

Spelt (*Triticum spelta* L.) Pasta Quality: Combined Effect of Flour Properties and Drying Conditions

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ABSTRACT

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Three spelt genotypes (Rouquin, Redoute, and HGQ Rouquin=Rouquin improved for gluten quality), each characterized by either high or low protein content, were processed to manufacture spaghetti, which was dried at both low (60°C) and high temperature (90°C) to assess the effects of flour properties and drying conditions on spelt pasta quality. Protein content in the spelt flour was considered low at $\approx 11.4\%$ db and high at $\approx 13.5\%$ db. Gluten properties, assessed by SDS sedimentation and gluten index values and by alveograph and farinograph parameters varied widely, ranging from poor for Redoute to very good for HGQ Rouquin. Pasta quality was assessed by determining color (L^* , a^* , and b^* values), furosine, and cooking quality (stickiness, bulkiness, firmness,

and total organic matter [TOM]). Furosine and color (a^* and b^* values) were significantly influenced by the intensity of the drying process. TOM and organoleptic judgement (OJ) showed that spelt pastas dried at low temperature, independent of their protein levels, were very poor (TOM ≥ 2.7 g/100 g of dry pasta, OJ ≤ 40), except for HGQ Rouquin which was characterized by good gluten strength. On the other hand, the cooking quality of spelt pastas dried at high temperature showed good values (TOM ≤ 1.8 g/100 g of dry pasta, OJ ≥ 53). The combination of high protein content ($\geq 13.5\%$ db) and high-temperature drying resulted in the production of satisfactory cooking quality pastas from spelt wheats (TOM ≤ 1.2 g/100 g of dry pasta, OJ ≥ 67).

Currently, there is considerable interest in the use of spelt (*Triticum spelta* L.) for food destined for health and organic food markets. Spelt is an ancient cereal that was once cultivated extensively in Europe and is now receiving a renewal interest for its nutritional qualities and, from an agronomic point of view, for its resistance to pests and its ability to grow in soils with limited fertility and in wet and cold climates where it is better adapted than wheat. The common way of consuming spelt is as bread and baking products because it is a hexaploid wheat (42 chromosomes) with rheological and technological properties close to those of soft wheat. The expansion of the cultivation of spelt largely depends on the possibility of using it in the production of other products such as pasta, flakes, etc., with good sensorial and nutritional properties (Cubadda and Marconi 1996; D'Antuono and Bravi 1996; Abdel-Aal et al 1998). Bread-making and baking properties of spelt flour have been widely studied and defined (Graber and Kuhn 1992; Ranhotra et al 1995; Abdel-Aal et al 1997), whereas knowledge about spelt pasta-making potential is scarce and preliminary (Cubadda and Marconi 1996). Durum wheat semolina is the best raw material for pasta-making because of its protein rheological properties and its high yellow pigment content. Unconventional raw materials can also be used, but adequate pasta processing and balanced formulations are needed to counteract poor technological properties (Marconi and Carcea 2001).

The results of a previous work (Marconi et al 1999) showed that spelt could be successfully used in the preparation of alimentary pasta and that such potential was not directly dependent on the cultivar, but rather on protein content and the drying technologies adopted. Pasta quality can be defined chiefly by its cooking characteristics and secondly by the color and appearance of the dried pasta. Raw material characteristics (protein content and gluten strength) and pasta-drying technologies are the main factors that define durum wheat pasta quality (Dexter and Matsuo 1977; Dexter et al 1981; Wyland and D'Appolonia 1982; Pagani et al 1986; Resmini et al 1988; D'Egidio et al 1990; Novaro et al 1993; Cubadda 1996). With regard to color, the determining factors are the intensity of the

drying process, the carotenoid pigments, the enzymatic activity (polyphenoloxidase and lipoxygenase), and some factors that induce the development of the Maillard reaction such as damaged starch, amylase, and reducing sugar content (Feillet and Dexter 1996; Sensidoni et al 1996; Acquistucci 2000).

The aim of this work was to assess how spelt flour characteristics (protein quantity and quality, starch damage, amylase, and reducing sugars) coupled with different drying temperatures influenced spelt pasta quality to optimize these variables to produce high quality spelt spaghetti. To this end, pasta samples were made from three spelt cultivars with different protein quality, each at two protein levels, and subjected to low and high drying temperature cycles.

MATERIALS AND METHODS

Spelt Samples

Grains of two spelt wheat (*Triticum spelta* L.) cultivars Rouquin and Redoute, both comprising high and low protein (HP and LP, respectively) samples, were obtained from Station d'Amelioration des Plantes, Gembloux, Belgium. In addition, Rouquin with improved gluten quality (HGQ Rouquin) selected by the Station d'Amelioration des Plantes was tested.

The samples were dehulled in an experimental dehuller (Namad 06/2000, Rome, Italy). Whole meal flour was obtained by grinding the grain in a Cyclotec 1093 laboratory mill with a 0.5-mm sieve (Tecator, Hoganas, Sweden). Flours were obtained from each cultivar by tempering the grains for 18–24 hr to 15.0% moisture and milling them in a MLU 202 experimental mill (Bühler, Uzwil, Switzerland) equipped with three break, three reduction rolls, and six steel screens. These milling conditions were adequate to process spelt grains characterized by low kernel hardness (Marconi et al 1999).

Because only the HGQ Rouquin LP sample was available, gluten was extracted from this sample and added to the flour to increase its protein content (HGQ Rouquin HP). Gluten was extracted according to Approved Method 38-10 (AACC 2000), frozen, lyophilized, milled, and stored dry at 4°C. The gluten contained 78.5% protein (db). Vital (undenatured) gluten was tested with Approved Method 38-20 (AACC 2000). Commercial durum wheat semolina samples with both high and low protein content were used as controls.

Pasta Making

Each flour sample (2,000 g) was made into spaghetti in a pilot pastamaking plant (Pavan, Padova, Italy). The flour samples were

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mixed with tap water (40°C) for 15 min to obtain a dough suitable for extrusion (dough moisture \approx 33%). Extrusion occurred at 40 \pm 5°C and at a pressure of 60 \pm 10 atm. All the spaghetti was dried according to high temperature (HT) and low temperature (LT) cycles (Fig. 1). HT was a 6-hr total drying cycle. Relative humidity was lowered on a linear gradient from 90 to 65% rh. The drying temperature was a 50-min linear gradient from 50 to 90°C, followed by 90 min at 90°C, then a 30-min linear gradient from 90 to 80°C, held at 80°C for 30 min, ending with a 160-min linear gradient from 80 to 40°C. LT was a 20-hr total drying cycle. Relative humidity was held at 90% rh for 60 min then decreased to 80% rh in 60 min and followed by a 18-hr linear gradient from 80 to 70%. The drying temperature was a 60-min linear gradient from 50 to 60°C and from 60 to 50°C and was held at 50°C for another 17 hr and then cooled to 40°C in 60 min. All the spaghetti samples were equilibrated to room temperature overnight. The diameter of the dried spaghetti was 1.70 mm.

Physicochemical Testing

Test weight was determined by a Schopper chondrometer (Bühler) equipped with a 250-mL cylinder. The 1,000 kernel weight, kernel hardness (hardness index), and kernel diameter were measured according to Approved Method 55-31 (AACC 2000) with the SKCS apparatus (model 4100, Perten Instruments, Huddinge, Sweden).

Flour particle-size distribution was determined with a sifter (Bühler, Uzwil, Switzerland), using 100 g of flour and a 5-min sifting time. Five sieves, 20 cm in diameter, with mesh sizes of 363, 183, 130, 85, and 65 μ m were used.

The whole meal flour, flour, semolina, and pasta samples were analyzed using standard methods (ICC 1995) for moisture (method 110/1), crude protein based on the Kjeldahl procedure (N \times 5.7) (method 105/2), and ash (method 104/1). Starch damage and the reducing sugars in flours were determined according to the Approved Methods 76-31 and 80-60, respectively (AACC 2000). The enzymatic kit for the determination of damaged starch was purchased from Megazyme Int. Ireland (Bray, Co. Wicklow, Ireland). Furosine was determined according to the HPLC procedure of Resmini et al (1990b) on hydrolysates obtained using the microwave procedure standardized by Marconi et al (1997). The furosine standard was obtained from Neosystem (Strasbourg, France).

α -Amylase activity of flour and semolina samples was determined by Falling Number apparatus (model 1500, Perten Instruments) according to standard method 107/1 (ICC 1995).

The SDS sedimentation values of the spelt whole meals were obtained according to standard method 151 (ICC 1995), in a 3% SDS solution. The SDS sedimentation volume per unit of protein was also calculated. The dry gluten and the gluten index of the flour and semolina were determined according to Approved Method 38-12A (AACC 2000) using a Glutomatic 2200 system (Perten Instruments). To determine the dry gluten, wet gluten balls were dried (Glutok 2020, Perten) at 150°C for 4 min and left to cool for 3 min.

The rheological evaluation of the flour and semolina was made using an alveograph (Chopin/Tripette et Renaud, Villeneuve-de-la-Garenne, France) according to standard method 121 (ICC 1995) and a farinograph (Brabender OHG, Duisburg, Germany) (water absorption, dough development time, stability, and degree of softening calculated 10 min from the start) according to standard method 115/1 (ICC 1995).

Color was evaluated by measuring L^* (brightness, 100 = white; 0 = black), a^* (+ = red; - = green) and b^* (+ = yellow; - = blue) parameters by means of a tristimulus reflectance colorimeter (CR300 chromameter, Minolta, Osaka, Japan) both on spelt flours poured into the special attachment provided (CR-50, Minolta) and on dry, uncooked spaghetti placed in an appropriate container to obtain a 1-cm tightly packed layer. Values are the means of five determinations. The apparatus, equipped with a pulsed xenon lamp, d/0 geometry, 8-mm area, was calibrated with a standard ceramic white tile ($L^* = 97.28$, $a^* = 0.23$, $b^* = 1.80$). Color was measured

in CIE L^* , a^* , and b^* color space, with a D65 illuminant and a 10° standard observer.

Cooking quality was assessed by cooking 100 g of spaghetti in 1L of unsalted boiling tap water with total hardness of 17 German degrees (standard method 153 [ICC 1995]). Optimum cooking time was indicated when the white core of the pasta disappeared when squeezed between two glass plates (Approved Method 66-50 [AACC 2000]). Spaghetti was evaluated using sensory and chemical procedures 9 min after being drained. Sensory assessment was made by a trained panel of three assessors. The general test conditions (order and presentation of samples) were conducted according to the 7304 international standard (ISO 1985). The stickiness, bulkiness, and firmness of the cooked spaghetti were determined according to the sensory assessment procedure as reported by Cubadda (1988). These parameters were rated on a five-point hedonic scale and then converted into numerical scores. The scale for both stickiness and bulkiness was 20 = very high, 40 = high, 60 = rare, 80 = almost absent, and 100 = absent. The firmness scale was 20 = rare, 40 = insufficient, 60 = sufficient, 80 = good, and 100 = very good. The score for each organoleptic parameter was the arithmetic mean of the values given by three assessors. The total score regarding cooking quality was obtained by summing the scores of the parameters, multiplying the total by 33.3 and dividing it by 100. The final score for cooking quality was correlated with a description. Spaghetti with a total score of \leq 40 was of poor or mediocre quality; $>$ 40 to \leq 50 was not completely satisfactory; $>$ 50 to \leq 70 was fair; $>$ 70 to 80 was good; and $>$ 80 was excellent.

Total organic matter (TOM), the amount of surface material released in the water after thoroughly rinsing the cooked pasta, was determined using the standard method 153 (ICC 1995). TOM values of more than 2.1 g/100 g correspond to low cooking quality; 2.1 to 1.4 g/100 g correspond to good cooking quality and less than 1.4 g/100 g correspond to very good cooking quality.

Statistical Analysis

All of the experiments, except for alveograph and farinograph, were done in duplicate. Data sets were evaluated using Student's t test to compare the effects of the drying technologies and the protein content.

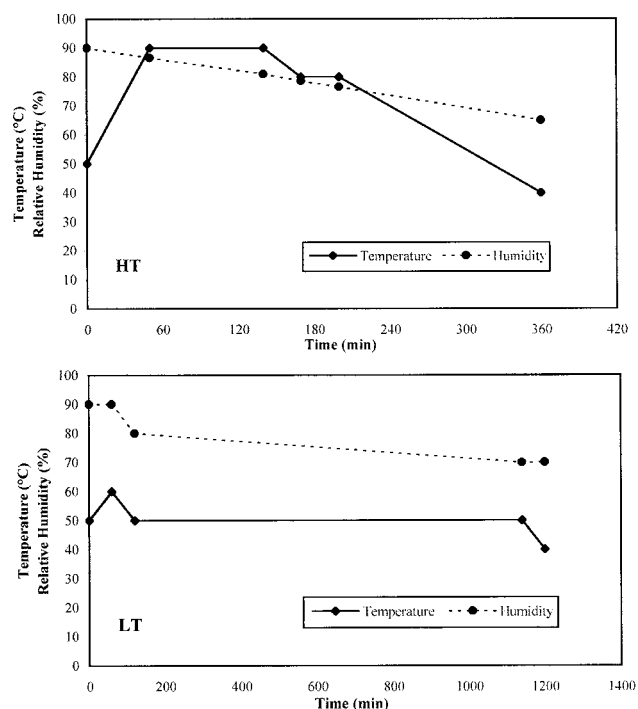


Fig. 1. Pasta drying diagrams: relative humidity and temperature vs. time (HT = high temperature, LT = low temperature).

RESULTS AND DISCUSSION

Kernel characteristics and milling properties of the different spelt varieties are shown in Table I. The test weight of the HP and LP samples of Redoute and Rouquin was low, ranging from 67.4 to 71.2 kg/hL. However, grains were not weathered nor sprouted. The HP samples were lighter than the LP samples. The test weight of HGQ Rouquin, however, was satisfactory (76.1 kg/hL) and was similar to those found in five spelt cultivars by Marconi et al (1999). Contrary to the test weight, the 1,000 kernel weight in the LP samples was lower than in the HP samples. Again, HGQ Rouquin had the highest value (50.3 g). With regard to kernel hardness, the lowest values were found in the LP and HP Rouquin samples (≈ 27 HI, corresponding to soft), intermediate values were found in the LP and HP Redoute (≈ 35 HI, corresponding to medium soft), and the highest values were found in the HGQ Rouquin (59 HI, corresponding to medium hard). The highest HI values of HGQ Rouquin could be partially attributed to its greater kernel diameter because hardness index is significantly influenced by kernel size (Gaines et al 1996). Flour yield was rather low in all samples (averaging 66%) due to the low test weights. The protein contents of Redoute LP and Rouquin LP were 12.8 and 12.6%, db, respectively, while in the respective HP samples they were higher, 16.0 and 15.2%. The HGQ Rouquin sample was similar to the LP samples in protein content (13.1%, db). The ash content of the flours averaged 0.56%, which was approximately one-fourth of that present in the average whole meal flour (2.05%). The lowest ash content was found in both the flour (0.50%) and kernel (1.67%) of HGQ Rouquin, which had the highest test weight and 1,000 kernel weight. The most representative flour particle size ranges were >85 to <130 μm and >65 to <85 μm as a consequence of spelt kernel softness and milling diagram adopted.

The protein-gluten content and protein-gluten quality of the spelt flours assessed using SDS sedimentation and gluten index values, and alveograph and farinograph parameters are reported in Table II. Since only low protein HGQ Rouquin sample was available, gluten was extracted from this sample and added to the flour, increasing protein content from 11.6% (HGQ Rouquin LP) to 13.5% (HGQ Rouquin HP). The gluten quality of the spelt samples, indicated by the SDS sedimentation value, gluten index, and rheological parameters varied widely, ranging from very good in the HGQ Rouquin samples to very poor in the Redoute samples. Considering gluten quality parameters as a function of pasta-making aptitude, it was observed that the Redoute samples showed inadequate values with regard to SDS sedimentation value (≤ 25 mL), gluten index (3), alveograph value ($W \leq 40 \cdot 10^{-4}$ J), and farinograph indices (stability ≤ 2 min; degree of softening ≥ 90 FU). On the other hand, HGQ Rouquin had satisfactory values of sedimentation test (58 mL), gluten index (>85), alveograph W ($\geq 144 \cdot 10^{-4}$ J), and farinograph stability (≥ 3 min). The Rouquin samples showed an intermediate behavior. In general, all spelt samples showed a more extensible than elastic gluten ($P/L < 0.5$), indicating an unsatisfactory pastamaking aptitude ($P/L > 1.0$). Short farinograph stability (1.0–3.5 min) and a high degree of softening (88–185 FU) calculated 12 min after dough development time were also found by Jorgensen et al (1997) in seven spelt cultivars. Data analysis showed that variations in protein content did not alter the ranking of the cultivars, even though differences in the actual values were observed and there were rheological improvements as protein content increased. Because the SDS sedimentation can be influenced by protein content, the specific sedimentation volume (SDS sedimentation volume per unit of protein) was also calculated (Halverson and Zeleny 1988). This reduced the differences between HP and LP samples of the same cultivar, confirming that it is influ-

TABLE I
Kernel Characteristics and Milling Performance of Spelt Cultivars

Sample ^a	Test Wt (kg/hL)	1,000 Kernel Wt (g)	Kernel Hardness (HI) ^b	Kernel Diam. (mm)	Kernel Protein ^c (% db)	Kernel Ash (% db)	Flour Yield (%)	Flour Ash (% db)	Flour Particle Size (%)				
									>183 μm	>130–<183 μm	>85–<130 μm	>65–<85 μm	<65 μm
Redoute LP	71.1	36.2	37	2.2	12.8	2.08	66	0.54	14.0	22.0	11.0	35.0	18.0
Redoute HP	67.4	39.2	35	2.3	16.0	1.96	64	0.56	15.5	22.2	34.5	19.5	8.3
Rouquin LP	71.2	39.3	28	2.5	12.6	2.16	68	0.60	19.9	15.6	31.2	22.0	11.3
Rouquin HP	67.6	41.6	27	2.4	15.2	2.37	65	0.62	14.6	24.7	30.0	20.0	10.7
HGQ Rouquin LP	76.1	50.3	59	2.9	13.1	1.67	69	0.50	18.6	20.6	12.7	28.6	14.0
Mean	70.7	41.3	37	2.5	14.0	2.05	66	0.56	17.4	21.0	23.9	25.0	12.5

^a HP = High protein; LP = low protein; HGQ = high gluten quality.

^b Hardness index.

^c $N \times 5.70$.

TABLE II
Protein Content, Gluten Quality, and Rheological Parameters of Spelt and Durum Wheat Samples^a

Sample ^b	Flour Protein (N \times 5.70) (% db)	SDS SV ^c		Gluten Quality		Alveo. Param. ^d		Farinograph Parameters ^e			
		Volume (mL)	Volume/Protein	Dry Gluten (% db)	Gluten Index	W (10^{-4} J)	P/L	WA (%)	DT (min)	Stability (min)	DS (FU) ^f
Spelt											
Redoute LP	11.4	13	1.2	10	3	14	0.7	51.5	1.0	1.0	140
Redoute HP	13.2	25	1.8	12	3	40	0.2	54.7	1.5	2.0	90
Rouquin LP	11.4	39	3.6	10	39	58	0.2	52.4	2.0	3.0	90
Rouquin HP	13.7	51	3.9	12	50	92	0.2	54.2	2.5	3.5	70
HGQ Rouquin LP	11.6	58	5.2	10	86	144	0.4	55.4	3.0	3.0	50
HGQ Rouquin HP	13.5	nd	nd	12	90	160	0.5	56.4	3.0	3.5	40
Durum wheat											
Semolina LP	11.8	nd	nd	10	85	187	1.3	nd	nd	nd	nd
Semolina HP	13.1	nd	nd	11	92	201	1.5	nd	nd	nd	nd

^a nd = Not determined.

^b HP = High protein; LP = low protein; HGQ = high gluten quality.

^c SV = Sedimentation values. Determined in whole meal at 15% mb.

^d Alveograph parameters.

^e WA = Water absorption; DT = development time; DS = degree of softening.

^f Farinograph units.

enced not only by gluten quality but also by protein content. The higher gluten strength of the HGQ Rouquin samples is thus made more evident from this index. Semolina samples (HP and LP), as expected, showed excellent gluten characteristics (gluten index ≥ 85 ; $W > 180$; $P/L \geq 1.3$) highly appropriate for pasta making.

Starch damage, reducing sugars, amylase activity (Falling Number), and color parameters of spelt flour and semolina are reported in Table III. With regard to spelt samples, the highest level of starch damage was found in HGQ Rouquin ($\approx 4.5\%$ vs. 2.1–2.6%), probably due to the hardness of its kernels (Table I). The amount of starch damage varies with the severity of the milling process and kernel hardness (Evers and Stevens 1985). The amount of starch damage in the durum wheat semolina samples was similar to that of the HGQ Rouquin samples. Fewer reducing sugars were found in the spelt flours (0.29–0.39%) than in the semolina samples (0.48–0.53%). These reducing sugar amounts were similar to those found by other authors in durum wheat (Acquistucci 1996; Pagani et al 1996; Sensidoni et al 1996), and together with Falling Number values of >300 sec were typical of sound, not sprouted grain (Dexter et al 1990). With regard to color, the yellowness of spelt flours was significantly less ($b^* \approx 10$) than that of durum wheat semolina ($b^* \approx 25$), which could be related to lower pigment content and finer particle size (Oliver et al 1992; Sgrulletta et al 1999). The higher brightness of spelt flours with respect to semolina can be attributed to finer particle size (20 vs. 80% $>183 \mu\text{m}$) because this difference disappeared in uncooked spaghetti samples (Table IV).

The results of the physicochemical tests (protein, furosine, color) made to assess pasta quality of the spelt flours and semolina are reported in Table IV. Furosine and color (red index a^*) were influenced by the intensity of the drying process. Furosine is an unnatural amino acid formed from the acid hydrolysis of Amadori

compound (ϵ -deoxy-fructosyl-lysine), produced during the early stages of the Maillard reaction (Resmini et al 1990a). High values of furosine (264.5–426.3 mg/100 g of protein) were found in the HT spelt and durum wheat samples, whereas much lower values (60.0–127.3 mg/100 g of protein) were found in the LT samples. These levels of furosine are typical of durum wheat pastas dried at high and low temperatures (Resmini et al 1990a; Pagani et al 1992; Acquistucci et al 1996). The same behavior was observed in the red index a^* because this index is strictly related to the development of the Maillard reaction (Feillet and Dexter 1996; Acquistucci 2000). The highest values of furosine in semolina spaghetti can be related to the higher content of reducing sugars or damaged starch in the semolina (Pagani et al 1996; Sensidoni et al 1996). Spelt pastas were not as yellow (lower b^*) as the durum wheat pastas, which was related to the lower yellow pigmentation of the spelt flour (Table III). The higher yellow index values of the HT samples may have resulted from lipoxygenase inactivation during HT drying (Dexter et al 1981; Abecassis et al 1984; Feillet and Dexter 1996; Acquistucci 2000). No significant differences were found in brightness values (L^*) between species (spelt and durum wheat) or between treatments (LT and HT drying). The relative lack of yellow color coupled with a redder tinge of spelt pasta was not a problem for consumers because users of whole meal, health, or organic foods are prepared to accept pasta that is not amber yellow (Marconi and Carcea 2001).

The cooking quality of spelt and durum wheat pastas are reported in Tables V and VI. All the spelt pastas dried at low temperature were poor in cooking quality, regardless of protein content. The TOM average value of LT spelt samples was significantly higher (2.6 g/100 g of dry pasta) than that of HT samples (1.4 g/100 g of dry pasta). On comparing spelt spaghetti with HP

TABLE III
Starch Damage, Reducing Sugars, Falling Number, and Color Parameters of Spelt Flour and Durum Wheat Semolina

Sample ^a	Starch Damage (% db)	Reducing Sugars (% db)	Falling Number (sec)	Color		
				L^*	a^*	b^*
Spelt						
Redoute LP	2.5	0.29	355	92.2	-1.4	11.2
Redoute HP	2.6	0.36	310	91.9	-1.0	9.7
Rouquin LP	2.3	0.29	430	92.8	-1.4	11.2
Rouquin HP	2.1	0.29	410	93.1	-1.1	10.3
HGQ Rouquin LP	4.5	0.39	445	91.1	-0.6	11.1
HGQ Rouquin HP	4.4	0.37	425	92.0	-0.7	10.7
Mean	3.1	0.33	396	92.2	-1.0	10.7
Durum wheat						
Semolina LP	4.0	0.53	490	85.6	-1.2	24.5
Semolina HP	4.2	0.48	455	87.3	-1.9	24.7
Mean	4.1	0.51	473	86.5	-1.6	24.6

^a HP = High protein; LP = low protein; HGQ = high gluten quality.

TABLE IV
Protein, Furosine, and Color of Spelt and Durum Wheat Pasta Processed at High Temperature (HT) and Low Temperature (LT) Drying

Sample ^a	Protein (% db)		Furosine (mg/100 g protein)		Color					
					L^*		a^*		b^*	
	HT	LT	HT	LT	HT	LT	HT	LT	HT	LT
Spelt										
Redoute LP	11.3	11.4	264.5	65.1	51.4	51.5	2.9	2.5	30.7	26.6
Redoute HP	13.2	13.1	279.3	63.3	50.1	51.6	4.6	3.4	29.4	27.0
Rouquin LP	11.3	11.5	332.4	60.0	52.7	53.9	3.3	2.6	30.9	27.0
Rouquin HP	13.6	13.7	271.5	64.9	53.3	52.8	2.9	2.3	31.5	27.9
HGQ Rouquin LP	11.5	11.5	325.8	71.9	51.8	53.4	3.2	2.6	27.6	24.6
HGQ Rouquin HP	13.5	13.5	305.0	70.2	50.2	50.4	3.0	2.5	28.1	25.7
Mean ^b	12.4a	12.5a	296.4a	65.9b	51.6a	52.3a	3.3a	2.7b	29.7a	26.5b
Durum wheat										
Semolina LP	11.9	11.9	426.3	127.3	53.3	54.0	2.9	0.9	37.6	34.8
Semolina HP	12.9	13.0	372.2	96.4	50.7	54.4	2.2	0.4	37.2	35.5
Mean ^b	12.4a	12.5a	399.3a	111.9b	52.0a	54.2a	2.6a	0.7b	37.4a	35.2a

^a HP = High protein; LP = low protein; HGQ = high gluten quality.

^b Different letters between means within a row indicate statistically significant differences at $P \leq 0.01$.

and LP protein content, it can clearly be seen that HT drying produced better quality pasta, as the sensorial and chemical tests both determined (Table VI). Durum wheat semolina pastas performed in an excellent or good way in all the protein-temperature combinations (LP × LT, LP × HT, HP × LT, and HP × HT) due to the excellent gluten quality of semolina in both samples either LP and HP (Table II).

During our research activities, protein content emerged as the key factor in the pastamaking performance of spelt. The unquestionable importance of gluten quality was again ascertained when LT drying was used in the pastamaking. In fact, when the spelt samples (HGQ Rouquin) with good gluten strength were dried at low temperature, they obtained acceptable cooking quality values (TOM = 2.0 and 2.3 g/100 g of dry pasta for HGQ Rouquin HP and LP, respectively), while Redoute and Rouquin spaghetti, in the same drying conditions, obtained very poor values (TOM = 2.7 and 3.0 g/100 g of dry pasta for HP and LP samples, respectively). However, protein content gains a more relevant role when HT technologies are used. In fact, all the samples characterized by HP content and HT drying attained satisfactory cooking quality characteristics (TOM = 1.1 g/100 g of dry pasta, OJ = 73).

These results confirm the findings obtained with conventional wheats (*T. durum* and *T. aestivum*) in which protein quantity and quality can act separately, depending on the drying technology adopted. At low temperatures (50°C), the variables mentioned are equally important in determining pasta cooking quality, whereas at high temperatures (≥80°C), protein quantity predominates (D'Egidio et al 1990; Novaro et al 1993; Cubadda 1996). High temperature and high protein content produce a coagulated and diffused protein network capable of preventing starch granules from exuding from pasta during cooking (Resmini and Pagani 1983; Cubadda and Acquistucci 1987).

In addition, a significant correlation ($r = 0.96$, $P \leq 0.01$) between stickiness and TOM was found in this study, which confirms the validity of this last chemical method for evaluating the cooking quality of pasta produced from unconventional wheats and cereals (Marconi et al 1999, 2000).

Therefore, these findings, together with those of a previous work (Marconi et al 1999), demonstrate that as long as protein content is >13.5% (corresponding to ≈15% protein content in grains) and high drying temperatures are used, spelt flours can be processed in manufacturing pasta with satisfactory cooking quality. Otherwise, the vital gluten extracted from spelt flour can be successfully used to increase flour protein content and to improve pastamaking potential of those spelt samples characterized by low protein content.

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TABLE V
Cooking Quality of Spelt and Durum Wheat Pasta Processed at High Temperature (HT) and Low Temperature (LT) Drying

Sample ^a	Organoleptic Judgement								TOM (g starch/100 g dry pasta)	
	Firmness		Stickiness		Bulkiness		Total Score		HT	LT
	HT	LT	HT	LT	HT	LT	HT	LT		
Spelt										
Redoute LP	Insufficient	Rare	Rare	Very high	Rare	Very high	53	20	1.6	3.0
Redoute HP	Sufficient	Rare	Almost absent	High	Rare	High	67	33	1.2	2.7
Rouquin LP	Sufficient	Rare	Rare	Very high	High	Very high	53	20	1.8	3.0
Rouquin HP	Sufficient	Insufficient	Almost absent	High	Rare	High	67	40	1.2	2.7
HGQ Rouquin LP	Sufficient	Insufficient	Almost absent	Rare	Rare	Rare	67	53	1.5	2.3
HGQ Rouquin HP	Good	Sufficient	Absent	Rare	Almost absent	Rare	87	60	1.0	2.0
Mean ^b							66a	38b	1.4a	2.6b
Durum wheat										
Semolina LP	Good	Good	Absent	Almost absent	Almost absent	Rare	87	73	1.1	1.4
Semolina HP	Very good	Very good	Absent	Absent	Absent	Almost absent	100	93	1.1	1.1
Mean ^b							94a	83a	1.1a	1.3a

^a HP = High protein; LP = low protein; HGQ = high gluten quality.

^b Different letters between means within a row indicate statistically significant differences at $P \leq 0.01$.

TABLE VI
Cooking Quality Differences Between Spelt and Durum Wheat Spaghetti with High and Low Protein Content^a

Pasta Grouping ^b	Organoleptic Judgement (Total score)		TOM (g starch/100 g dry pasta)	
	HP	LP	HP	LP
Spelt HT ($n = 3$)	73a	58b	1.1a	1.6 b
Spelt LT ($n = 3$)	44a	31b	2.5a	2.8 a
Spelt HT + LT ($n = 6$)	59a	45b	1.8a	2.2 b
Durum wheat HT + LT ($n = 2$)	93a	83a	1.1a	1.3 a

^a For each parameter different letters within a row indicate statistically significant differences at $P \leq 0.01$. HP = High protein; LP = low protein.

^b HT = High temperature; LT = low temperature.

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