Influence of Gluten Proteins and Drying Temperature on the Cooking Quality of Durum Wheat Pasta

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ABSTRACT

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It is well known that gluten plays a major role in determining cooking quality in durum wheat pasta. This work is an attempt to systematically elucidate the role of gluten quantity and nature in determining cooking quality as a function of the drying cycle used in the manufacturing process. Gluten and starch were fractionated from two durum wheat cultivars possessing good and poor gluten quality. Either of them were then added back to the original base semolina to alter its protein content and to produce two semolina series with identical protein contents. Semolinas were processed into pasta and dried following three drying programs (low, medium, and high temperature). Cooking quality was determined with sensorial, chemical, and instrumental methods. The results indicate that optimum cooking time is governed by gluten quality. The positive effect on cooking quality of increasing gluten contents and of the application of HT drying is evident in weak gluten samples, but it is not significant in the strong gluten samples.

In durum wheat pasta, cooking quality is certainly the characteristic to which consumers attribute most importance. It is generally accepted that textural properties such as firmness and stickiness are the main quality factors of cooked pasta which, to be considered good, must resist surface disintegration, retain a firm structure, and have a chewy bite.

Many variables are involved in pasta quality and their role is not completely understood. Several studies have established that content and composition of durum wheat proteins, gluten strength in particular, are important (Matsuo et al 1982; D'Egidio et al 1990; Malcolmson et al 1993; Novaro et al 1993; Feillet and Dexter 1996). Other investigations have shown that temperature in the drying process can interact with proteins, thus modifying pasta cooking properties. Cooking quality of pasta dried at high temperatures (HT) or very high temperatures (VHT) were superior to that of pasta dried at low temperatures (Manser 1980; Dexter et al 1981; De Stefanis and Sgrulletta 1993; Manthey and Schorno 2002). According to experimental results, HT denatures protein extensively, producing a strong network capable of preventing starch granules escaping from pasta during cooking (Resmini and Pagani 1983). Moreover, there are indications that the adhesion strength between starch and proteins increases during HT drying as the extractability of starch from pasta decreases during drying (Vansteelandt and Delcour 1998). Zweifel et al (2003), studying influence of HT drying on structural and textural properties of durum wheat pasta, found that at the molecular level, HT drying promoted protein denaturation. At the microscopic level, HT drying contributed to a better preservation of the protein network and reduced swelling of starch and disintegration of granules. At the macroscopic level, HT drying enhanced the firmness of cooked pasta and reduced surface stickiness. Some studies have also attempted to characterize starch properties of industrially produced or pilot plant produced pasta using differential scanning calorimetry, viscoamylography, a Rapid Visco Analyser, an X-ray diffractometer, and brightfield and polarized light microscopic examination after applying HT and VHT drying treatments (Vansteelandt and Delcour 1998; Yue et al 1999; Zweifel et al 2000; Güler et al 2002). These and other recent works where the quality of spaghetti made from full and partial waxy durum wheat were investigated, confirm that protein-starch interactions occur in pasta that affect texture and, consequently, its firmness, stickiness, and cooking losses (Gianibelli et al 2005; Vignaux et al 2005) and that these interactions vary depending on the drying procedure.

It may be observed that it is difficult to compare results of different studies because drying cycles, as well as the characteristics of the original semolinas, are always different. As a consequence, in spite of the important wealth of knowledge acquired on the effect of HT drying on pasta quality, pasta manufacturers are still waiting to know which is the most important property of the raw material that will allow them to obtain optimum cooking quality in pasta as a function of the drying program adopted. Therefore, we thought it worthwhile to assess the relationships between the gluten amount and quality in semolina and the cooking quality of pasta dried following different drying programs. An addition and reconstitution experiment was planned to produce semolinas with different gluten protein contents starting from the same raw materials. This was possible thanks to a special equipment built in our laboratory where vital gluten was produced in bulk and added back to the same semolina to obtain raw materials possessing different gluten protein contents. In fact, in the present study, two very popular Italian cultivars widely used by the pasta industry and renowned for their good and poor gluten quality, respectively, were the starting raw material for the production of semolinas belonging to five different gluten protein classes. The resulting 10 semolina samples were transformed into spaghetti that were dried at low (60°C), medium (75°C) and high (90°C) temperature in a semi-industrial pilot plant. A total of 30 pasta samples were produced and analyzed for their cooking properties using objective and sensorial methods. Therefore, this work can be considered as the first attempt to systematically elucidate the role of gluten quantity and nature in determining pasta cooking quality as a function of the drying cycle chosen by the manufacturing industry.

MATERIALS AND METHODS

Materials

Semolina used in pasta making experiments was obtained from two Italian cultivars (Simeto and Ofanto) possessing good and poor gluten quality, respectively. A starting batch (200 kg) of each of the two cultivars was cleaned, conditioned (16.5% moisture), and milled in a MLU 202 mill (Bühler, Uzwill, Switzerland) equipped with three break and three reduction rolls and six steel screens, fitted with a small-scale purifier, following Approved Methods 26-10A and 26-41 (AACC International 2000). Semolina yield (ash <0.90% dm) was ≈66%; granulation was within the

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limits of Italian law on this matter (25% maximum passed through a 180-µm mesh sieve).

Analytical and Technological Tests

Grains and semolina samples were analyzed by standard ICC procedures for moisture (Standard method No. 110/1) total protein (N × 5.70) (Standard method No. 105/2), gluten content (Standard method No.137), and ash (Standard method No. 104/1) (ICC 2003).

The SDS sedimentation value was obtained on whole meal according to Standard method No.151 using a 2% SDS solution (ICC 2003). The gluten index was determined according to Standard method No. 158.

The rheological properties of the dough were determined with an alveograph by the method of Chopin (Standard Method No. 121) (ICC 2003), except that the dough was mixed for 4 min and, after a rest of 18 min, mixed again for 4 min.

Extraction of Gluten and Starch

Semolina (2 kg) was mixed in a dough mixer (prototype built for this study by NAMAD, Roma, Italy) with 1.2 L of water at room temperature for 4 min (95 rpm) and 6 min (140 rpm). The obtained dough was allowed to rest for 15 min at room temperature. The dough was poured over the sieve (pore size 420 µm) of the gluten washing machine (prototype as above). After 30 min of washing, the gluten fraction was recovered from the sieve and dried under vacuum at <50°C in a special drier (NAMAD, Roma, Italy). The filtrate of the first 10 min was collected and decanted in a refrigerated room at 4–5°C overnight. The sediment consisted of a yellow-brown layer of water-soluble components (pentosans, albumins, and globulins, etc.) with a starch layer underneath. The top layer was scraped off and discarded, whereas the white bottom layer was resuspended in distilled water and centrifuged (1,800 × *g*, 10 min, room temperature). The sediment was collected as a starch fraction and dried as described above for the gluten fraction. The dried gluten contained 80–82% of protein (dm); the protein content of dried starch was <0.5%. Dried gluten and starch (moisture ≈4–5%) were milled in a laboratory mill to pass a 150–200 µm mesh size, sealed in plastic bags, and kept at room temperature before use. In this way, the natural viscoelastic properties of gluten were preserved. Gluten vitality was checked according to Approved Method 38-20 (AACC International 2000).

Reconstitution of Gluten Protein Classes

The quantity of dried gluten or starch to be added to its original semolina to obtain for each cultivar a series of samples, each possessing the same protein levels (10.5, 11.5, 12.5, 13.5, 14.5% dm) was calculated. Each sample of every protein level was analyzed for its protein content according to the above-mentioned method to verify the correspondence between the predetermined and the actual value.

Pasta Processing

Long pasta (spaghetti) was manufactured by means of an experimental pasta making apparatus (NAMAD, Roma, Italy) composed of a press and a dryer essentially following Approved Method 66-41 (AACC International 2000). The press (capacity 5–20 kg) was equipped with a vacuum mixing and extruding system as well as with a water-cooling jacket of the barrel and the extrusion head to reduce heat and to maintain a constant extrusion temperature of no more than 50°C.

The dryer was equipped with 1) a heat ventilator unit to ensure uniform temperature and ventilation in all parts of the apparatus; 2) a moisture regulation and control unit; 3) a regulation and program unit equipped with a computer and a dedicated software.

Semolina was mixed for 15 min with tap water (30°C) to obtain a dough suitable for extrusion. The moisture content of the dough was ≈30%. Extrusion occurred at 30°C ± 2 and at a pressure of 76 ± 5 bar. Each series of spaghetti was dried according to three different drying cycles: low temperature (maximum 60°C) (LT), medium temperature (maximum 75°C) (MT), and high temperature (maximum 90°C) (HT). Three drying diagrams are shown in Fig. 1. The diameter of the spaghetti was 18 mm. At the end of the drying cycle the spaghetti were conditioned at room temperature (20°C) for 24 hr.

Determination of Cooking Quality

Cooking quality, firmnes, and stickiness were evaluated by both sensorial and instrumental methods. Stickiness was also determined by the chemical total organic matter (TOM) method. Optimum cooking time for firmness and stickiness for instrumental measurements was determined according to Approved Method 66-50 (AACC International 2000) where it corresponds to the disappearance of the white color in the central core of the spaghetti.

The instrumental determination was conducted using a TA-XT2 texture analyzer (Stable MicroSystems, England) interfaced with a PC. The preparation of the sample was done according to Approved Method 66-50 (AACC International 2000). In particular, when optimum cooking time was reached, the pasta sample was drained into a funnel and rinsed with a stream of distilled water for 30 sec. The cooked pasta was transferred into a beaker of distilled water at room temperature before testing. Testing was performed immediately after cooking to minimize changes resulting from storage in a liquid medium. Cooked firmness was determined according to AACC Approved Method 66-50 and it was considered as the work in (g/cm) required to shear five

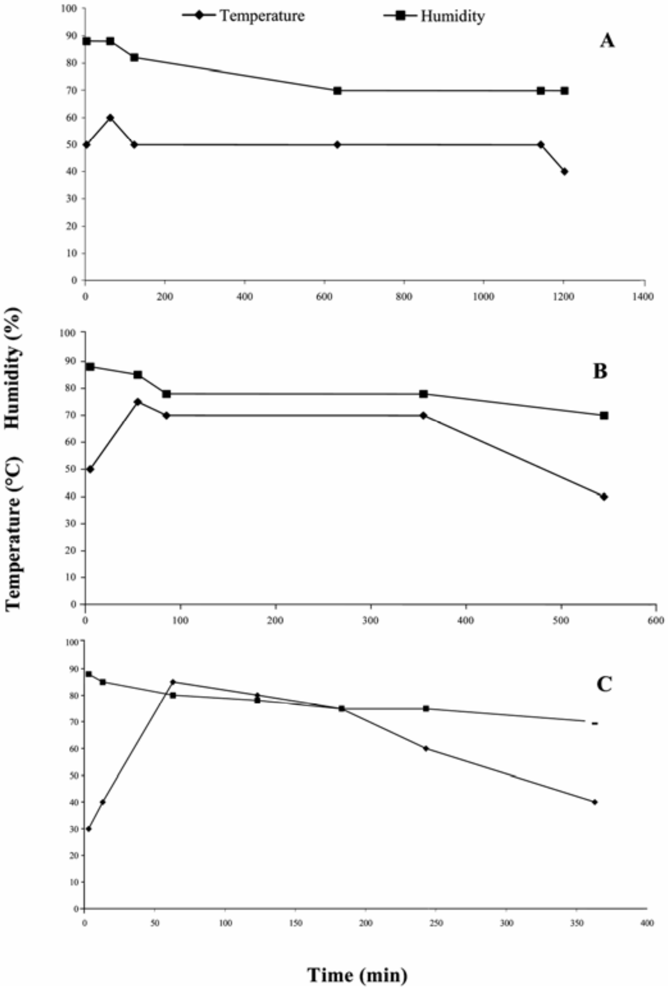

Fig. 1. Drying diagrams for pasta processed at **A**, low (LT) ; **B**, medium (MT); **C**, high (HT) temperature cycles.

strands of spaghetti. The maximum cutting force per unit area was also considered. For stickiness measurements, the HDP/PFS MicroSystems pasta stickiness rig with a 5-kg load cell was used (Stable MicroSystems, England). The test speed was 0.5 mm, whereas the pretest and posttest speeds were 1.0 mm/sec and 10.0 mm/sec, respectively. The compression force was 1,000 g for 2 sec.

The sensorial evaluation was conducted on pasta cooked to optimum cooking time as above by a trained panel of three or more experts. Stickiness, bulkiness, and firmness were evaluated by each expert on a scale of 10–100 according to Cubadda (1988). Spaghetti with a total score of ≤40 was of poor or mediocre quality; >40 to ≤50 was not completely satisfactory; >50 to ≤70 was fair; >70 to 80 was good; and >80 was excellent. Each cooking test was replicated three times in a laboratory under controlled temperature.

Total organic matter (TOM), the surface material released from cooked pasta after exhaustive rinsing, was determined in duplicate by a chemical method according to Standard Method No. 153 (ICC 2003). TOM values >2.1 g/100 g corresponded to low quality, values between 2.1 and 1.4 g/100 g predicted good quality, and <1.4 g/100 g estimated very good quality.

Statistical Analysis

All measurements were done at least in duplicate and data relative to instrumental determination of cooking quality were subjected to an analysis of variance using the Statistical Analysis System (SAS Institute, Cary, NC). Means were separated by Fisher's least significant difference ($P < 0.05$).

RESULTS

Composition of Raw Materials

The most important technological quality parameters in both durum grains and semolina belonging to Ofanto and Simeto are reported in Table I. Simeto grains had an inferior total protein, gluten protein, and ash content (11.2, 8.5, and 1.62% dm, respectively) than Ofanto (11.7. 9.4, and 1.71% dm) However, quality tests on gluten proteins, in particular the gluten index and the SDS sedimentation test, confirmed that the Simeto gluten was, as expected, stronger than Ofanto gluten. Simeto grains scored 71% and 45 mL and Ofanto grains scored 16% and 21 mL for the gluten index and the SDS sedimentation test, respectively.

For the same determinations on semolina, the values obtained were higher than those obtained in grains, due mainly to the interfering action of fiber components when the above-mentioned tests are performed on whole meal. In addition, the alveograph *W* value and *P/L* ratio, which can be determined on semolina only, confirmed the superiority of Simeto over Ofanto. Both semolinas, as a consequence of the removal of bran layers during milling, had a lower protein and ash content than the original grains and these values were within the limits established by Italian legislation on this matter. Therefore, both original semolinas could be considered equivalent to commercial products.

Pasta Cooking Quality

The cooking quality results for 30 pasta samples that were obtained by adding their own gluten or starch in suitable proportions to original semolinas of two cultivars possessing opposite gluten qualities to create recombined mixtures of fixed gluten protein contents that were dried under the same conditions according to a low, medium, and high temperature drying program are reported in Tables II–V. Several studies have demonstrated that fractionation and reconstitution experiments are valid approaches for investigating the contribution of the different semolina components in determining pasta quality and that the functionality of the different components is not impaired by the extraction procedure if properly performed (Sheu et al 1967; Delcour et al 2000a,b; Sissons et al 2002; Gianibelli et al 2005). Also the objection that semolina is a coarse material and that it is difficult to reconstitute it in a totally functional way because the separation of the components breaks down the particle structure and the reconstituted material is much finer than semolina, found contrary evidence in the work of Sissons et al (2002), who concluded that pasta can be made from both normal semolina and reconstituted semolina components without significant changes in quality.

Pasta consumers attribute fundamental importance to textural properties such as chewiness, stickiness, firmness, and bulkiness. Stickiness and bulkiness are surface characteristics and together with firmness, which depends on the intrinsic structure of pasta, are considered the best predictors of consumer sensations when eating pasta. Therefore, sensory tests that incorporate those attributes are considered reliable tests to judge cooking quality. Moreover, in many cases, sensory tests are considered reference methods to assess the predictability of instrument-based methods.

Sensory judgement and TOM are considered by Cubadda (1988), D'Egidio et al (1993), and more recently by Kovacs et al (1997) as useful tests to evaluate overall cooking quality. The TOM test was developed to measure spaghetti stickiness by the determination of the amount of material that could be obtained by exhaustive rinsing of drained, cooked spaghetti. This method shows a close relationship to sensory and instrumental evaluation of cooked spaghetti stickiness and cooking quality in general because it has been observed that higher firmness is generally associated with smaller stickiness. Therefore, the smaller the amount of material lost during cooking, the better the pasta quality.

Sensorial and chemical cooking quality of pasta strands belonging to Ofanto (weak gluten) and Simeto (strong gluten) with different gluten protein content dried according to three different drying programs are shown in Tables II and IV, respectively. The same tables also report the optimum cooking time for different pastas. Note that samples belonging to the Ofanto (weak gluten series) (Table II) exhibited the same trend at all protein levels, i.e. the longest cooking time corresponded to the lowest drying temperature. At a gluten protein content of ≥13.5% dm, the MT and the HT pasta had the same cooking time. If we consider the Simeto (strong gluten) series (Table IV), most of the samples (except 11.5% dm), showed an opposite trend: at all gluten protein levels,

TABLE I
Average Technological Properties of Ofanto and Simeto Grains and Semolina

	Ofanto		Simeto	
Parameter[a]	Grain/Wholemeal	Semolina	Grain/Wholemeal	Semolina
Protein content (% dm)	11.7	11.1	11.2	10.5
Gluten content (% dm)	9.4	9.9	8.5	9.1
Ash (% dm)	1.71	0.86	1.62	0.83
Gluten index (%)	16	21	71	91
SDS sedimentation test (mL)	21	20	45	43
Alveograph *W*	–	80	–	171
Alveograph *P/L*	–	1.40	–	3.67

[a] Alveograph indices: W = dough strength ($\times 10^{-4}$ J); L = extensibility (mm); P = tenacity (mm); P/L = tenacity-to-extensibility ratio.

the HT samples had the longest cooking times. In other words, given the same gluten protein level and the same drying programs, the optimum cooking time is governed by gluten quality. If we then compare results, we observe that the strong gluten series (Simeto) has a longer optimum cooking time than the weak gluten series (Ofanto) for all HT samples, but this is not true for the LT samples, where values were the same or shorter in the Simeto (strong gluten) series. If we consider instead the influence of protein content on the optimum cooking time within the weak gluten series (Ofanto), we can say that a higher level of proteins is responsible for a longer cooking time at LT only. At HT, cooking times are similar or equivalent for all samples. For the strong gluten series, increasing gluten protein content does not affect the cooking time at LT nor does it increase it at HT. Considering our evidence, we could conclude that HT drying limits the diffusion of water into the spaghetti strand, thus increasing cooking time as already observed by Zweifel et al (2003), but this is only true for samples possessing a strong gluten. So, even though it is reasonable to think that, as also observed by Sissons et al (2005), a reduced amount of gluten allows gelatinization to occur more rapidly, reducing the cooking time, we must also consider the influence of the drying temperature on the starch-gluten matrix.

The sensory evaluation of cooked pasta (Tables II and IV) showed that stickiness (material adhering to the surface of cooked pasta) was classified as high only with samples of the Ofanto (weak gluten) series, LT drying cycle, and gluten protein content <12.5% dm. Samples of the Simeto series showed a better performance at low gluten protein levels and at LT drying than did the Ofanto series. A similar picture emerges also for bulkiness, which is the degree of adhesion between pasta strands. For firmness (resistance of cooked pasta to chewing with teeth), both Ofanto and Simeto showed a positive rating ("good") appears at a protein level of ≥13.5% dm for all the drying cycles. For both series a "very good" ranking is achieved by samples with 14.5% dm protein and dried at HT. Taking the total score, which is a combination of the three considered parameters (arithmetic mean value weighted equally for stickiness, bulkiness, and firmness), Tables II and IV show that at all protein levels, the LT dried samples always had the lowest score, with the Ofanto series constantly producing lower scores than the Simeto series. For both series, increasing protein contents in the HT dried samples increased total scores. This is particularly evident in the Ofanto series; in the Simeto series, samples with a protein content of ≥12.5% dm present identical or very close values. In fact, in the Simeto series, samples with a protein content of ≥13.5% dm can all be classified as good, irrespective of their drying temperature. So, according to our results, the positive effect of increasing gluten content and applying HT drying is evident in weak gluten

TABLE II
Cooking Quality of Ofanto Pasta with Different Gluten Protein Content Dried at Low (LT), Medium (MT), and High Temperature (HT) Measured by Sensorial and Chemical Tests

Samples[a]	Cooking Time (min)	Stickiness	Bulkiness	Firmness	Total Score[b]	Total Organic Matter[c]
10.5 LT	12.00	High	High	Insufficient	40	2.2
10.5 MT	11.00	Rare	Rare	Sufficient	48	1.9
10.5 HT	11.50	Rare	Rare	Sufficient	57	1.7
11.5 LT	12.30	High	High	Rare	40	2.3
11.5 MT	11.40	Rare	Rare	Sufficient	50	1.9
11.5 HT	11.20	Almost absent	Rare	Sufficient	62	1.7
12.5 LT	12.10	High	High	Sufficient	43	2.2
12.5 MT	11.10	Rare	Rare	Sufficient	60	1.8
12.5 HT	11.40	Almost absent	Almost absent	Sufficient	67	1.6
13.5 LT	12.30	Rare	Rare	Sufficient	56	1.8
13.5 MT	11.20	Almost absent	Almost absent	Good	65	1.7
13.5 HT	11.20	Almost absent	Almost absent	Good	73	1.4
14.5 LT	12.40	Rare	Rare	Good	63	1.8
14.5 MT	11.50	Almost absent	Almost absent	Good	71	1.5
14.5 HT	11.50	Almost absent	Almost absent	Very good	78	1.2

[a] Protein content (% dm).
[b] According to Cubadda (1988).
[c] According to Standard method No. 153 (ICC 2003).

TABLE III
Instrumental Measurement of Stickiness and Firmness Determined with Microsystem TA-XT2 Texture Analyzer on Ofanto Pasta with Different Gluten Protein Content Dried at Low (LT), Medium (MT), and High Temperature (HT)[a]

Samples[b]	Stickiness (max force) (g)	Stickiness (total work) (g × sec)	Firmness (max force) (g)	Firmness (total work) (g × sec)
10.5 LT	73.6a	3,810a	261.0a	3,149a
10.5 MT	58.5c	2,790d	289.4b	3,363b
10.5 HT	38.7d	1,850e	306.9d	3,533c
11.5 LT	63.1b	3,280b	297.3c	3,620e
11.5 MT	30.4e	1,860e	304.6d	3,571d
11.5 HT	28.4f	1,360f	324.2e	3,679f
12.5 LT	62.2b	3,110c	332.1f	4,014g
12.5 MT	27.0g	1,240g	348.7g	4,108h
12.5 HT	19.7i	950i	345.4g	4,049g
13.5 LT	38.4d	1,870e	354.3h	4,304i
13.5 MT	26.2g	1,260g	360.7h	4,276i
13.5 HT	17.2l	870l	450.8m	5,175m
14.5 LT	38.0d	1,850e	385.8i	4,681l
14.5 MT	21.5h	1,090h	404.7l	4,723l
14.5 HT	16.4l	730m	453.6m	5,163m

[a] Mean values of 7 determinations. Within the same column, values followed by a different letter are significantly different at $P \leq 0.05$.
[b] Protein content (% dm).

samples. Increasing gluten quantity in strong gluten pasta at levels >12.5% dm produces little effect in pasta cooking quality, which is more independent of the drying cycle adopted. In other words, in strong gluten semolina, at protein levels >12.5% dm, the effects of the drying cycle are not so evident, and there is an overlap of values in several situations.

It is interesting to note that in the strong gluten series at almost all protein levels, the MT drying samples scores were the same as those obtained by the HT drying series. In the weak gluten series, the MT values were always intermediate between those obtained by the LT and HT samples. This improving effect on pasta cooking quality of HT drying when weak gluten is present in semolina was already observed by Cubadda (1996) and also in spelt (*Triticum spelta* L.) pasta by Marconi et al (1999).

The same trend observed for the sensory evaluation of spaghetti cooking quality is evident from the observation of the TOM data (Tables II and IV). The Simeto series values were 1.5–1.1 and consistently showed lower values than the corresponding values of Ofanto (2.3–1.2). These results indicate that, in general, a higher amount of starch exudate is produced during the cooking of the weak gluten series. As for the sensory evaluation, in the weak gluten series, at all protein levels, the application of HT drying produced a noticeable decrease in the amount of surface material released from cooked pasta into the cooking water. In the strong gluten series, even though lower protein contents corresponded to higher TOM values within the same protein content group, TOM values were often the same, irrespective of the drying cycle adopted. The range of all values was very narrow and all samples could be classified as either good or very good according to the classification reported in the standard method. It might be noted that the higher the protein content, the closer the TOM values for the HT samples of both the weak and strong gluten series. A value of 1.2 for the 14.5% dm gluten protein in the Ofanto series corresponds to a value of 1.1 for the Simeto series; whereas at 13.5% dm, gluten protein has a value of 1.4 for the Ofanto series corresponding to 1.1 for the Simeto series.

The instrumental determination of pasta cooking quality involved the measurement of stickiness by means of the compression-retraction method and firmness by means of the cutting method in a texture analyzer. In Tables III and V, data are reported relative to the force-time curves that were obtained on Ofanto (weak gluten) and Simeto (strong gluten) samples when the adhesive test or the cutting test was performed in the TA-XT2 instrument. In particular, the maximum adhesion force (peak height of the force-time curve) and the work of adhesion (area under the curve) were reported for stickiness together with the maximum cutting force (peak height of the force-time curve) and the total work to cut (area under the curve), which were reported for pasta firmness. In

TABLE IV
Cooking Quality of Simeto Pasta with Different Gluten Protein Content Dried at Low (LT), Medium (MT), and High Temperature (HT), Measured by Sensorial and Chemical Tests

Samples[a]	Cooking Time (min)	Stickiness	Bulkiness	Firmness	Total Score[b]	Total Organic Matter[c]
10.5 LT	12.00	Rare	Rare	Insufficient	56	1.5
10.5 MT	11.50	Rare	Rare	Insufficient	54	1.5
10.5 HT	12.30	Rare	Rare	Insufficient	56	1.5
11.5 LT	12.10	Rare	Rare	Insufficient	59	1.5
11.5 MT	11.10	Rare	Rare	Sufficient	64	1.3
11.5 HT	12.00	Almost absent	Almost absent	Sufficient	64	1.4
12.5 LT	12.10	Almost absent	Almost absent	Sufficient	65	1.4
12.5 MT	11.00	Almost absent	Almost absent	Sufficient	68	1.3
12.5 HT	12.50	Almost absent	Almost absent	Good	72	1.3
13.5 LT	12.00	Almost absent	Almost absent	Good	68	1.4
13.5 MT	11.20	Almost absent	Almost absent	Good	72	1.2
13.5 HT	12.50	Almost absent	Almost absent	Good	72	1.1
14.5 LT	12.00	Almost absent	Almost absent	Good	71	1.2
14.5 MT	11.50	Almost absent	Almost absent	Good	76	1.2
14.5 HT	12.20	Almost absent	Almost absent	Very good	76	1.1

[a] Protein content (% dm).
[b] According to Cubadda (1988).
[c] According to Standard method No. 153 (ICC 2003).

TABLE V
Instrumental Measurement of Stickiness and Firmness Determined with Microsystem TA-XT2 Texture Analyzer on Simeto Pasta with Different Gluten Protein Content Dried at Low (LT), Medium (MT), and High Temperature (HT)[a]

Samples[b]	Stickiness (max force) (g)	Stickiness (total work) (g × sec)	Firmness (max force) (g)	Firmness (total work) (g × sec)
10.5 LT	55.1a	2,710a	269.4a	3,230b
10.5 MT	27.3c	1,390e	262.4a	3,141a
10.5 HT	26.9c	1,130i	273.2b	3,140a
11.5 LT	56.8a	2,320b	279.2b	3,368c
11.5 MT	26.8c	1,250g	361.8e	3,534d
11.5 HT	27.0c	1,300f	326.0d	3,777e
12.5 LT	30.3b	1,630c	311.4c	3,772e
12.5 MT	24.5d	1,020m	373.7f	4,393i
12.5 HT	22.6e	1,140i	331.6d	3,945f
13.5 LT	31.7b	1,570d	374.1f	4,141g
13.5 MT	24.0d	1,170h	361.8e	4,500l
13.5 HT	22.9e	1,110l	359.1e	4,292h
14.5 LT	20.1f	850n	413.0g	4,893n
14.5 MT	20.4f	870n	412.8g	4,893n
14.5 HT	21.3e	1,040m	411.2g	4,695m

[a] Mean values of 7 determinations. Within the same column, values followed by a different letter are significantly different at $P \leq 0.05$.
[b] Protein content (% dm).

both stickiness and firmness, maximum force, and total work showed the same trend and therefore either can be used to measure one of the two parameters.

Stickiness values in the Ofanto (weak gluten) series (Table III) were 16.4–73.6 g for peak force and 730–3,810 g × sec for work of adhesion. For the Simeto series, the same parameters were 20.1–56.8 g and 850–2710 g × sec. So stickiness is directly or indirectly influenced by gluten quality. In particular, comparing the results relative to corresponding samples in Tables III and V clearly indicates that, in the great majority of cases, samples of the weak gluten series are stickier than the samples of the strong gluten series. Moreover, in the weak gluten samples (Table III), stickiness decreases as gluten protein contents and drying temperature increase. This positive influence is more evident when HT drying is applied. The best results were obtained for samples with a gluten protein content of 13.5–14.5% dm dried at HT. In the strong gluten series, HT drying shows positive effects on stickiness only for samples with a low protein content (<11.5% dm), whereas at higher gluten protein contents, this positive influence is negligible. In the same series, we could also observe that, at all protein levels, there were no significant differences, or differences were very small for samples dried at MT and HT. Therefore, we can say that a temperature increase >70°C to reduce stickiness in pasta coming from semolina possessing a strong gluten does not produce any evident improvement.

The firmness values in the Ofanto (weak gluten) series (Table III) were 261.0–453.6 g for peak force and 3,149–5,163 g × sec for work of compression. The firmness values in the Simeto series (Table V) were 262.4–413.0 g and 3,140–4,893 g × sec. In our experiment, comparing results relative to the weak and strong gluten we can say that, in both cases, firmness increases as gluten content increases. If we consider the influence of the drying temperature when using semolina with weak gluten, a temperature increase from LT to HT produces an increase in firmness at all protein levels. This is not true for the strong gluten series, where at >13.5% dm there is no significant difference in the firmness of the samples dried at different temperatures. So considering firmness, gluten quality in combination with the drying temperature is a determinant for pasta cooking quality. The improvement of pasta firmness consequent to temperature drying is consistent with results obtained in other recent experiments (Zweifel et al 2003) but the gluten quality of semolina was not reported. On the contrary, no information is present in the literature about the ineffectiveness of HT drying on firmness of pasta manufactured with good gluten semolina.

From analysis of all the data in Tables II–V, we can say that the data of the sensorial, chemical, and instrumental determinations, when they refer to the same quality trait, are in close agreement.

DISCUSSION

For stickiness, Dexter et al (1983) showed that cooked HT dried spaghetti was generally less sticky and exhibited lower cooking loss than LT spaghetti, and stickiness was influenced by cultivar, wheat class, raw material granulation, and protein content.

Some authors found a relationship between amylose and stickiness (Dexter et al 1985; Grant et al 1993). Amylose exuding from the starch granules during cooking may be responsible for this attribute in pasta. HT drying also decreased the amount of amylose in the cooking water (Grant et al 1993). Moreover, the same authors using two cultivars with similar protein content but different strength characteristics observed that spaghetti strand disintegration during cooking is not related as much to protein content as it is to protein quality. They concluded that the presence or absence of certain gluten components may play a significant role in spaghetti stickiness.

Yue et al (1999) studied semolina from different genotypes processed into spaghetti dried at LT, HT, and UHT and found small but significant changes in starch properties that were interpreted as reorganization to more homogeneous crystalline species of starch granule structure. UHT dried starch was altered to a greater extent than LT and HT starch. They speculated that these changes are likely to contribute to reduced losses of solids during cooking and increased firmness in pasta. It is also interesting to consider activity of amylolitic enzymes. Lintas and D'Appolonia (1973) investigated the changes that occur in starch during processing of semolina at LT drying. They reported that during the drying, amylolitic enzymes could act on mechanically damaged starch. Amylolytic enzymes are active at LT and they can also reduce amylose during the mixing and extruding phases of processing, resulting in the release of free maltose. Naturally, the more starch and damaged starch and the less proteins there are in pasta, the more evident the action of the amylolitic enzymes.

Güler et al (2002), in a study of the effects of industrial pasta drying temperatures (HT and VHT) on various starch properties examined by RVA, DSC, X-ray diffractometry, and polarized light microscope, concluded that the starch undergoes significant changes. All these changes might be due to the conformational changes in starch granules that affect cooking properties, causing a lower level of exudates in VHT dried pasta. They also reported that HT dried pasta samples (max temperature 67°C) compared with VHT dried pasta samples (max temperature 94°C) showed a higher level of starch damage, thus indicating that a greater amount of starch damage might have occurred during the drying steps of HT pasta. All observations are in agreement with our results and they might all be considered to explain what we observed for stickiness. Of course, as proteins increase in the pasta strand, starch decreases so there is less material to be lost during pasta cooking and therefore less chance to have a sticky pasta. However, drying temperature affects starch transformation, protein coagulation, and the interactions occurring between starch and proteins.

It is clear that in durum wheat pasta, starch gelatinization and protein coagulation are responsible for the structural changes that occur during pasta cooking in water. Both transformations occur at approximately the same temperature and moisture level (Cunin et al 1995). If we take into account previous studies where cooked spaghetti strands were observed under light microscopy, scanning electron microscopy, and confocal scanning laser microscopy (Dexter et al 1978; Resmini and Pagani 1983; Fardet et al 1998; Manthey and Schorno 2002; Heneen and Brismar 2003; Zweifel et al 2003), we can say that drying conditions are determinant for the phase morphology of protein and starch in cooked pasta which, in turn, govern the textural properties of pasta. The physical competition between the process of starch swelling and gelatinization and the process of protein coagulation and firm network formation during cooking has been stressed, and differences in structure of external, intermediate, and central regions of cooked pasta have been indicated. Del Nobile et al (2003) studied the influence of raw materials and processing conditions on the hydration kinetic during cooking and overcooking of commercially available spaghetti and on three different types of homemade spaghetti. All the phenomena involved during spaghetti hydration were separately described and the conclusion was that processing conditions have a greater influence on spaghetti quality than the raw material, even though it must be observed that Del Nobile et al (2003) did not account for any difference in protein content between the samples studied. Based on our evidence, we can partially agree with this conclusion, which is certainly true when the raw material is made up of a weak gluten semolina. All our tests were performed at optimum cooking time, which depends primarily on the rate of water penetration and pasta strand swelling. We can postulate that the presence of a continuous and dense protein network formed in the early stages of pasta drying, as it could happen with HT drying, might disturb the swelling and gelatinization of starch granules from the periphery to the central core. During pasta cooking, the protein network limits water diffusion of the starch granules, which limits swelling in the central zone of pasta (Fardet et al 1998). Grains with gluten proteins of better quality are more susceptible to the formation of a protein matrix. Fusions of starch granules at common border lines that lead to fewer interconnections between proteins have been observed in pasta prepared with bread wheat that notoriously possesses fewer proteins (and of inferior quality) than durum wheat, which has been given as a reason for its inferior cooking quality in comparison with durum wheat (Heneen and Brismar 2003). Strong gluten proteins could therefore be an obstacle to the fusions of starch granules at common border lines.

Studies of Güler et al (2002) have clearly demonstrated that starch granules in HT and VHT dried pasta samples still retain their birefringence. The fact that starch is not completely gelatinized during HT and VHT pasta drying was also confirmed by their DSC studies. In other words, the amount of available water might not have been sufficient to already cause complete swelling and starch gelatinization as during cooking. Therefore, if a protein network is capable of entrapping starch granules (Resmini and Pagani 1983; Fardet et al 1998; Heneen and Brismar 2003), the physical constraints of this matrix could certainly limit the swelling of starch granules and the leaching of material into the cooking water.

Vansteelandt and Delcour (1998) studied the physical behavior of durum wheat starch during industrial pasta processing and in particular during HT (max temperature 88°C) drying. They found that the first drying steps rendered the starch granules in general (and the small ones in particular) less extractable, possibly due to increased physical inclusion or interaction between starch and gluten components. The HT pasta drying produces less permeable and thus more rigid starch granules with lower solubility and swelling capacity.

Zweifel et al (2003) studied the effect of HT drying at high, intermediate, and low product moisture on the structural changes of the starch fraction at the molecular level by DSC. They concluded that LT drying (55°C) of pasta decreases the enthalpy of gelatinization due to a partial melting of starch. In contrast, HT drying (100°C) increases the molecular order of starch at the double helical level, but the crystallinity is not affected. It is reasonable to assume that an increased thermostability of starch has a positive influence on the cooking properties of pasta. They concluded that the relative importance of starch and protein on the structural and textural properties of pasta remains to be clarified.

Zweifel et al (2003) studied the influence of HT drying (80 and 100°C) on structural and textural properties of durum wheat pasta. The changes in the protein fraction at the molecular level were measured for glutenin and gliadin solubility. They found that during drying at LT (55°C), almost no changes in the extent of glutenin denaturation occurred, but a decrease of glutenin and gliadin solubility was observed at HT with the decrease being more pronounced as temperature increased. Zweifel et al (2003) explained the reduced solubility of wheat gluten proteins in HT dried pasta by an enhanced aggregation of the denatured proteins. The same authors examining the microstructure of the protein phase by confocal laser scanning microscopy found that, in pasta dried at HT, a continuous protein phase is visible. According to the same authors, HT drying induces changes in both the protein and the starch fraction, which, in turn, determine the microstructure of cooked pasta. LT drying does not induce protein denaturation and results in a weak protein network. Starch swelling during pasta cooking leads to disruption of the protein network. In contrast, thermal denaturation of proteins at low moisture conditions, as happens when high temperature is applied at a later stage, results in an extensively cross-linked protein phase that maintains its continuity during cooking. It is very likely that the preservation of the protein network in pasta dried at HT is also favored by rearrangements in the starch fraction that reduce swelling. They also stressed the fact that drying leads to moisture gradients within the product and it is conceivable that the extent of protein and starch transformation is different in the outer layer and in the core of pasta. They also stated that the structural and textural properties of HT drying cannot solely be explained based on the extent of protein denaturation and changes in the starch fraction are also responsible for the properties of cooked pasta. This is supported by the fact that pasta dried at 80°C presented lower stickiness depending on the application time of high temperature, although similar levels of gluten denaturation were measured.

CONCLUSIONS

Based on the results of our study where the effect of different drying programs (LT, MT, and HT) on the cooking quality of pasta were tested on semolinas with different gluten quantity and quality, and on previous evidence, we can agree that starch swelling capacity and strength and coherence of the protein network govern pasta cooking quality expressed as stickiness and firmness, with the protein network being more important in quantitative terms. All the factors that promote the formation of a strong and coherent gluten network from an early stage of drying such as high gluten content, strong gluten, and HT drying have a positive effect on pasta cooking quality. In strong gluten semolina, increasing gluten content at levels >12.5% dm produces small effects on pasta cooking quality irrespective of the drying cycle adopted. In other words, in strong gluten semolina at protein levels >12.5% dm, increasing drying temperature to >70°C does not produce noticeable improvements. So gluten quality can be an important criterion to determine how far to go with the increase in drying temperature if stickiness and firmness are to be controlled in cooked pasta.

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