RESEARCH ARTICLE

Genotypic and environmental effects on starch properties of Argentinean wheat flours

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The aim of this study was to determine the influence of different environments and genotypes on starch characteristics and properties of Argentinean wheat flours. Amylose content, starch granule size distribution, thermal characteristics, and pasting properties of flours were determinate on 24 wheat genotypes from six environments. There were significant differences for all parameters analyzed among genotypes and environments ($p < 0.05$). The environment was the main factor responsible for the increase of variability observed in amylose content. According to variance ratios, environmental conditions have a greater influence on the characteristics of A granules, while genotype influenced mostly B granules diameter and volume percentage. Balcarce-2010 and Reconquista-2010, environments which showed drought during grain filling, were the environments that presented the highest volume percent of B granules and the lowest percent of A granule. Genotype was the greatest source of variation, according to variance relationship, for DSC parameters. ΔH values were the highest on MarcosJuarez-2009 and Reconquista-2010 where high temperatures during grain filling period were recorded. Besides, these two environments also presented high pasting temperature values. Environment had a noticeable greater impact on starch properties of wheat than genotype for all pasting properties parameters except for pasting temperature. Both genetic and environmental factors control physicochemical characteristics of starch and the size distribution of starch granules in wheat grains at different degrees.

Received: February 17, 2016
Revised: March 18, 2016
Accepted: March 19, 2016

Keywords:
Environment / Genotype / Starch / Wheat

1 Introduction

Wheat grain is one of the major cereals consumed by human beings. Starch, the predominant component of the wheat grain, constitutes two-thirds to three-quarters of the dry weight of a wheat kernel, depending on the cultivar and serves as a multifunctional ingredient for the food or nonfood industries [1]. During grain development, starch is deposited in the endosperm as discrete semicrystalline aggregates known as starch granules: B-type and A-type granules [1, 2]. Several studies have reported structural and functional differences between this two type of granules [3, 4]. A-type granules with a diameter of 10–35 μm begins synthesis in an amyloplast 4 days after flowering and the diameter stops increasing at approximately 19 days after flowering, but the volume (thickness) continues to

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Abbreviations: ØA and B, diameter of A and B granules; **% Vol. A and B,** average contribution of the A or B granule population to the total volume; **B-2009,** Balcarce 2009; **B-2010,** Balcarce 2010; **DSC,** differential scanning calorimetry; **FV,** final viscosity; **MJ-2009,** Marcos Juarez 2009; **MJ-2010,** Marcos Juarez 2010; **PT,** pasting temperature; **PV,** peak viscosity; **PW,** peak width; **RVA,** rapid visco analyzer; **R-2009,** Reconquista 2009; **R-2010,** Reconquista 2010

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increase [5], whereas the small B-type granules, with a diameter 1–10 μm, are initiated some days after anthesis and remain considerably smaller [3]. Granule size has been reported to influence the functional and baking properties of wheat flour [4, 6] and the pasting behavior of starch [3, 7].

Starch is composed of two glucose polymers, amylose and amylopectin, with the ratio of amylose/amylopectin ranging between 25–28% and 72–75%, respectively [8]. In wheat starches, amylopectin is considered to contribute to water absorption, swelling, and pasting of starch granules, whereas amylose and lipids tend to retard these processes [9, 10]. Viscosity changes suffered by a mixture of flour and water during heating and cooling cycles are related to the gelatinization and retrogradation of starch as it was demonstrated by Loney et al. [11], who found that wheat cultivars with high flour paste viscosity had high viscosity starch too. Nowadays flour viscosity can be evaluated using a rapid visco analyzer (RVA) [12]. Pasting behavior of starch is related to genotype and is also influenced by environmental factors during crop growth [13, 14]. Although starch is the primary determinant of flour paste viscosity, other components such as arabinoxilan [15, 16] and gluten fractions exert an effect on it [17].

The gelatinization behavior, which is an irreversible order-disorder transition, has been widely studied for many different starches by differential scanning calorimetry (DSC). DSC is a particularly useful probe of this structural disordering, showing an endothermic melting process that is assumed to be directly related to the loss of crystalline order [18]. The functionality of starch becomes especially dominant during the heating process, although gelatinization parameters are affected by the polar and non-polar polymers present in flour [19].

Granule composition, morphology, pasting, and thermal behavior are, to a large extent, under genetic control [17], although environmental conditions during starch synthesis could also affect the packing of starch polymers within granules [20, 21]. Plant reproductive development is extremely sensitive to abiotic stress; therefore, any environmental perturbation may strongly affect final yield and quality [22]. A considerable research effort has been devoted to understanding the influence of specific environmental factors on wheat starch characteristics and properties. Temperature during growth, particularly during grain filling, is perhaps one of the most studied and significant environmental parameters influencing starch characteristics. An excessively high temperature during growth reduces starch accumulation in wheat kernels [23, 24] due to reduced starch synthase activity and a curtailed grain filling period [24]. An elevated temperature during growth has also been reported to alter A- to B-type granule ratios [24, 25]. Until now little is known about whether the properties of flour and starch are more influenced by environmental factors or by genotype. Apart from that, there is scarce information about starch characteristics of wheat flour from Argentinean cultivars. The aim of this study was to determine the influence of different environments on starch characteristics and properties on Argentinean wheat cultivars.

2 Materials and methods

2.1 Plant material

Twenty four commercial bread wheat cultivars (ACA 303, ACA 315, ACA 320,Atlax, Baguette 9, Baguette Premiun 11, Biointa 1005, Biointa 1006, Biointa 3004, Buck 75 Aniversario, Buck Meteoro, Buck Puelche, Cronox, Klein Capricornio, Klein Chaja, Klein Guerrero, Klein Leon, Klein Nutria, Klein Tauro, Klein Tigre, Klein Yarara, Klein Zorro, LE 2330, LE 2331) were grown at three different locations in Argentina: Reconquista (sub-region I), Marcos Juarez (sub-region II), and Barrow (sub-region IV). Grains were provided by the Comparative Trials Network for Wheat Varieties (RET) and harvested in two consecutive periods: 2009–2010 and 2010–2011. Data from locations and years were combined to form six environments: B-2009, MJ-2009, and R-2009 correspond to wheats from Balcarce, Marcos Juarez, and Reconquista, respectively, harvested in 2009, while B-2010, MJ-2010, and R-2010 correspond to the same locations harvested in 2010. Nitrogen fertilization was applied for both years according to local practice. The localization and meteorological data of wheat for the three selected regions are shown in Table 1. Grain samples were milled on a four-roller laboratory mill (Agromatic AG AQC 109, Laupen, Switzerland) obtaining a total of 144 flour samples. Moisture content was determined using Approved Method 44-19.01 [26].

2.2 Starch isolation

Starch was isolated from flour by acid digestion using pepsin A (P7012, Sigma, St. Louis, MO) in 0.04 N HCl and incubated for 60 min at 37°C. After protease treatment sample was incubated with Hemicellulase 90 (90,000 U/g activity, Amano Enzyme USA, Lombard, IL) in 0.1 M sodium acetate buffer (pH 4.5) and incubated for 3 h at 45°C. A detergent mix (5% SDS, 5% Triton X-100, 5% Tween 40, and 5% Triton X-15) was added after incubation, and the suspension was vortex-mixed for 30 s. The enzyme-treated starch was centrifuged at 2500 rpm for 5 min. The starch was washed with water. The extracted starch was dried in an oven at 37°C overnight and ground in a mortar.

2.3 Amylose content

Amylose content of starch was determined by the method of Gibson et al. [27], using an amylopectin–amylose assay kit (Megazyme Int. Ireland Ltd, Wicklow, Ireland).

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Table 1. Localization and weather conditions in the different sampling regions

				Annual average temperature (°C)		Average temperature during grain filling period (°C)		Average precipitation during grain filling period (mm)	
Location	Altitude (m)	S Latitude	W Longitude	2009	2010	2009	2010	2009	2010
Marcos Juarez	110	32°42	62°6	25.08	23.9	28	23.5	118.5	47
Reconquista	49	29°14	59°56′	25.48	19.09	23	29	282	13.2
Barrow	112	38°22	60°16	15.08	14.06	15.5	14	103.15	46.8

2.4 Starch granule size distribution

Granule size distribution of starches was determined using a Horiba model LA-950E, (Particle Sizing Systems, Japan) with a standard refractive index of 1.32 for water and 1.52 for starch. A 10 μm cutoff was used to differentiate A- and B-type starch granule populations, B granules being smaller than this value. Diameter and volume percentage of granules were taken at the peakin each granule population curve (Granules A and B).

2.5 Differential scanning calorimetry

The thermal characteristics of the flour were measured using a DSC 823 (Mettler-Toledo, Switzerland) calibrated with indium and zinc. For gelatinization studies, 10.0 mg of flour were weighed into 100 μL silver pans with the addition of twice its weight in water. Before the heating process, pans were sealed and stored for 24 h at 25°C. Nitrogen was used to purge the system. The samples were scanned at 10°C/min from 30 to 120°C. An empty capsule (air) was used as reference. Onset temperature (To), completion temperature (Tc), peak temperature (Tp), peak width (PW), and ΔH (expressed as mJ/mg of sample) were calculated. Samples were evaluated in duplicate.

2.6 Starch pasting properties

Pasting properties of starch were measured in flour samples in duplicate using a RVA (Tecmaster, Perten Instruments, NSW, Australia), according to AACC method 76–21 (2000). The heating cycle was 50–95°C in 282 s, holding at 95°C for 150 s, and then cooling to 50°C. Each cycle was initiated by a 10 s mix at 960 rpm paddle speed and then 160 rpm paddle speed was used for the rest of the test. The RVA studies were carried out using 3 g of sample (dry basis) and 25 mL of water in an aluminum canister. Pasting temperature (PT), peak viscosity (PV), final viscosity (FV), trough, breakdown, and setback were obtained from the pasting curves. Samples were evaluated in duplicate.

2.7 Statistical analysis

Results were expressed as the mean of two replicates. The data were analyzed by ANOVA and the results were compared by Fisher's test at a significance level of 0.05. The relationship between measured parameters was assessed by Pearson's test (significance levels at $p < 0.05$ and $p < 0.001$). The magnitude of the effect of environmental factor in relation to genotype can be shown through the use of the variance component ratio. Each variance was calculated with INFOSTAT statistical software and a ratio between Environment and Genotype (VE/VG) larger than 1.0 indicates a greater influence of environmental factor relative to the variability associated with the genotype. Cluster analysis was performed on the basis of Euclidean distances, using the Ward method with a maximum cluster number arbitrarily set to two. The cluster was made using parameters that were more affected by genotype as variables. All analyses were performed using the INFOSTAT statistical software [28].

3 Results and discussion

Based on ANOVA, large variations in starch characteristics were found among all samples, indicating the great variability among wheat genotypes and environments.The average and range of amylose content and particle size distribution of starch granules for the 24 cultivars and 6 environments are summarized in Table 2.

Amylose content varied from 17.57 to 36.47% with an average content of 28.63%. Similar results were found by Raeker et al. [29] who reported values between 26.7

Table 2. Ratio of variance, medium, minimum, and maximum values for amylose content and granule size distributions of starch

	ØB μm	% Vol. B	ØA μm	% Vol. A	Amylose %
Medium	3.09	19.6	20.62	80.45	28.63
Minimum	1.73	9.02	10.71	59.43	17.57
Maximum	4.47	40.57	29.9	90.99	36.47
δ E/G	0.89	0.69	1.04	0.709	1.11

ØA and B, diameter of A and B granules; % Vol. A, average contribution of the A granule population to the total volume; % Vol. B, average contribution of the B granule population to the total volume; δ E/G, ratio of variance for environment and genotype.

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and 28.8% for soft wheat starches, whereas Blazek and Copeland [30] found values ranging from 35 to 43% for hard wheat. Significant differences on amylose content were found between 24 cultivars and 6 environments. If we analyze variances, the environment was the main factor responsible for the increase of variability observed, although there were significant differences between genotypes and genotype x environment interaction ($p < 0.001$). These observations are in good agreement with the results of Morris et al. [17] and Zeng et al. [31] who have also shown that grain amylose content is influenced by environment as well as genotype. Rosicka-Kaczmarek et al. [32] proposed that the environment has some degree of influence because of its ability to regulate the activity of enzymes that take part in the biosynthesis of starch. B-2009 was the environment with lower amylose content while wheats from MJ-2009 and R-2010 presented the highest contents (Table 3). The last two environments recorded high temperatures during the grain filling period (Table 1). Hurkman et al. [24] and Labuschagne et al. [33] also reported that, with high temperatures during grain filling, amylose increased slightly.

Granule size distribution showed a typical bimodal distribution for wheat and granules were classified into B (<10.1 μm) and A (>10.1 μm). A wide range of values from six environments and 24 cultivars were found (Table 2). Average diameter of granules at the peak in population B was 3.09 μm, whereas A granules average was 20.62 μm. Li et al. [1] found higher values for diameter at the peak in both granule populations: 5.6–6.1 μm and 20.7–24.9 μm for B and A granules, respectively. Average contribution of the A granules population to the total volume was 80.45%, whereas B granules average contribution was 19.56%. Differences reported in this study and those found in literature values have been previously observed by other authors. Apart from the influence of genotypic and environmental factors, different extraction methods, equipment used for measurement and cutoff points produce variations on results [1, 34]. Based on the analysis of variance (ANOVA), significant differences were observed among genotypes, environments, and genotype x environment interaction with respect to granule characteristics ($p < 0.001$). According to variance ratios, environmental conditions have a greater influence on A granule characteristics, while genotype influenced mostly B granules diameter and volume percentage, in agreement with Morrison and Scott [35] who found that the mean volume of A-type granules within a cultivar varied 1.5 times in different growing conditions. Temperature variation reduces starch granules size as well as their quantity in the endosperm of wheat [32]. Peña et al. [36] also revealed that the physicochemical characteristics of starch and the size distribution of starch granules in wheat grains are both genetically and environmentally controlled. MJ-2009 presented the highest volume percent of A granules and the lowest of B granules. This could be due to the highest temperatures during the grain filling period recorded by the National Institute of Seeds (INASE). Dupont and Altenbach [37] and Nahan et al. [38] also demonstrated that when wheat was exposed to high temperatures during grain filling volume percent of B-granules was reduced, an effect consistent with a shorter duration of starch accumulation because of the inactivation of specific biosynthetic enzymes. Synthesis of B-granules is initiated about 14 days after anthesis [39], and hence the timing of external influences may be an important factor on the size distribution of wheat starch granules [24, 38]. B-2010 and R-2010 were the environments who presented the highest volume percent of B granules and the lowest percent of A granule. Besides, the diameter of B granules was greater than in other environments. Both B-2010 and R-2010 showed drought during grain filling (recorded by INASE) and, as demonstrated by Dai et al. [40], rainfed treatment increased the percent volume and percent surface area of <9.8 um starch granules and decreased those of >18.8 um starch granules. The reason may be that starch accumulation rate and the activities of the related enzymes are significantly increased by the deficit of soil water at 10–21 days after anthesis [41], when the B starch granules are synthesized rapidly. Therefore, the synthesis of B starch granules may be more strongly influenced at this period than at other stages, and B granules result in higher percent volume and surface area, under the rainfed condition [40].

Table 3. Average amylose content and granule size distributions of starch on six environments

Environment	ØB μm	% Vol. B	ØA μm	% Vol. A	Amylose %
B-2009	3.07b	16.05b	20.72a	83.98c	27.35a
MJ-2009	2.80a	12.88a	19.86a	87.00d	29.74d
R-2009	3.12b	20.66c	19.96a	79.34b	28.18b
B-2010	3.11b	23.6d	19.5a	75.37a	29.1c
MJ-2010	2.97b	19.68c	20.48a	80.72b	27.91b
R-2010	3.41c	24.74d	23.22b	75.26a	29.49d

Values followed by the same letter within an environment and column show no significant difference ($p > 0.05$). ØA and B, diameter of A and B granules; % Vol. A, average contribution of the A granule population to the total volume; % Vol. B, average contribution of the B granule population to the total volume.

These results reinforce the idea about the influence of environmental conditions on the starch granule size distribution reported by Panozzo and Eagles [42].

There was a wide and significant variation according to genotypes on amylose content and granule size distribution among 24 cultivars ($p < 0.001$). Some varieties may, therefore, react very differently to environmental conditions than others. Granule B diameter and percentage of volume occupied by both granule types were both slightly more influenced by genotype than environment, although significant genotype x environment interaction was detected for

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Table 4. Ratio of variance, medium, minimum, and maximum values for differential scanning calorimetry (DSC) parameters recorded

	To (°C)	Tc (°C)	Tp (°C)	PW	ΔH (J/g)
Medium	60.07	72.22	65.67	12.15	2.26
Minimum	56.06	62.81	61.17	5.54	1.01
Maximum	63.36	76.96	69.68	15.86	3.45
δ E/G	0.76	0.86	0.63	0.82	0.79

To, onset temperature; Tc, completion temperature; Tp, peak temperature; PW, peak width.

amylose content and granule size distribution parameters ($p < 0.001$).

In order to evaluate the thermal and viscosity properties of flour wheat starch, a DSC and RVA were performed. Regarding DSC parameters, the values obtained are reported in Table 4. Similar To, Tp, and Tc range of values were found by Singh et al. [8] and Addo et al. [43]. Significant differences were found among genotypes and environments for all parameters ($p < 0.001$). However, genotype was the greatest source of variation according to variance relationship. B-2009 had the lowest values for To, Tp, Tc, and PW, whereas ΔH was highest on it. MJ 2010 presented the highest To, Tc, and Tp and the lowest ΔH (Table 5). Matsuki et al. [44] reported a great effect of environmental temperature on starch content, amylopectin structure, and gelatinization properties of wheat starch. The differences in To values could be due to different degrees of crystallinity or to structural differences in starch granules [25]. The ΔH data suggest that the crystallite structure of starches from wheat grown at a higher temperature is more stable, which means that they need more energy to dissociate the granules double crystalline helix [45] as well as was found by Matzuki et al. [44]. It is in agreement with the highest ΔH found in MJ-2009 and R-2010 where high temperatures during grain filling were recorded. B-2009 also presented high ΔH, although temperatures during grain filling were not as high as temperatures mentioned previously for other environments. Other factors such as planting and harvesting dates and other environmental conditions also affect the gelatinization characteristics as found by Tester and Karkahas [20] and Sriroth et al. [46]. PW reflects the uniformity among crystalline regions of starch. When amylopectin crystallites are more uniform this difference is smaller. During the 2009 harvest year in the three locations, PW values were narrower than during 2010. It seems that higher temperatures would lead to more uniform starch crystallites. However, genotype influenced gelatinization strongly and, therefore, no clear environmental influence was observed on DSC parameters.

Table 5. Differential scanning calorimetry (DSC) average parameters recorded on six environments

Environment	To (°C)	Tc (°C)	Tp (°C)	PW	ΔH (J/g)
B-2009	58.55a	63.85a	69.79a	11.25a	2.49c
MJ-2009	60.25c	65.9c	71.98c	11.72a	2.38c
R-2009	59.14b	64.96b	70.64b	11.5a	2.22b
B-2010	60.79d	66.68d	73.67d	12.88b	2.28b
MJ-2010	61.08e	66.44d	73.73d	12.65b	1.8a
R-2010	60.61d	66.17c	73.51d	12.9b	2.36c

Values followed by the same letter within an environment and column show no significant difference ($p > 0.001$). PW, peak width.

Medium, minimum, and maximum values for all RVA parameters are shown in Table 6. In pooling data across genotypes and environments, significant differences for all pasting properties were found ($p < 0.001$), as stated by Ragaee et al. [47]. It can be noticed that environment had a much greater impact on the starch properties of wheat than genotype for all parameters, except for pasting temperature (Table 6). Zhang et al. [48] also found that RVA parameters were more affected by environment than genotype. Different authors have also demonstrated that adverse environmental conditions during grain development could affect the pasting properties of flour [9, 17]. High temperatures and drought during anthesis and grain filling have been identified as major constraints on the quality of wheat worldwide, affecting starch synthesis and their properties [49, 50]. Environment B-2009 presented the highest peak and breakdown values (Table 7). High values of breakdown are associated with high PV, which in turn, is related to the degree of swelling of the starch granules during heating. The strong swelling power of some starch granules makes it easy for granules to reach their maximum viscosity; also, they are likely to breakdown easily because of their weak intermolecular force, thus becoming more sensitive to the shear force with temperature increase [51]. More starch granules with a high swelling capacity result in a higher PV [47]. R-2010 presented low values of all parameters, except for PT values which were the highest ones. Low setback values indicate low rate of starch retrogradation and syneresis [47]. MJ 2009 presented the lowest breakdown values and high FV and setback.

In MJ-2009 and R-2010, high temperature was recorded during grain filling, as well as high pasting temperature values. In B-2009, which presented low PT values and the highest PV

Table 6. Ratio of variance, medium, minimum, and maximum values for pasting behavior parameters

	PV (cP)	Trough (cP)	Breakdown	FV (cP)	Setback	PT (°C)
Medium	2863.17	1783.47	1077.95	3224.38	1441.1	69.46
Minimum	832.5	24.8	468.9	569.7	346.5	58.63
Maximum	4001	2588.3	1790.8	4408.8	1929.4	95.92
δ E/G	2.01	1.71	1.78	1.32	1.27	0.89

PV, peak viscosity; FV, final viscosity; PT, pasting temperature; δ E/G, ratio of variance for environment and genotype.

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Table 7. Pasting behavior average parameters recorded on six environments

Environment	PV (cP)	Trough (cP)	Breakdown	FV (cP)	Setback	PT (°C)
B-2009	3104.63c	1791.5b	1315.17c	3221.25b	1432.79b	66.19a
MJ-2009	2818.5b	1884.33c	934.67a	3371.58c	1489.13c	73.54c
R-2009	2848.83b	1779.29b	1059.58b	3200.88b	1420.92b	67.13a
B-2010	2899.58b	1841.92c	1057.67b	3343.29c	1501.38c	66.85a
MJ-2010	2775.25a	1748.58b	1026.67b	3184.42b	1435.83b	69.56b
R-2010	2732.25a	1655.19a	1073.96b	3024.83a	1366.54a	73.51c

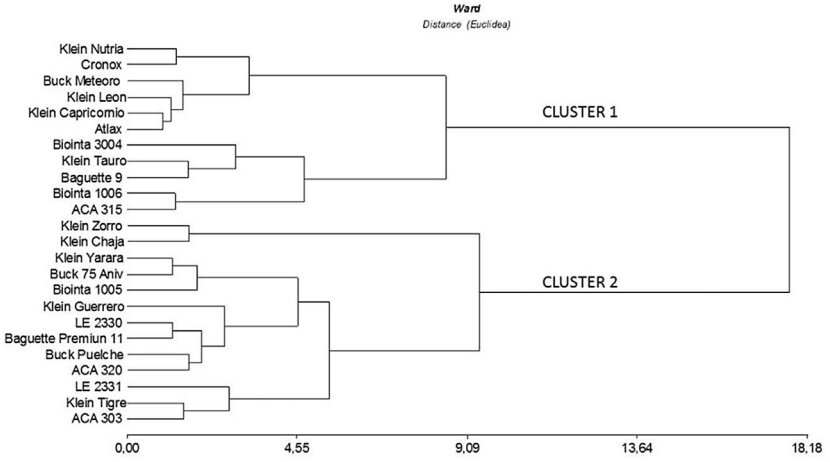
Values followed by the same letter within an environment and column show no significant difference ($p > 0.001$). PV, peak viscosity; FV, final viscosity; PT, pasting temperature.

values, there was water stress after flowering. Higher PV in starches from wheat exposed to water stress conditions may be attributed to a decrease in lipid content. Lipids inhibit starch swelling and amylose leaching during heating, which results in a decrease in hot paste viscosity [8]. Phospholipids influence the swelling behavior of starch by inhibiting the movement of water into granules, resulting in reduced starch granule swelling, amylose leaching, and PV [52].

Fluctuations in starch granule bound lipids, though very small, could also have contributed to mean pasting attribute differences between environments [14].

In order to identify groups of genotypes with similar starch characteristics, a cluster analysis was carried out. The number of groups was arbitrarily set to two and clusters were made using parameters that were more affected by genotype, such as % Vol. B, % Vol. A, ØB, To, Tp, TC, and PW. The resulting dendrogram shows the distribution of genotypes in the two groups (Fig. 1). Cluster 1 included eleven samples with the highest % Vol. A, ØA, and lowest gelatinization temperatures. Cluster 2 grouped 13 cultivars characterized for the highest gelatinization temperatures, PW and ØB. No amylose content or ΔH showed significant differences between clusters (Fig. 1). As expected, values of viscosity parameters were similar since environment had a strong influence in these properties (data not shown).

It is clear that genotypes with a higher proportion of B granules (cluster 2) presented higher gelatinization temperatures and slightly lower ΔH, although ΔH



	ØB	ØA	% Vol. A	% Vol. B	To (°C)	Tp (°C)	Tc (°C)	PW	ΔH	Amylose
Cluster 1	3.14a	21.68b	81.99b	18.12a	59.56a	65.14a	71.42a	11.87a	2.29a	28.40a
Cluster 2	2.99a	19.73a	79.14a	20.85b	60.51b	66.12b	72.89b	12.39b	2.23a	28.82a

Figure 1. Dendrogram classification of cultivar by Ward's method using % Vol. B, % Vol. A, ØB, To, Tp, TC, and PW parameters as variables. Cluster analysis of 24 cultivars from 6 environments based on previous cited parameters as variables. [a)] Values followed by different letters are significantly different ($p < 0.05$). [b)] Mean quality parameters of each cluster analyzed by analysis of variance. [c)] Cluster 1: Klein Nutria, Cronox, Buck Meteoro, Klein Leon, Klein Capricornio, Atlax, Biointa 3004, Klein Tauro, Baguette 9, Biointa 1006, ACA 315. [d)] Cluster 2: Klein Zorro, Klein Chaja, Klein Yarara, Buck 75 Aniversario, Klein Guerrero, LE 2330, Baguette Premiun 11, Buck Puelche, ACA 320, LE 2331, Klein Tigre, ACA 303.

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differences between both clusters were not significant (Fig. 1). These results are in agreement with Chiotelli and Le Meste [53] who found that B granules had a less ordered arrangement of the polysaccharide chains that lead to high hydrophilic capacity and higher gelatinization temperatures compared with A granules.

4 Concluding remarks

Significant differences on all the parameters analyzed were found between 24 cultivars and 6 environments. Both genetic and environmental factors control the physicochemical characteristics of starch and the size distribution of starch granules in wheat grains at different degrees. According to variance ratios, environmental conditions have a greater influence on A granule characteristics, while genotype influenced mostly B granules diameter and volume percentage. Environments which registered highest temperatures during the grain filling period presented the highest volume percent of A granules and the lowest of B granules. In relation to DSC parameters, genotype was the greatest source of variation according to variance relationship. However, differences between environments were recorded, demonstrating an effect of environmental temperature on starch content and gelatinization properties of wheat starches. ΔH and pasting temperature values were the highest on MJ-2009 and R-2010 where high temperatures during grain filling were recorded. Besides climatic conditions, planting and harvesting dates also affect gelatinization characteristics. Environment had a noticeable greater impact on the starch properties of wheat than genotype for all pasting properties parameters, except for pasting temperature. These findings shed additional light on the complexity of growing environment-genotype effects on wheat starch properties. Furthermore, they provide crucial information to define which genotype-location combinations should be used to optimize flour yields or a specific wheat flour property which depends on starch characteristic.

The authors acknowledge Gabriela Diaz Cortez for providing useful suggestions to improve the English in this manuscript, and both the Consejo Nacional de Ciencia y Técnica (CONICET and the Agencia Nacional de Promoción Científica y Tecnológica (ANPCyT) for financial support.

The authors have declared no conflicts of interest.

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