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Evolution of bread-making quality of Spanish bread-wheat genotypes

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Abstract

In this study, 36 Spanish wheat genotypes (five modern commercial cultivars, four cultivars introduced after the green revolution and 27 landraces from northwestern Spain) were evaluated. Grain (yield, specific weight, protein content and falling number) and flour (yield, protein content, Zeleny index, wet gluten and gluten index) properties were analyzed. Dough behaviour during mixing (DoughLAB) and handling (alveograph) was also considered. An evolution in grain and flour properties was observed over time. In modern cultivars, grain yield was improved owing to higher grain production. In landraces, higher grain yields were related to larger grain size. Unlike in landraces, an inverse correlation between grain yield and protein content was found in modern cultivars. In addition, because of their high protein quality, modern cultivars surpassed landraces in bread-making properties. Landraces showed considerable variability in protein quality and scored lower curve configuration ratio values than other cultivars with similar strength. Cultivars introduced after the green revolution reached the highest levels of bread-making quality, a feature attributable to their high protein quality.

Additional key words: alveograph, biodiversity, landraces, mixing behaviour, *Triticum aestivum.*

Resumen

Evolución de la calidad panadera de variedades de trigo cultivadas en España

En este estudio se han evaluado 36 genotipos de trigo cultivados en España (cinco cultivares comerciales actuales, cuatro cultivares introducidos después de la revolución verde y 27 variedades autóctonas del noroeste de España). Se han analizado tanto las características del grano (rendimiento, peso específico, contenido proteico e índice de caída) como las de la harina (rendimiento harinero, contenido proteico, índice de Zeleny, gluten húmedo y gluten seco). También se ha considerado el comportamiento de la masa durante el amasado (DoughLAB) y el manejo de la misma (alveógrafo). Se ha observado una evolución de las características de los granos y las harinas a lo largo del tiempo. En los cultivares modernos se ha observado un incremento del rendimiento en cosecha basado en la mayor producción de granos. Por otro lado, en las variedades autóctonas los mayores rendimientos se relacionaron con un mayor tamaño de grano. Para los cultivares modernos se encontró una correlación inversa entre el rendimiento en grano y el contenido proteico, la cual no fue significativa cuando se analizaron las variedades autóctonas. Los cultivares modernos también mostraron mejores propiedades para los procesos de panificación debido a la mayor calidad de sus proteínas. Las variedades autóctonas presentaron una gran variabilidad en su calidad proteica y un equilibrio más bajo que el mostrado por otras variedades con fuerza similar. Los cultivares introducidos tras la revolución verde mostraron las mejores características panaderas, lo que se relacionó con su alta calidad proteica.

Palabras clave adicionales: alveógrafo, biodiversidad, comportamiento en el amasado, *Triticum aestivum,* variedades autóctonas.

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Abbreviations used: FU (farinograph units), HZT (Harina Tradicional Zamorana), ITACYL (Instituto Tecnológico Agrario de Castilla y León), P/L (curve configuration ratio).

Introduction

The primitive cultivars, landraces and wild relatives of crop plants constitute a pool of useful genetic variability generally required for the effectiveness of breeding programs (Blum *et al*., 1987; Valkoun, 2001; Juhász *et al*., 2003). Much of the rich plant biodiversity which supported agriculture in the past has been eroded or is being rapidly eroded by the introduction of new high-yielding cultivars. Moreover, it is thought that old cultivars or landraces are better adapted to an ecological production (low-input and organic farming systems) than modern cultivars because the latter's usual yield advantage is negated under low-fertility conditions (Shroyer and Cox, 1993). This seems to open interesting new avenues for further study since organic production has increased in recent years due to growing consumer demand (Guarda *et al*., 2004).

The varietal structure of bread wheat, *Triticum aestivum* L., in Spain has been slowly but steadily altered. Throughout the first half of the 1900s, growers relied on cultivars and local landraces, favored by the isolation of the growing areas and very diverse climates. During the 1970s, CIMMYT cultivas, like Yécora, Cajeme and Anza, were introduced and had a rapid expansion displacing the local landraces. In the last 20 years, the varietal change has been very limited. It is observed that new bread wheat cultivars grown in Spain have traditionally been imported, principally French and Italian. These cultivars have a high potential but it is hardly realized under the harsh environmental conditions they are grown in Spain. Evaluation of wheat cultivars from different sources spanning the entire 1900s enables breeders to determine how changes in agronomic and end-use quality characteristics associated with improved grain yield and higher end-use quality have occurred over the course of roughly a century.

Numerous studies have evaluated the quality of old landraces. These studies are usually centred in those landraces grown in Eastern European countries, such as Hungary (Bedó *et al*., 1998; Juhász *et al*., 2003), Slovakia (Francakova and Bojnanska, 2003), Poland (Górny *et al*., 2006) or Russia (Khlestkina *et al*., 2004); in Near and Middle Eastern countries, such as Syria (Mirali, 2000), Iran (Bhattacharya *et al*., 2003), Turkey (Dokuyucu *et al*., 2004) or Israel (Blum *et al*., 1987); and in Asian countries such as India (Singh *et al*., 2007) Pakistan (Niwa *et al*., 2008) and Japan (Nakamura, 2001). Although studies referred to Mediterranean countries do exist (Nascimento *et al*., 1998; Guarda *et al*., 2004; Cartelle *et al*., 2006), none of them considers Spanish cultivars. Most of them are focused on the study of agronomic characteristics, grain composition, or protein quality, and only a few deal with dough rheological properties. Only Guarda *et al*. (2004) analyzed alveographic properties while Bedo *et al*. (1998) and Francakova and Bojnanska (2003) analyzed dough behaviour during mixing.

The aim of this study was to investigate grain yield and quality in a set of genotypes that have been grown in Spain sometime between 1900 and the present by comparing results from three different field experiments. The long term objective is to promote the introduction of some of these genotypes into wheat breeding programs for the development of new bread wheat cultivars with improved end-use quality traits and well adapted to Spanish growing environments.

Material and methods

Material and growing conditions

Three field experiments were carried out at two different sites in northwestern Spain, one in 2005 and two in 2007 (Table 1). Thirty six genotypes of bread wheat, including five current Spanish commercial cultivars, released between 1980 and 2000, four cultivars that were being grown around 1970 and 27 Castilla and León landraces were used in the experiments (Table 2). For each entry the seed source was described by origin and bank germplasm code. In each trial, cultivars were sown in a randomized completed-block design with three replications in 6 m-long, six-row plots with 20 cm row spacing. The seed rate was adjusted for each genotype to achieve a density of 350 viable seeds m^{-2}. Soil analyses were done prior to sowing, and fertilizers were applied as recommended. Weeds and diseases were controlled and treated with appropriate chemicals.

Grain properties

Grain yield (kg ha^{-1}) was determined on the basis of the averaged harvested plot in all the trials. Specific weight was measured in a sample of 250 g per plot, and was expressed as kg hL^{-1}. Grain protein (%) was determined with Kjeldahl´s method.

Table 1. Location, site description and mean yield of the three experiments

	Exp. 1	Exp. 2	Exp. 3
Year	2005	2007	2007
Site	Zamadueñas[a]	Zamadueñas[a]	Villahoz[b]
Coordinates	41º 41'N, 4º 43' W	41º 41'N, 4º 43' W	42º 5' N, 3º 39' W
Altitude (m above sea level)	700	700	864
Soil texture	Slimy sandy loam	Slimy sandy loam	Sandy loam
Soil pH	8.2	8.2	8.0
Seasonal rainfall (mm^3)	137	351	319
Mean yield (kg ha^{-1})	4922 ± 672	4113 ± 915	4402 ± 721

[a] Province: Valladolid. [b] Province: Burgos.

Flour properties

To evaluate the bread-making quality of the different cultivars, grain samples from each one were individually milled with a Chopin CD-1 experimental mill (Chopin, France) Flour yield was only determined for the 2007 experiments. Flour quality was evaluated using the AACC methods (AACC, 2000) including: falling number (AACC 56-70), flour protein (AACC 39-11), gluten wet (AACC 38-11), gluten index (AACC 38-12) and Zeleny index (Zeleny 1947).

Bread-making properties

The viscoelastic properties of the wheat dough were assessed using an alveograph MA 82 (Chopin, France) following the AACC 54-30A method (AACC, 2000). The following parameters were automatically recorded: tenacity or resistance to extension (P), dough extensibility (L), curve configuration ratio (P/L) and the deformation energy (W).

The mixing behaviour of each flour cultivar was studied using the doughLAB equipment (Newport Scientific Pty. Limited, Warriewood, Australia). The dough was developed in the mixing bowl by the rotary action of two sigma-arm mixing blades and its resistance to kneading as a torque value was obtained. Data obtained from the doughLAB were analyzed using doughMAP software (Newport Scientific Pty. Limited, Warriewood, Australia). Values measured from the mixing profile were: 1) absorption (quantity of water necessary for the dough to reach 500FU); 2) development time (time taken for the dough to reach its peak resistance); 3) stability (difference between the time required for the top curve to reach the peak resistance and the required time for the top curve to fall below the peak resistance); 4) softening (difference between the peak resistance and the mid-curve torque at 12 min after the development time), and 5) resistance.

Statistical analysis

Data were analyzed by analysis of variance (ANOVA). First, all the cultivars were considered, and in a second analysis the cultivars were grouped in three categories based on their origin: landraces, cultivars introduced after the green revolution, and modern commercial cultivars. LSD test at a significance level of 0.05 was used in order to compare samples. Pearson correlation coefficients between characteristics were also calculated. Only significant correlations (95%*, 99%**, 99.9%***) have been considered. All analyses were performed using the Statgraphic plus 5.1 software.

Results and discussion

Grain properties

Grain yield showed significant differences ($p < 0.05$) across genotypes (Table 3). Grain yield ranged from 3495 to 6191 kg ha^{-1} for Barbilla de León and Marius respectively. Differences between groups for grain yield were also statistically significant. LSD test separated the three groups. The modern cultivars showed the highest values for grain yield and landraces the lowest. It would seem that plant breeding has played an important role in increasing grain yield. A similar tendency was observed in the study of the cultivars growing in Italy since the early 1900s (Guarda *et al*., 2004).

Cultivars introduced in Spain after the green revolution had the highest flour yields but no significant dif-

Table 2. Name, code, seed origin and group of wheat genotypes used in this study

Genotype name	Province	Origin[a]	Bank code
Landraces			
Barbilla 1		CRF-INIA	BGE 000084
Barbilla 2	Salamanca	CRF-INIA	BGE 013803
Barbilla de Alcañices 1	Zamora	CRF-INIA	BGE 012869
Barbilla de Alcañices 2	Zamora	CRF-INIA	BGE 013194
Barbilla de Alcañices 3	Zamora	HTZ	ZT – 269
Barbilla de Carbajales de Alba 1	Zamora	CRF-INIA	BGE 013195
Barbilla de Carbajales de Alba 2	Zamora	CRF-INIA	BGE 013196
Barbilla de León	León	CRF-INIA	BGE 018228
Barbilla de Ayoo de Vidriales	Zamora	CRF-INIA	BGE 029799
Barbilla de Quintanilla	Zamora	CRF-INIA	BGE 030462
Barbilla roja de Matallanes	Zamora	CRF-INIA	BGE 030461
Barbilla de Villanueva de Valrojo	Zamora	CRF-INIA	BGE 030460
Barbilla de Villar del Buey	Zamora	CRF-INIA	BGE 029796
Mombuey	Zamora	CRF-INIA	BGE 013215
Candeal de Arévalo 1	Avila	CRF-INIA	BGE 012577
Candeal de Arévalo 2	Avila	ITACYL	ZT – 265
Candeal de Castilla		ITACYL	ZT – 262
Candeal de Castrillo del Val	Burgos	HTZ	ZT – 266
Candeal de Juarros de Voltoya	Segovia	CRF-INIA	BGE 031114
Candeal de Muelas del Pan	Zamora	HTZ	ZT – 268
Candeal de Muñogrande	Avila	CRF-INIA	BGE 012575
Candeal de Nava del Rey	Valladolid	CRF-INIA	BGE 013129
Candeal de Salamanca	Salamanca	CRF-INIA	BGE 013131
Candeal de San Román de los Oteros	León	CRF-INIA	BGE 025415
Candeal de Teruel		ITACYL	ZT – 264
Candeal de Tierra de Campos	Palencia	CRF-INIA	BGE 013128
Candeal de Villaseco del Pan	Zamora	CRF-INIA	BGE 029798
Thrid half of 20th century cultivars			
Pané 247		CRF-INIA	BGE 014264
Florence Aurore		CRF-INIA	BGE 012144
Tailor de Melgar de Fernamental		HTZ	ZT – 267
Candeal Argelino		ITACYL	ZT – 263
Modern cultivars			
Marius		Commercial	Test
Isengrain		Commercial	Test
Soissons		Commercial	Test
Craklin		Commercial	Test
Etecho		Commercial	Test

[a] CRF: Centre of Genetic Resources in INIA-Madrid. ITACYL: material in the germplasm bank of Instituto Tecnológico Agrario de Castilla y León. HZT: material provided by milling industry "Harina Tradicional Zamorana".

ferences were found between the three groups of cultivars (Table 3). In relation to specific weight, only significant differences between landraces and late 1900s cultivars were observed. The correlation between specific weight and flour yield was positive (*r*=0.65***) (Figure 1). Also a significant correlation between grain yield and grain specific weight was found (*r*=0.39*), but the correlation coefficient increased to 0.58*** if modern cultivars were eliminated.

The percentage of grain protein was significantly lower in modern cultivars than in landraces. In fact, the five cultivars with the lowest protein content corresponded to the five modern cultivars. Guarda *et al*. (2004) found a similar tendency in Italian cultivars, despite of

Table 3. Mean yield and quality properties of 36 wheat genotypes grouped by their genotype group. Means averaged over three experiments

Genotype	Grain yield (kg hL^{-1})	Specific weight (%)	Flour yield (%)	Grain protein content (%)	Falling number (s)
Landraces*	**3932a**	**78.9a**	**63.2a**	**16.7b**	**394a**
Barbilla 1**	4313	79.4	63.1	16.0	368
Barbilla 2**	3941	77.3	57.8	16.1	406
Barb Alcañices1**	3904	82.7	69.0	15.8	381
Barb Alcañices2**	3874	76.0	57.8	17.7	393
Barb Alcañices3**	4332	78.3	61.9	17.1	446
Barb Carbajales Alba1**	3824	72.4	58.6	15.9	390
Barb Carbajales Alba2**	3663	66.9	55.0	15.8	332
Barb León**	3495	75.5	63.8	16.6	397
Barb Ayoo de Vidriales**	3833	74.6	63.1	16.5	389
Barb de Quintanilla**	4040	77.5	63.9	15.8	385
Barb Roja de Matallanes**	3637	75.7	57.8	16.6	393
Barb Villanueva Val**	4146	76.2	61.9	16.1	430
Barb. Villar del Buey**	4326	78.1	56.6	17.2	391
Mombuey**	4624	84.1	70.8	16.5	419
Cand Arevalo 1**	4016	78.8	59.6	16.4	429
Cand Arevalo 2**	4471	78.4	63.9	16.7	419
Cand Castilla**	4574	83.2	74.6	17.6	383
Cand Castrillo del Val**	4660	79.1	55.9	15.8	352
Cand Juarros Voltoya**	4692	79.2	65.7	16.6	375
Cand Muelas de Pan**	4339	83.4	73.3	17.8	430
Cand de Muñogrande**	4119	78.9	58.0	16.2	365
Cand. Nava del Rey**	4751	81.4	59.8	16.4	403
Cand. Salamanca**	4085	79.3	63.2	16.2	380
Cand San Román**	3899	77.0	68.5	17.3	395
Cand Teruel**	4800	83.4	74.3	17.8	420
Cand. Tierra de Campos**	4707	81.6	63.2	16.4	397
Cand Villaseco del Pan**	4136	81.1	65.7	16.4	361
Thrid half of 20th century cultivars*	**4441b**	**83.0b**	**69.1a**	**16.5b**	**391a**
Pane 247**	5053	82.0	65.7	14.6	439
Florence Aurore**	4483	83.2	66.6	17.6	369
Tailor de Fernamental**	4410	83.6	77.6	17.9	375
Candeal Argelino**	4878	83.4	66.6	16.8	381
Modern cultivars*	**5865c**	**80.0ab**	**67.2a**	**13.8a**	**379a**
Marius**	6191	78.9	64.6	13.4	383
Isengrain**	5791	81.8	71.0	13.8	355
Soissons**	5551	81.8	68.7	14.3	381
Craklin**	6079	77.6	62.8	13.3	385
Etecho**	5934	79.9	68.8	14.1	393
LSD $_{(0,05)}$***	290	1.2	2.6	0.4	37

* Mean of the variety groups [different letters in the same column are significantly different (p<0.05)]. ** Mean of the individual cultivars. *** LSD value for the analysis of individual cultivars.

the fact that all modern varieties showed higher gluten strength values than landraces. A negative relationship was observed between grain yield and grain protein content (r=-0.64***), but this correlation could be misleading since it was strongly influenced by the presence of modern cultivars, with high yields and low protein levels. In fact, if these cultivars were not considered in the analysis, the correlation became not significant (Figure 2). When only modern cultivars were considered, a significant correlation was found (r=-0.52***). If only landraces and cultivars introduced after the green revolution were analyzed, it was observed that as the grain protein

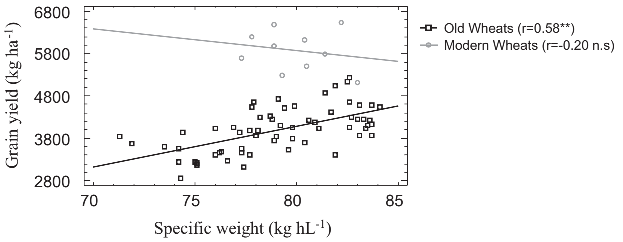

Figure 1. Relationship between grain yield and grain specific weight for old wheat genotypes (landraces and cultivars introduced after the green revolution) and for modern commercial cultivars**.**

content increased, flour yield (r=0.36*) and specific weight (r=0.26*) also increased. Nevertheless, if the modern cultivars were included in the analysis the relationships became not significant. Modern cultivars had similar specific weight and flour yield than landraces and cultivars introduced after the green revolution, but they showed higher grain yields (Figure 1). No significant correlations were found when considering only modern commercial cultivars.

Falling number is indicator of the amylase activity in the grain and it is related with the mobilization of reserves for grain germination (Atwell, 2001). All cultivars analyzed in this study showed high values of falling number (Table 3). In Mediterranean environments, characterized by dry and hot summers, high falling numbers are normal (Gooding, 2003). Statistical significant differences between falling numbers across cultivars and groups were not observed.

Flour properties

The mean values for flour protein content, wet gluten percentage, gluten index, and Zeleny index are shown in

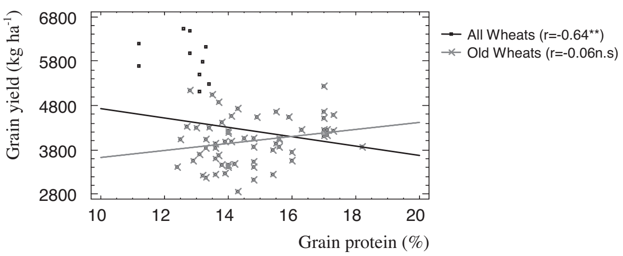

Figure 2. Relationship between grain yield and grain protein content for all wheat genotypes studied and only for the old wheat genotypes (landraces and cultivars introduced after the green revolution)**.**

Table 4. Flour protein content and wet gluten are related to protein quantity, and gluten and Zeleny indexes are related to protein quality. Flour protein content ranged between 11.2% for Craklin and 17.3% for Taylor de Fernamental. Similar to grain protein content, the modern wheat cultivars had the lowest flour protein content. Five out of six cultivars which showed the lowest flour protein content belonged to the group of modern cultivars. As expected, a significant correlation between the protein content in grain and flour (r=0.63***) was found. However, unlike the grain protein content, the flour protein content from cultivars introduced after the green revolution was significantly higher than that from landraces.

The Zeleny index indicates protein quality (Zeleny, 1947). No significant differences in the Zeleny index between landraces and modern cultivars were found, although cultivars introduced after the green revolution showed the highest Zeleny indexes. A correlation between flour yield and Zeleny index was observed (r=0.52***) that could be related to the fact that the cultivars introduced after the green revolution also showed high flour yields. In general, it was observed that modern cultivars showed intermediate Zeleny indexes. Blum *et al*. (1987) observed that modern cultivars had a higher Zeleny index than landraces and indicated that their results seemed to suggest that the Zeleny index was improved in the modern hexaploid cultivars beyond the highest level found in the tested landraces. The discrepancies with our results could be due to the modern cultivars selected in Blum's work, since all of them had good or medium bread quality and possessed high Zeleny indexes (>33).

The gluten is formed by wheat reserve proteins, which are responsible for producing cohesive and elastic doughs, and retaining the gas produced during fermentation. The wet gluten was not determined in 10 landraces (Table 4) due to difficulties in its formation and nine of them showed Zeleny indexes lower than 20. This could indicate that, in general, cultivars with the lowest protein quality showed problems in gluten formation. Only five cultivars with Zeleny indexes lower than 20 could form gluten, and only one of them had a Zeleny number lower than 15. A significant correlation was observed between gluten content and flour protein quantity (r=0.61***), and between gluten content and Zeleny index (r=0.49**). The highest gluten content values corresponded to three cultivars introduced after the green revolution (Taylor, Florence Aurore and Candeal Argelino) and three landraces characterized by

Table 4. Mean of flour characteristics of 36 wheat genotypes across three experiments

Genotype	Flour protein content (%)	Zeleny index (mL)	Wet gluten (%)	Gluten index (%)
Landraces*	**14.6b**	**22.9a**		
Barbilla 1**	15.1	18.0	33.4	43.1
Barbilla 2**	13.5	17.5	ND	ND
Barb Alcañices1**	13.7	25.5	38.0	54.2
Barb Alcañices2**	13.9	28.5	34.6	61.0
Barb Alcañices3**	14.9	20.0	ND	ND
Barb Carbajales Alba1**	13.5	21.5	34.5	48.4
Barb Carbajales Alba2**	13.1	18.5	32.3	35.7
Barb León**	14.1	42.0	36.2	78.6
Barb Ayoo de Vidriales**	14.5	25.0	34.1	54.5
Barb de Quintanilla**	14.2	26.0	34.7	57.3
Barb Roja de Matallanes**	13.5	27.5	ND	ND
Barb Villanueva Val**	14.9	22.0	35.8	53.4
Barb. Villar del Buey**	14.5	18.0	ND	ND
Mombuey**	15.5	18.5	33.8	42.0
Cand Arevalo 1**	14.7	22.5	28.1	18.9
Cand Arevalo 2**	14.3	19.0	38.7	25.3
Cand Castilla**	16.0	42.0	43.4	44.7
Cand Castrillo del Val**	17.0	6.5	ND	ND
Cand Juarros Voltoya**	15.7	14.5	ND	ND
Cand Muelas de Pan**	17.3	44.5	52.3	58.0
Cand de Muñogrande**	13.9	12.0	29.1	26.7
Cand. Nava del Rey**	13.8	20.0	30.3	21.2
Cand. Salamanca**	13.7	16.0	ND	ND
Cand San Román**	15.8	18.5	ND	ND
Cand Teruel**	17.1	42.0	43.8	45.1
Cand. Tierra de Campos**	13.4	17.5	ND	ND
Cand Villaseco del Pan**	13.5	15.0	ND	ND
Thrid half of 20th century cultivars*	**16.0c**	**39.8b**		
Pane 247**	14.3	22.0	31.2	55.5
Florence Aurore**	15.8	42.0	43.0	66.6
Tailor de Fernamental**	17.3	38.5	60.9	53.0
Candeal Argelino**	16.5	56.5	36.2	91.1
Modern cultivars*	**12.7a**	**29.1a**		
Marius**	12.8	21.0	30.8	51.7
Isengrain**	12.9	35.5	30.4	61.7
Soissons**	13.1	37.0	32.2	77.5
Craklin**	11.2	21.0	24.9	25.8
Etecho**	13.4	31.0	33.5	42.8
LSD $_{(0.05)}$***	0.8	2.5		

* Mean of the variety groups [different letters in the same column are significantly different ($p<0.05$)]. ** Mean of the individual cultivars. *** LSD value for the analysis of individual cultivars.

their high protein content (Candeal de Muelas del Pan, Candeal de Teruel and Candeal de Castilla). All these cultivars also showed high Zeleny index values and, consequently, good protein quality. The gluten index is another indicator of protein quality, and thus; both the gluten index and the Zeleny number were correlated, although this correlation was not very high (r=0.44**). In fact, the tendencies observed in the Zeleny index in the cultivars introduced after the green revolution were not found in the gluten index. One of these cultivars, Candeal Argelino, had the highest gluten index values while Florence Aurore had the lowest.

Bread-making properties

In Table 5 the alveographic values from the different cultivars are shown. These values are especially important, not only because of the information about flour quality in the different processes, but also because wheat classifications and wheat merchant operations in different countries such as France, Italy, Spain and Mexico are based on alveograph parameters. Gaines *et al.* (2006) reported that the alveograph is one of the best methods to determine gluten strength. The cultivars introduced after the green revolution studied in this

Table 5. Mean of deformation energy (W), tenacity (P), dough extensibility (L) and the ratio P/L of 36 wheat genotypes across three experiments

Genotype	W ($J \cdot 10^{-4}$)	P (mm)	L (mm)	P/L
Landraces*	**106a**	**48a**	**92a**	**0.60ab**
Barbilla 1**	88	45	93	0.52
Barbilla 2**	74	40	78	0.45
Barb Alcañices1**	129	52	122	0.48
Barb Alcañices2**	191	71	124	0.57
Barb Alcañices3**	75	54	89	0.77
Barb Carbajales Alba1**	104	44	107	0.42
Barb Carbajales Alba2**	105	40	94	0.47
Barb León**	195	60	137	0.45
Barb Ayoo de Vidriales**	124	49	114	0.44
Barb de Quintanilla**	110	51	99	0.53
Barb Roja de Matallanes**	116	49	121	0.41
Barb Villanueva Val**	111	46	121	0.39
Barb. Villar del Buey**	82	43	93	0.52
Mombuey**	80	48	113	0.57
Cand Arevalo 1**	101	51	112	0.51
Cand Arevalo 2**	82	50	80	0.74
Cand Castilla**	164	47	138	0.35
Cand Castrillo del Val**	27	26	47	0.77
Cand Juarros Voltoya**	56	31	87	0.49
Cand Muelas de Pan**	185	54	165	0.34
Cand de Muñogrande**	58	31	94	0.34
Cand. Nava del Rey**	98	49	94	0.54
Cand. Salamanca**	54	30	91	0.39
Cand San Román**	62	39	84	0.61
Cand Teruel**	187	48	162	0.29
Cand. Tierra de Campos**	88	48	87	0.73
Cand Villaseco del Pan**	42	28	86	0.56
Third half of 20th century cultivars*	**287b**	**84b**	**118ab**	**0.76b**
Pane 247**	134	69	58	0.90
Florence Aurore**	359	104	121	0.86
Tailor de Fernamental**	252	72	120	0.66
Candeal Argelino**	460	100	153	0.82
Modern cultivars*	**154a**	**51a**	**122b**	**0.43a**
Marius**	78	27	138	0.20
Isengrain**	223	60	129	0.50
Soissons**	234	72	114	0.77
Craklin**	88	36	102	0.35
Etecho**	180	75	101	0.75
$LSD_{(0.05)}$***	23	6	18	0.13

* Mean of the variety groups [different letters in the same column are significantly different (p<0.05)]. ** Mean of the individual cultivars. *** LSD value for the analysis of individual cultivars.

work showed highest deformation energy (W) mean, while the variety Candeal Argelino had the highest value for W, $460 \cdot 10^{-4}$ J, across the experiments. No significant differences were detected between landraces and modern cultivars, and only five landraces showed values higher than $150 \cdot 10^{-4}$ J. The cultivars introduced after the green revolution also showed the highest tenacity (P) values, and no differences between landraces and modern cultivars were observed. A high correlation between W and P values was found (r=0.81***). Considering extensibility, the five landraces with the highest gluten strength, obtained also the highest extensibil-

Table 6. Mean of DoughLAB parameters of 36 wheat genotypes across three experiments

Genotype	Absorption (%)	Development time (s)	Stability (s)	Softening 12min (FU[1])	Resistance 20min (FU[1])
Landraces*	**55.8a**	**136a**	**148a**	**152b**	**178b**
Barbilla 1**	55.6	112	112	178	201
Barbilla 2**	56.4	113	96	152	172
Barb Alcañices1**	58.8	155	219	105	130
Barb Alcañices2**	56.1	149	211	96	123
Barb Alcañices3**	62.7	126	86	206	236
Barb Carbajales Alba1**	53.7	116	135	139	172
Barb Carbajales Alba2**	53.6	113	138	145	180
Barb León**	55.2	210	363	92	116
Barb Ayoo de Vidriales**	53.2	116	125	169	199
Barb de Quintanilla**	55.3	126	140	143	178
Barb Roja de Matallanes**	54.4	138	183	110	142
Barb Villanueva Val**	54.3	137	151	151	185
Barb. Villar del Buey**	56.9	109	88	181	211
Mombuey**	56.4	125	104	158	183
Cand Arevalo 1**	55.7	108	110	149	173
Cand Arevalo 2**	61.5	126	80	217	247
Cand Castilla**	60.0	285	296	93	107
Cand Castrillo del Val**	51.2	66	54	244	259
Cand Juarros Voltoya**	53.7	105	86	172	206
Cand Muelas de Pan**	59.8	259	286	100	114
Cand de Muñogrande**	50.6	90	93	180	199
Cand. Nava del Rey**	55.5	102	111	159	179
Cand. Salamanca**	51.5	105	109	197	221
Cand San Román**	55.5	124	101	178	202
Cand Teruel**	60.4	264	309	93	111
Cand. Tierra de Campos**	55.8	102	104	160	178
Cand Villaseco del Pan**	54.5	107	117	164	187
Thrid half of 20th century cultivars*	**61.5b**	**278b**	**420c**	**87a**	**101a**
Pane 247**	61.1	153	145	121	144
Florence Aurore**	64.6	35	600	58	67
Tailor de Fernamental**	59.9	232	245	115	134
Candeal Argelino**	60.4	376	692	57	61
Modern cultivars*	**54.4a**	**177a**	**285b**	**104a**	**124a**
Marius**	51.6	103	123	130	151
Isengrain**	55.0	249	391	90	103
Soissons**	57.1	266	451	70	83
Craklin**	50.6	101	136	143	162
Etecho**	57.6	165	327	91	123
$LSD_{(0.05)}$***	1.3	16	39	21	21

* Mean of the variety groups [different letters in the same column are significantly different ($p<0.05$)]. ** Mean of the individual cultivars. *** LSD value for the analysis of individual cultivars. [1] Farinograph units.

ity. In modern cultivars the opposite behaviour was observed: the cultivar with the lowest strength (Marius) showed the highest extensibility. Among the landraces, a significant correlation between dough extensibility (L) and the wheat protein was found (r=0.45**) which was not observed when all cultivars were analyzed. In consequence, landraces with a W value higher than $150 \cdot 10^{-4}$ J had lower P/L values compared to modern cultivars, such as Soisson or Etecho, and cultivars introduced after the green revolution, such as Pane 247, with similar gluten strength values.

In Table 6 the variables that define dough mixing behaviour can be observed. It was noticeable the high values of water absorption of cultivars introduced after the green revolution. This could be related to the high protein content of their flours. Absorption data did not show significant differences between landraces and modern cultivars, despite the fact that flours from landraces had higher protein content than flours from modern cultivars. Also, positive correlation (r=0.41**) between absorption and protein content was found.

Zhu and Khan (2001) found significant correlations between SDS-soluble and SDS-insoluble glutenin polymers and dough mixing properties. Konopka *et al.* (2004) found that the rheological properties of doughs were better correlated with the Zeleny index than with the protein content, which would indicate that the development time and the stability were related to the protein quality. In fact, in the present work significant correlations were found between these values and the Zeleny index (r=0.93*** and r=0.86***, respectively) and the strength (W) (r=0.95*** and r=0.92***). Similarly, softening or resistance values were highly and inversely correlated to stability (r=-0.8*** and r=-0.83***). In this sense, the studied cultivars introduced after the green revolution showed high absorption, development time and stability, and low softening and resistance compared to the other cultivars. At the same time, modern cultivars showed better stability, softening and resistance values than landraces, which could be occasioned by the high quality of their proteins. Among landraces, those with the highest strength (Barbilla de León, Candeal de Teruel, Candeal de Muelas del Pan and Candeal de Castilla) showed the highest development time and stability values. Only Barbilla de Alcañices 2 did not follow this tendency, although their values were also high. Softening and resistance showed the opposite tendency. Candeal Argelino and Florence Aurore (cultivars introduced after the green revolution) and Soisson and Isengrain (modern cultivars) were noticeable because of their high development time and stability values.

Conclusions

Marked differences were observed between landraces and modern cultivars, especially in protein content and consequently, in bread-making characteristics. An evolution in grain and flour properties was observed over time. Landraces showed a great variability in protein quantity and quality, but whilst some of them showed the highest gluten and protein contents, others failed to even form gluten. Such differences have disappeared in modern cultivars because of genetic improvement. Modern cultivars have increased the grain yield based on higher grain production, decreased the protein content, and improved the bread-making characteristics owing to their high protein quality. It was noticeable the high bread-making quality of cultivars introduced after the green revolution, which was related to their high protein quality.

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