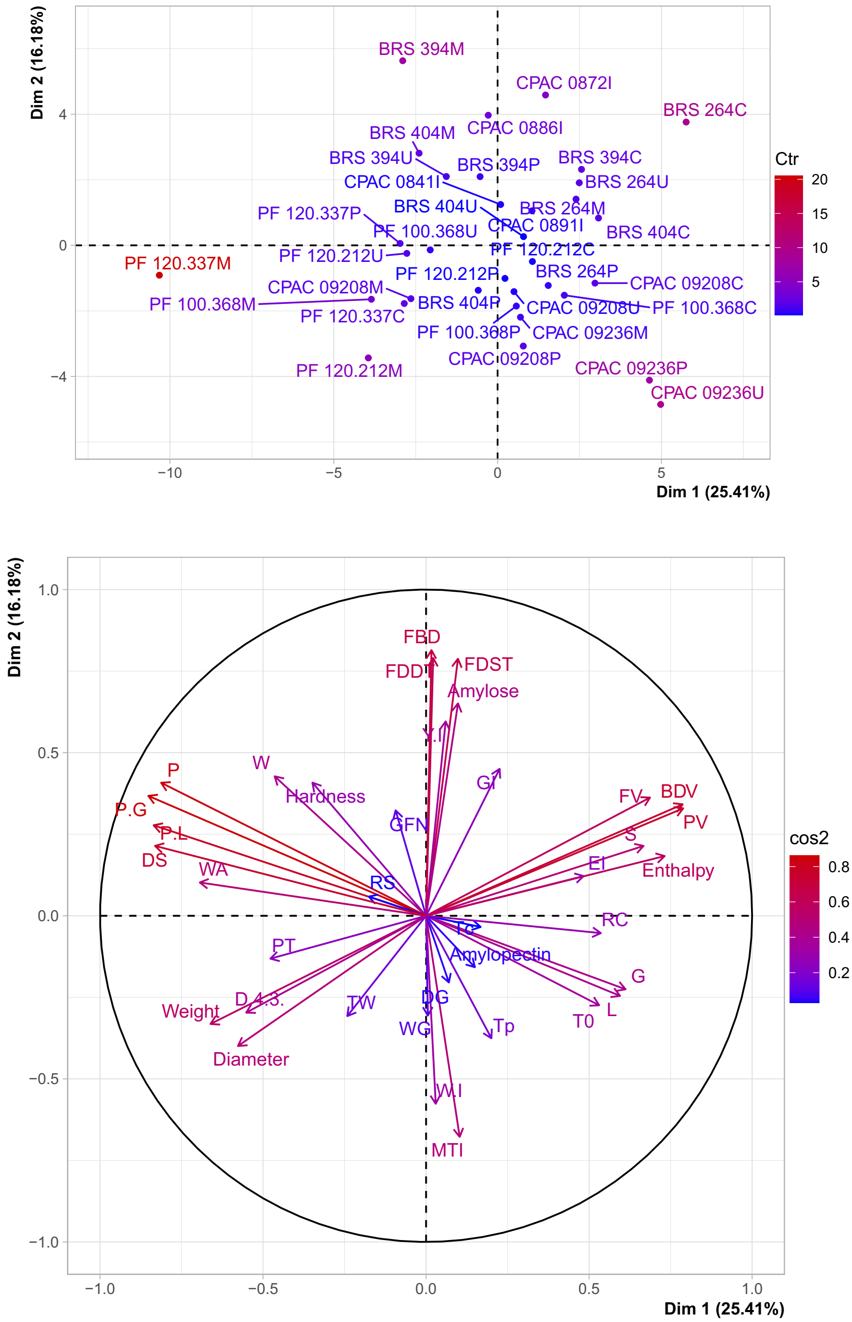

FIGURE 3 Two-dimensional loading plot from principal component analysis (PCA) using PCA Dimension 1 (Dim 1) and PCA Dimension 2 (Dim 2). Loading plot based on different variables of grain quality and flour and starch properties of wheat from the Brazilian *Cerrado*

BDV, FV), enthalpy, and RC. A positive correlation was also found between amylose content and FN. However, there was a negative correlation between particle size and amylose, amylopectin, and the pasting properties (Figure 2).

PCA was used to evaluate the relationship among the 37 variables related to wheat quality; the main goal was to get new set of variables able to summarize the features of the data set. PCA plot was generated by two components: Dimension 1 (Dim 1) and Dimension 2 (Dim 2). Variability explained by Dim 1 and Dim 2 was ~25.41% and ~16.18%, respectively, thus, accounting for ~41.59% of total variability. Dim 1 is described by TW, SK weight, SK diameter, WG, DG, MTI, WI, PT, D [4,3], To, Tp, Tc, and amylopectin. In contrast, the most variables are described by Dim 2: SK hardness index, GFN, W, P, L, G, EI, GI, FWA, FDDT, FDST, FBD, PV, BDV, S, FV, YI, amylose, RS, and DS (Figure 3). The parameters of the close vectors are positive and correlated.

A Hierarchical tree and Individual Factor Map from the principal components (Dim 1 and Dim 2) of PCA were used to better explain the relationship between the variables (grain quality, rheological, physical, and starch properties) and factors (wheat samples). These results confirmed the groups formatted according to their similarities (Figure 4). Cluster 1 (PF 120.337 M, PF 120.337 P, PF 120.212 U, CPAC 09208 M, PF 100.368 U, PF 100.368 M, PF 120.337 C) was formed by samples with similar values of SK weight, SK diameter, TW, PT, and RS. Cluster 2 (BRS 264 C, BRS 284 M, BRS 264 U, BRS 394 U, BRS 404 M, BRS 394 P, BRS 394 M, CPAC 08721 I, CPAC 08861 I) was composed of the samples located on the positive axis of Dim 2 and correlated with GFN, amylose, SK hardness index, enthalpy, FDST, FBD, GI, BDV, and EI. Finally, cluster 3 (BRS 394 C, BRS 404 C, CPAC 0841 I, CPAC 0891 I, BRS 404 U, PF 120.212 P, PF 120.212 C, CPAC 09208 C, PF100.386 P, PF100.386 C, BRS 404 P, BRS 284 P) was formed by the majority of samples and was related to intermediary parameters, while cluster 4 (CPAC 09208 U, CPAC 09236 M, CPAC 09208 P, CPAC 09236 P, CPAC 09236 U, CPAC 0841 I, CPAC 0891 I) was related to starch gelatinization and farinograph parameters.

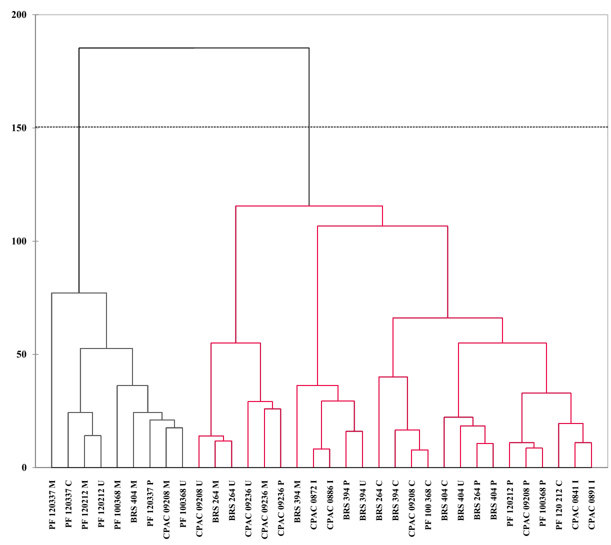

FIGURE 4 Hierarchical tree and Individual Factor Map from the principal components of PCA

4 | CONCLUSION

The present study compared 12 different wheat genotypes grown in five regions of the Brazilian *Cerrado*, a promising new agricultural frontier. These results are the most comprehensive to date and contribute to the comprehension of the effects relative of genotype and location on technological quality of wheat and grain, flour, and starch properties. Growth location and genotype influenced pasting properties and starch content. The irrigation system strongly influences the starch characteristics, rheological, and pasting properties, especially peak viscosity. Particularly, *Piumhi* location showed the highest values of resistant starch, enthalpy, and relative crystallinity, consisting of an interesting prebiotic functional appeal. Relative crystallinity and enthalpy showed to be more influenced by genotype than the environment, especially for the genotypes BRS 264 and CPAC 09236. The results of gluten index (mean values = 89 and 94) and damaged starch (mean values = 4.7% and 4.4%) showed that the genotypes from *Iraí de Minas* and *Madre de Deus de Minas* could be used for bakery products. As perspective, it will be interesting to expand the work to study the effect of crop years to provide a summary of suitable genotypes and location regarding the applications as end-product. Further studies applying baking tests are required to better describe and correlate quality parameters of flours with bakery characteristics using tropical wheat grains.

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CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

AUTHOR CONTRIBUTIONS

Maria Eugenia Araújo Silva Oliveira: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Visualization; Writing – original draft; Writing – review & editing. **Thais de Oliveira Alves:** Formal analysis; Investigation; Methodology; Visualization. **Luiz Carlos Gutkoski:** Writing – review & editing. **Martha Zavariz de Miranda:** Conceptualization; Data curation; Funding acquisition; Investigation; Methodology; Resources; Validation; Visualization; Writing – review & editing. **Mariana Simões Larraz Ferreira:** Conceptualization; Data curation; Funding acquisition; Investigation; Methodology; Project administration; Resources; Software; Supervision; Validation; Visualization; Writing – review

& editing. **Cristina Yoshie Takeiti:** Conceptualization; Data curation; Funding acquisition; Methodology; Project administration; Resources; Supervision; Validation; Visualization; Writing – original draft; Writing – review & editing.

DATA AVAILABILITY STATEMENT

Data openly available in a public repository that issues datasets with DOIs.

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