Effect of Source and Proportion of Waxy Starches on Pasta Cooking Quality

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ABSTRACT

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Starches from the endosperm of three types of total-waxy cereals (bread wheat, maize, and barley) were used in reconstitution studies of durum wheat semolinas to investigate the effect of waxy starch on pasta cooking quality. The chemical composition and the pasting and gelatinization properties of the starches used in this study were evaluated to define the functional properties of each waxy starch. The rheological properties of dough semolinas were evaluated by small-scale mixograph. Spaghetti was prepared using a small-scale pasta extruder and its cooking quality was assessed using a texture analyzer. Cooked pasta firmness, resilience, and stickiness were measured. The substitution of semolina starch with waxy starches from different sources changed the functional properties of dough and their pasta quality. A decrease in firmness was detected in all the semolinas reconstituted with waxy starches. An increase in stickiness was found when semolinas with waxy starch from wheat were evaluated. No improvement in pasta quality should be expected if the waxy character is introduced in durum wheat.

Semolina from durum wheat (*Triticum turgidum* L. subsp. *turgidum* conv. *durum* (Desf.) MacKey) is considered the best material for making high quality pasta products. Protein content and composition have been considered the main factors affecting semolina dough properties and pasta cooking quality (Dexter and Matsuo 1977; D'Egidio et al 1990). Starch is the major component of semolina (≈70% by weight) and is composed of two types of polysaccharide molecules (amylose and amylopectin) normally in the ratio of ≈1:3 by weight. The composition of starch is controlled by comparatively few genes, and naturally occurring alleles of these genes exist in cereals, including the genus *Triticum*, leading to phenotypes with starches ranging from almost no amylose (the waxy starches) to very much higher than normal amylose content. The waxy character is caused by a mutation in the waxy locus that affects the production of amylose. Therefore, waxy mutants do not produce amylose and their starches are basically 100% amylopectin. Waxy mutants, lacking the functional waxy protein (granule-bound starch synthase), have been identified in several plants species (maize, rice, barley, and sorghum). Hexaploid waxy wheat (*T. aestivum*) has been developed by crossing partial waxy wheats (wheats with one or two nonfunctional waxy alleles) (Nakamura et al 1995; Yamamori et al 1995a) and this starch has been characterized (Yasui et al 1996; Kiribuchi-Otobe et al 1997). In tetraploid wheat, partial waxy wheats have been identified (Yamamori et al 1995b; Urbano et al 1996) and more recently two null combinations in durum wheat have been produced (Urbano et al 2002) and these will aid our understanding of the relationships between amylose content with semolina properties. The starch properties of partial and total waxy durum wheats have unique pasting properties (Grant et al 2001) and the addition of waxy durum flour to a bread flour at 20% reduced staling more effectively than the use of shortening, indicating a possible use for waxy durum wheat (Bhattacharya et al 2002).

Limited information is available on the effects of starch on pasta cooking quality. Reconstitution studies, involving separation, fractionation, and substitution of flour components, have been successfully used in bread wheat (*T. aestivum*) to analyze the effects of different components on breadmaking quality (MacRitchie 1985, 1987). More recently, Baik and Lee (2003) investigated the effects of amylose content on the textural properties of white salted noodles without the interference of protein by preparing reconstituted flours with waxy wheat starch. As the proportion of waxy wheat starch increased (amylose content varied 20.2–11.0%), there were increases in peak viscosity, decreases in peak temperature, and decreases in cooked noodle hardness. However, only a few attempts have been made regarding the use of reconstitution studies on durum wheat (Sheu et al 1967; Dexter and Matsuo 1979). Early studies using reconstitution where durum starch was substituted with waxy maize starch showed a positive correlation between pasta quality and starch amylose content (Dexter and Matsuo 1979). This technique has recently been optimized for durum semolina, offering the potential to evaluate the contribution of starch in a constant protein background (Sissons et al 2002). Recently, partial waxy durum wheats lines (*Wx-B1* null) were produced and found to reduce pasta cooking loss (Sharma et al 2002). A very recent report has shown the pasta quality of a full waxy durum wheat has shorter cooking time and reduced firmness compared with the nonwaxy (Vignaux et al 2003).

The purpose of this study was to describe the functional properties of partial and total waxy starches from different botanical sources and show their effect on the cooking quality of pasta derived from reconstituted semolina, where the original durum starch has been replaced with a waxy starch.

MATERIALS AND METHODS

Starch Sources

Three different types of waxy starch were used in this study: 1) maize waxy starch, kindly supplied by I. Brown from Starch Australasia Ltd (Lane Cove, NSW, Australia); 2) starch from waxy barley grains (cultivar Waxiro, CSIRO Plant Industry, Canberra, ACT, Australia); and 3) waxy wheat starch, from hexaploid grain kindly supplied by the Quality Wheat CRC, from a line developed by Zhao and Sharp (1998). A set of waxy starch mixtures was produced by blending starches from two wheat sources: a starch from durum wheat semolina (≈23% amylose content) and starch from waxy wheat flour (0% amylose). The blends were made covering an amylose content range of 0–23%.

Starch Isolation

To minimize alterations in starch properties, the following method was adopted to isolate starch from waxy wheat flour and durum wheat semolina. Hand-kneading of semolina and water was used to form dough with 55% water absorption. After a short resting period (at least 10 min), the dough was washed with distilled water, continuing with the kneading process until no visible starchy endosperm particles were found in the washing water. The gluten was then freeze-dried. The suspension was passed through a sieve (120 μm) and then centrifuged. The supernatant containing

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material soluble in water was decanted and also freeze-dried. Four fractions were obtained in this way: gluten, starch, water-soluble materials, and a residue that remained on the sieve after the suspension of starch and water-soluble materials was filtered. All fractions were freeze-dried and typical yield, protein, and moistures of these fractions have been reported previously (Sissons et al 2002). Starch from waxy barley was isolated according to Vasanthan and Bhatty (1995) with the addition, in the last wash, of 50% iso-propanol containing 2% β-mercaptoethanol for elimination of any residual protein present in the pellet.

Starch Chemical Analyses

Moisture was assayed by oven-drying a sample for 1 hr at 130°C according to Approved Method 44-16 (AACC 2000). Protein content (N × 5.7) was determined according to Approved Method 46-13. Starch ash was determined by Approved Method 08-01 at 550°C. Lipid content was determined after acid hydrolysis was done with 3*M* hydrochloric acid for 30 min in a water bath at 100°C. Samples were filtered and washed with deionized water until the filtrate was neutral. After drying at 65°C overnight, fat was extracted using a Soxhlet extraction apparatus. Amylose determination of the starch samples was made using SE-HPLC (size-exclusion high-performance liquid chromatography) based on the procedure described by Batey and Curtin (1996).

Starch Granule Size Distribution

The particle-size distribution of the starch slurries were determined using a laser diffraction particle-size analyzer (Mastersizer 2000, Malvern Instruments, Malvern UK) as A- and B-type granule content (% >10 µm or <10 µm, respectively). Size distribution was determined by volume and because it is reasonable to assume that all the granules have the same density, the volume should equate to mass.

Swelling Test

Swelling test was performed using 40 mg of starch, according to the method described by Konik-Rose et al (2001). This test measures the uptake of water during the gelatinization of the starch.

Pasting Properties

Starch pasting properties were analyzed on a Rapid Visco-Analyser (RVA, Newport Scientific Pty. Ltd., Warriewood, Australia) and working conditions were as reported by Batey et al (1997). Pasting viscosity of 3.00 g of starch from semolina and 2.50 g from waxy starches (in 25.0 mL of water) were analyzed using the RVA. The test took 20 min with a temperature profile as follows: hold at 50°C for 2 min, heat to 95°C at 7.5°/min in 6 min, hold at 95°C for 4 min, cool to 50°C at 11.25°/min in 4 min, and hold at 50°C for 4 min. The parameters measured were peak viscosity (the maximum hot paste viscosity), holding strength (the trough at the minimum hot paste viscosity), peak time, pasting temperature, and final viscosity (the viscosity at the end of the test after cooling to 50°C and holding at this temperature). All values were expressed in RVA units (RVU).

Thermal Properties

Thermal properties of starch samples were determined by differential scanning calorimetry (DSC) (DSC-Pyris 1, Perkin Elmer Corp. Norwalk, CT). Native starch slurry samples (1:2 starch-to-water ratio, sealed in stainless steel pans) were heated from 30 to 130°C at a heating rate of 10°C/min. An empty pan was used as the reference. Enthalpy (ΔH) was determined by measuring the area of the DSC endotherm curves. The temperature of the characteristic transitions at onset (T_o), peak (T_p), and completion (T_c) were recorded. Measurements on the amylose-lipid endotherm in the 90–120°C range were also measured.

TABLE I
Composition (%) of Waxy Starches from Different Botanical Sources and Semolina Starch

Starch Source	Protein	Ash	Lipids	Amylose
Semolina	0.4	0.15	1.0	22.9
Waxy maize	0.2	0.02	0.6	0.0
Waxy barley	0.3	0.22	0.8	1.8
Waxy wheat	0.5	0.15	0.9	0.0

Reconstitution Studies

Semolina reconstitution was conducted according to Sissons et al (2002). Substitution of semolina starch was made by replacing the starch with an equal amount of starch from each waxy mutant or composite starch from the mixed waxy and semolina starches. A constant amount of gluten, residue, and water-soluble fractions from durum wheat were used and mixed with waxy starches. A reconstituted sample using all durum wheat components was included as a control (ReSem).

Dough Mixing Properties

Mixing tests were conducted with a prototype 2-g mixograph (TMCO, Lincoln, NE) with water absorption calculated from the flour protein and moisture content (Approved Method 54-40A, AACC 2000). The resulting masses calculated for 35 g of flour were scaled to provide a constant 3.50 g of dough. Mixing was conducted in triplicate. Mixing parameters were determined using the software developed for the prototype 2-g mixograph (Rath et al 1990). Parameters determined included mixograph dough development time (MDDT), peak dough resistance (PR), and resistance breakdown (RBD). Resistance breakdown was calculated as the change in the value of the resistance 3 min after peak resistance, and expressed as a percentage (Bekes et al 1994).

Pasta Preparation and Cooking Quality

Semolina (25 g) was used for making pasta with a microscale extruder with addition of 30% water and dried using a low temperature (50°C) cycle (Sissons et al 2002; Sharma et al 2002). Cooking quality was evaluated with a suite of tests. The minimum cooking time (MCT, time for the white core in the middle of the strand to disappear when squashed between two microscope slides) was determined for each sample. The pasta was cooked to MCT, and the firmness and stickiness were measured using the TA.XT2 texture analyzer (Wood et al 2000). Cooking loss (CL%) was based on measuring the iodine binding materials lost into the boiling water during cooking (Matsuo et al 1992).

Statistical Analysis

S-Plus 2000 (MathSoft Inc. Data Analysis Products Division, Seattle, WA) was used for analysis of variance. LSD was calculated for each parameter and used to test for significance ($P < 0.05$) between samples.

RESULTS AND DISCUSSION

Effect of Botanical Source of Waxy Starch on Dough and Pasta-Making Quality

Starch properties. The chemical composition of the starches used in this study is summarized in Table I. The protein content of the starches is very low and varied from 0.2 to 0.5%. Variation in lipid content was observed among samples. Durum wheat semolina starch had the highest amylose content among the samples analyzed (22.9%, which is lower than those reported previously in durum wheat) (Vansteelandt and Delcour 1999). The waxy maize and wheat starches had no detectable amylose, while the waxy barley starch had a very small amount of amylose (1.8%). Small grain cereals such as barley and wheat have a bimodal distribution of starch granules, whereas most other plants have a unimodal distribution. In wheat, starch is deposited in two types of granules, small B-type granules (with an average of 3–5 µm diameter) and the larger A-type granules (with an average of 13–16 µm diameter) (Soulaka and Morrison 1985). In these two species, a range in the distribution of B- and A-type granules between genotypes has been observed (Stoddard 1999). In *Zea maize* (corn), only one type of starch granule is observed with a size similar to the wheat starch A-type granule. The size distribution of the starches used in the present study are represented in Fig. 1. Waxy wheat showed an increase in the % of starch granules with small diameter (higher % of B-type granules) compared with nonwaxy wheat starches (*unpublished data*). The surface-to-volume ratio of the B-type granules is higher and makes them more absorbent of water than the A-type granules and, therefore, an increase in the proportion of B-type granules can affect the volume of bread (Stoddard 1999). Waxy maize has a unimodal starch granule distribution (Fig. 1).

Pasting properties analyzed by the RVA test revealed differences between the semolina starch and waxy starches. An increase in peak viscosity was observed in the waxy starches compared with semolina starch (Table II). Waxy barley had the highest peak viscosity, followed by waxy maize and waxy wheat. Lower peak viscosity of waxy wheat compared with waxy maize starches has been observed before by Hayakawa et al (1997). In contrast to these results, lower peak viscosity was reported in waxy maize compared with waxy wheat (Kiribuchi-Otobe et al 1997; Yoo and Jane 2002). The reason for these differences is not well established but different experimental or environmental conditions or variation between cultivars may be responsible for these contradictory reports. As expected, all waxy starches had a higher peak viscosity, a lower holding strength, and lower final viscosity than the durum starch. Their pasting temperatures were lower than those of durum starch, and waxy wheat and waxy barley starch had lower pasting temperatures than waxy maize starch (Table II).

DSC of semolina starch showed two peaks, the first at ≈60°C and the second (smaller one) at ≈103°C. These are the gelatinization and lipid-amylose complex dissociation peaks, respectively. Clear differences were found in the thermal properties of semolina starch compared with the waxy starches. Semolina starch showed a sharp, narrow, well-defined gelatinization peak, whereas the waxy starches produced broader, flatter peaks. Waxy starches showed only one peak corresponding to gelatinization. The absence of the second peak is due to the lack of amylose, as there should be no amylose lipid complex present. Of the three waxy starches, the gelatinization temperatures from the waxy maize were highest (Table III).

Dough Mixing Properties

Changes in dough mixing properties were observed in the reconstituted semolinas with waxy starch (Table IV). A decrease in mixing time was observed in all the waxy reconstituted semolinas but only the reconstituted dough with waxy maize starch had significantly higher RBD, indicating a dough with less tolerance to overmixing. Graybosch et al (2003) found a decrease in quality estimated by a decrease in the SDS sedimentation test, in the mixograph peak times and the tolerance scores in hexaploid waxy lines. However, it was not possible to establish if this behavior was the result of the waxy character or a reflection of the poor gluten quality derived from the parental source of the waxy alleles. On the other hand, Grant et al (2004), working with durum lines, have reported an increase in mixing properties indicating a stronger dough when using waxy lines. Reconstitution experiments are unique in the sense that only one component is changed and therefore its effects are clearly evaluated. Our results showed that changes in the starch properties produced a reduction in mixing time and a weakening of the dough properties in all the waxy reconstituted semolinas, independent of the botanical source (Table IV). It has been reported that waxy starch endosperm is more friable and less resistant to mechanical work than starch endosperm of non-waxy wheat (Vignaux et al 2004); this characteristic could contribute to the decrease in the mixing time observed in all the waxy reconstituted semolinas. On the other hand, an increase in peak resistance was observed in the waxy

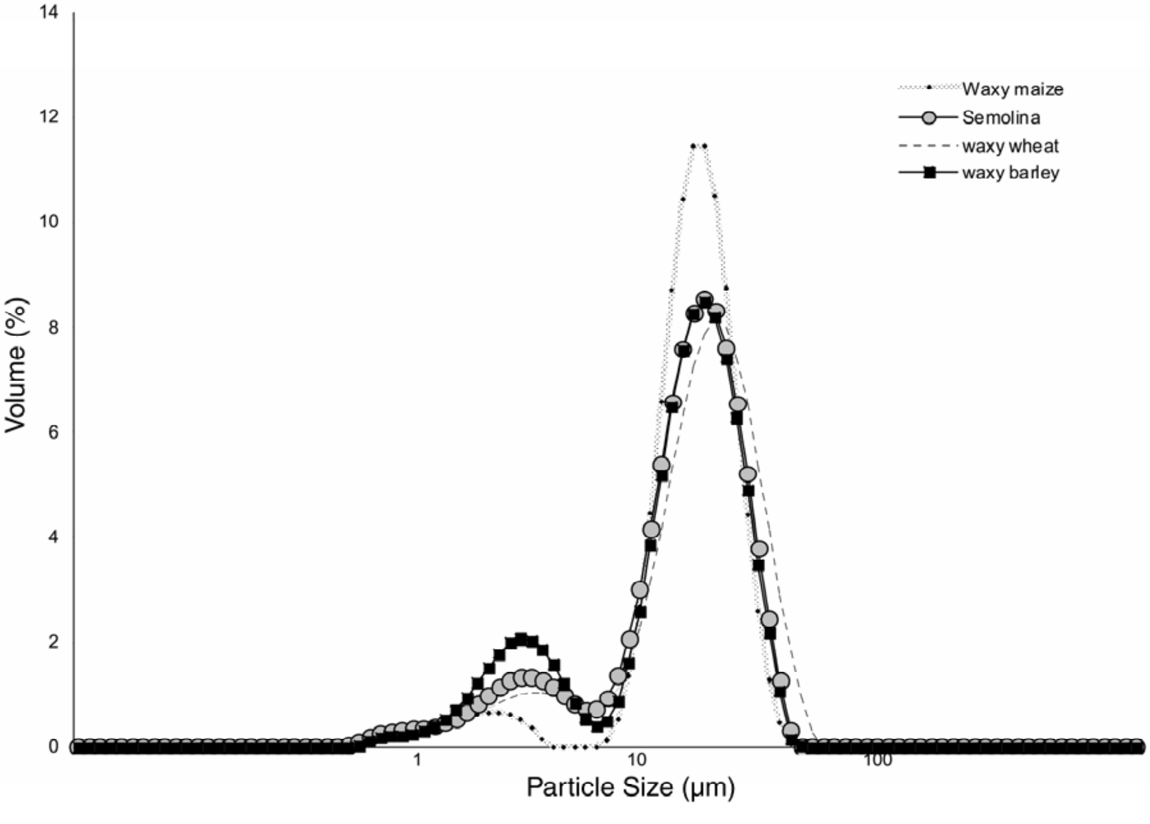

Fig. 1. Particle-size distribution of waxy starches from different botanical origins.

reconstituted semolinas. Peak resistance is mainly affected by protein content and water absorption of the flour or semolina (Finney and Shogren 1972). Since protein content in the reconstituted samples is the same (as in content and composition), we attributed the increases in peak resistance to the higher water absorption capacity of the waxy starches compared with the starch from semolina.

Pasta cooking quality. The cooking quality is considered the most important property in evaluating overall quality of spaghetti (pasta). Cooking quality depends on two main parameters: viscoelastic behavior (particularly firmness after cooking) and surface condition (extent of disintegration), which determines stickiness and degree of smoothness of the cooked product. These two aspects of pasta quality are relatively independent of each other (Autran et al 1986). The MCT of the waxy reconstituted samples was lower than that of the reconstituted semolina, especially the waxy wheat sample. Cooking time is affected by protein content and spaghetti diameter, but in this series of samples, there were no differences in these properties. MCT was lower for the waxy samples and lowest for waxy wheat starch. This confirms what has been reported in waxy durum wheat (Grant et al 2004). It is probably due to faster starch swelling and starch gelatinization.

Pasta made from the waxy reconstituted samples was less firm and released less material into the cooking water compared with the reconstituted durum sample (Table V). Softer pasta results from waxy granules being less tightly packed without amylose, and on swelling, having less resistance to rupture and deformation. Because most of the material lost in the cooking water is reported to be amylose (Lintas and D'Appolonia 1973), it is not surprising that starches with the waxy character, which are low in amylose, have a low cooking loss, a desirable attribute. In contrast, Grant et al (2004) found no change in cooking loss in waxy durum wheat compared with normal durum but used a gravimetric method of determining cooking loss, whereas in partial waxy durum wheats, a lower cooking loss (iodine method) was observed (Sharma et al 2002). Although a reduction in CL% is desirable, if this coincides with a reduction in firmness, the al dente quality will not be achieved and the pasta will be too soft. Only the pasta made with the waxy wheat starch absorbed significantly less water (128%) compared with the reconstituted semolina control (154%), giving it a lower cooked weight, a less desirable feature. This seems unexpected because waxy starches swell more and absorb more water, which might be expected to result in a pasta with a higher water absorption. A possible explanation is that the swollen waxy starch is softer and less able to exert the force necessary to extend the protein component of the matrix. Thus, the actual swelling of the pasta reflects more the strength of the protein than the swelling power of the starch. Pasta was stickier from the waxy wheat sample, an undesirable feature. These results show that waxy starch from three different sources, when substituted for the normal durum starch (≈23% amylose), produces pasta with inferior quality.

Effect of Waxy Wheat Starch Content on Pasta Cooking Quality

In this experiment, the durum starch was substituted with different amounts of waxy wheat starch to prepare a range of starches of 0–100% waxy wheat starch. The amylose value of this waxy set represents a range in amylose content (23–0%) not previously observed in commercial cultivars of bread or durum wheat (Miura and Tanii 1994; Vansteelandt and Delcour 1999; Araki et al 2000) and may allow a detailed analysis of how amylose content affects pasta quality.

Starch properties. The method used to measure amylose in this study (SE-HPLC) usually gives lower values than the iodine method. Lower values of amylose were observed for the semolina starch compared with those of the iodine method used previously by Gianibelli et al (1999). Amylose content of the mixtures of durum and waxy starch are shown in Table VI.

The swelling test measures the amount of water that the starch granules absorb when they are heated in excess water. This test has been recognized as a good indicator of Japanese noodle quality (Crosbie 1991). The decrease in the amylose content of the waxy set caused an increase in the swelling value (Table VI). Inverse relationships between these two parameters were reported earlier in hexaploid wheat (Crosbie et al 1992) and in waxy and partial waxy durum wheat (Grant et al 2001; Sharma et al 2002). The amylopectin fraction is responsible for swelling power because the lack of amylose results in a loosely bonded micellar structure (Tester and Morrison 1990). As the waxy starch content in the reconstituted semolina was increased, the amount of the amylose-lipid complex would gradually decrease. This complex acts as an inhibitor of starch swelling (Morrison et al 1993; Sasaki et al 2000). Waxy starch (100%) had the greatest swelling value among the mixed waxy and semolina starches. Cereal starch granules have a crystallite structure formed by crystalline and amorphous regions. Amylose is located mainly in the amorphous regions, reducing the access of water. In this way, amylose reduces the capacity of the starch granule to absorb water. In the waxy starch, there is almost no amylose and therefore less restriction in the transport of water through the starch granule, so it absorbs water

TABLE II
Rapid Visco-Analyser Parameters of Semolina Starch and Different Waxy Starches

Starch Source	Peak (RVU)	Holding Strength (RVU)	Final Viscosity (RVU)	Peak Time (min)	Pasting Temp (°C)
Semolina	186	169	278	10.9	91
Waxy Maize	256	103	135	6.1	71
Waxy Barley	265	103	139	6.1	61
Waxy Wheat	226	93	117	5.3	64
LSD[a]	8.6	5.2	4.4	0.3	0.4

[a] Least significant difference ($P < 0.05$).

TABLE III
Thermal Transition Temperatures (°C) and Enthalpy of Semolina Starch and Different Waxy Starches

Starch Source	Phase	Onset Temp (°C)	Peak Temp (°C)	End Temp (°C)	ΔH (J/g)
Semolina	Gelatinization	54.3	60.1	65.8	6.6
Semolina	Amylose-lipid complex	95.7	103.5	110.3	0.6
Waxy maize	Gelatinization	63.8	72.5	86.9	7.3
Waxy barley	Gelatinization	54.5	60.9	69.7	6.9
Waxy wheat	Gelatinization	54.4	63.5	77.9	5.6
LSD[a]		0.9	0.7	2.6	0.5

[a] Least significant difference ($P < 0.05$).

to its maximum capacity. Differences in the particle-size distribution of the starch granules were observed between the waxy wheat starch and the semolina starch (0% waxy). These differences were small (Table VI) with 35% of B-type granules for the waxy wheat and 33% for the semolina starch and are within the range of B-type granule values observed in Australian cultivars of hexaploid wheat (Stoddard 1999). The differences found in these samples were not considered large enough to affect the results of this experiment, which was to identify the effects of the amylose content on pasta properties.

An increase in the amylopectin (decrease in amylose) content of the starch leads to an increase in starch granule swelling, and this increased the peak viscosity of the paste but reduced final viscosity. Similar results have been observed in partial and waxy starch for cereals such as wheat, corn, and barley (Kiribuchi-Otobe et al 1997; Yamamori and Quynh 2000; Baik and Lee 2003). The time to reach peak viscosity and the pasting temperature was reduced as the amylose content of the flours decreased. For the 100% waxy starch, the starch granules swell rapidly and produce a peak in viscosity much sooner than the pure semolina starch (Table VII). Similar results have been observed in starches of hexaploid wheat (Hayakawa et al 1997; Kiribuchi-Otobe et al 1997; Baik and Lee 2003). On the other hand, the lowest final viscosity was observed in the 100% waxy starch flour and was attributed to the lack of amylose and a lower level of starch retrogradation upon cooling in the RVA. Amylose is needed to form a strong, continuous gel matrix, and waxy starches do not have the capacity to form this type of structure. The reduction in amylose content affects the reorganization of the starch structure and a clear decrease in the final viscosity is observed as the amylose content decreases.

Clear differences were found in the gelatinization behavior of starches of the waxy mixtures. Gelatinization temperature (onset, peak, and end) increased with the increase in the proportion of waxy starch (Table VIII). The temperature range of gelatinization (end minus onset) was also increased, reflecting the heterogeneity of the starch mixtures.

Pasta Quality

As the percentage of the waxy starch was increased in the reconstituted semolinas, there was a progressive decrease in pasta firmness, cooking loss, and pasta water absorption (cooked weight) and an increase in stickiness (Table IX). It was noted that the MCT also decreased with the decrease in amylose content (data not shown) for reasons similar to those described using waxy starches of different botanical origin. As the percentage of amylose was reduced in this set of starches, this led to a progressive increase in pasta stickiness. Amylose exuding from the starch granules during cooking is thought to be largely responsible for the stickiness of pasta (Grant et al 1993). A possible explanation for this apparent contradiction, and in the reduced firmness and water absorption, lies in the increased swelling described earlier. The highly swollen granules will be softer and more subject to rupture, thus decreasing pasta firmness. The rupture of these granules during cooking, perhaps as a result of the force exerted by the granules as they swell against the protein matrix, will also release absorbed water and reduce the total water absorption of the pasta. This also explains the increased stickiness; carbohydrate in the form of amylopectin or amylopectin fragments, not amylose, will also be released and contribute to the stickiness on the pasta surface. The anomaly in the cooking losses in waxy pasta measured by colorimetric and gravimetric methods is also explained by rupture of the starch granules in this way. Waxy granules contain little or no amylose, and amylopectin has a much lower absorption at the wavelength used (650 nm), so waxy pasta will have an apparent reduction in cooking loss when measured colorimetrically. Measured gravimetrically, the released amylopectin will contribute in full to the calculated cooking loss.

A decrease in the amount of material lost during cooking is desirable for good pasta quality, although, in this case, there may only be an apparent reduction. However, if any reduction in the cooking loss is associated with a reduction in firmness and an increase in stickiness, as we observed, the overall effect on the quality of the pasta is undesirable. Thus, waxy starch in durum wheat is undesirable for making traditional pasta because it produces pasta that is soft, swells poorly during cooking, and has greater stickiness. A 100% waxy wheat flour was unsuitable for making bread or noodles (Morita et al 2002; Baik and Lee 2003). Noodles produced from waxy wheat flour were sticky and very soft upon cooking. However, Baik et al (2003) found that flour from a partial waxy wheat with intermediate amylose content improved white salted noodle cooking quality. However, we did not observe any improvement in this set of starches incorporating waxy starch. Pasta quality is based on firmness, and having only 10% waxy wheat starch in the reconstituted mixture resulted in cooked pasta of lower firmness and water absorption, and higher

TABLE IV
Mixograph Parameters of Reconstituted Doughs Using Semolina Starch and Waxy Starches

Reconstituted Dough	Mixing Time (sec)	Peak Resistance (AU)[a]	Resistance Breakdown (%)
ReSem[b]	513	350	3
Starch waxy maize	292	433	8
Starch waxy barley	318	396	3
Starch waxy wheat	291	406	2
LSD[c]	33	12	1.6

[a] AU, arbitrary units.
[b] Reconstituted sample using all durum wheat components.
[c] Least significant difference ($P < 0.05$).

TABLE VI
Starch Properties of Mixed Semolina and Waxy Starches

Waxy Starch Content (%)	Swelling Test Value	Amylose Content (%)	B-Type Granules (%)
0	5.9	22.9	32.7
10	7.4	19.6	32.1
25	7.9	17.6	31.2
50	9.3	12.7	31.5
75	14.3	6.9	32.5
90	14.5	3.3	35.7
100	15.7	0.7	35.5
LSD[a]	0.8	1.2	2.7

[a] Least significant difference ($P < 0.05$).

TABLE V
Quality Parameters of Pasta from Reconstituted Doughs

Reconstituted Pasta	Min. Cooking Time (min)	Firmness (g)	Stickiness (g)	Water Absorption (%)	Cooking Loss (%)
ReSem[a]	14.5	622	30.3	154	6.1
Starch waxy maize	13.5	322	30.1	171	2.9
Starch waxy barley	12.3	429	32.7	152	3.1
Starch waxy wheat	9.2	317	36.3	128	2.9
LSD[b]	0.3	26	2.9	20	0.2

[a] Reconstituted sample using all durum wheat components.
[b] Least significant difference ($P < 0.05$).

TABLE VII
Rapid Visco-Analyser Parameters of Mixed Semolina and Waxy Starches

Waxy Starch Content (%)	Peak (RVU)	Holding Strength (RVU)	Final Viscosity (RVU)	Peak Time (min)	Pasting Temp (°C)
0	143	132	221	11.00	92
10	160	141	198	11.07	89
25	172	135	197	10.17	68
50	196	130	205	8.43	64
75	249	122	188	5.47	63
90	270	118	155	5.14	63
100	286	114	143	5.13	63
LSD[a]	8.8	3.5	12.1	0.28	0.7

[a] Least significant difference ($P < 0.05$).

TABLE VIII
Thermal Transition Temperatures and Enthalpy of Mixed Semolina and Waxy Starches for Gelatinization and Starch-Lipid Complex

Waxy Starch Content (%)	Onset Temp (°C)	Peak Temp (°C)	End Temp (°C)	Enthalpy ΔH (J/g)
Gelatinization				
0	56.0	61.7	67.0	4.1
10	56.0	62.1	68.2	3.9
25	56.2	62.2	69.9	4.0
50	56.2	62.3	71.7	4.1
75	56.4	64.1	72.4	3.9
90	56.8	64.8	72.8	3.9
100	57.5	65.2	73.6	4.3
LSD[a]	0.6	0.5	1.3	0.4
Amylose-lipid complex				
0	97.0	103.7	109.1	0.6
10	95.4	102.8	108.0	0.5
25	94.7	102.9	107.4	0.4
50	92.2	102.3	107.3	0.3
75	92.7	101.3	106.3	0.2
90	91.1	100.1	107.0	0.1
100	0.0	0.0	0.0	0.0
LSD[a]	1.9	0.8	1.9	0.04

[a] Least significant difference ($P < 0.05$).

TABLE IX
Quality Parameters of Pasta from Flours Reconstituted Using Mixed Semolina and Waxy Starches

Waxy Starch Content (%)	Stickiness (peak height)	Stickiness (area)	Firmness (peak height)	Firmness (area)	Cooking Loss (%)	Water Absorption (%)
0	20	11	595	738	5.5	156
10	27	10	526	598	4.8	134
25	32	15	482	535	4.7	147
50	37	20	569	529	3.9	125
75	38	17	380	345	3.4	123
90	41	22	438	360	3.0	128
100	36	22	335	270	3.0	127
LSD[a]	6.6	5.3	49	42	1.2	9.0

[a] Least significant difference ($P < 0.05$).

stickiness (peak height). White salted noodle quality is determined by softness, the reverse of firmness. Thus, it is not unexpected that we do not see any improvement in pasta quality.

CONCLUSIONS

The substitution of semolina starch with waxy starches with little or no amylose from wheat, maize, and barley changed the pasta quality of the reconstituted pastas. A decrease in firmness was detected with all waxy starches, independent of the botanical source. An increase in stickiness was found when pastas were made with various waxy wheat and durum starch mixtures were evaluated. Changes in the amylose content while maintaining protein content and composition constant, clearly affected pasta properties. Decreases in amylose content produced a deleterious effect on pasta quality even with as little as 10% waxy wheat starch. According to these results, no improvement in pasta quality should be expected if the waxy character (partial or double null allele) is introduced in durum wheat when traditional pasta is the sole use of the durum wheat. The effect of reduced amylose content on durum bread and couscous quality is yet to be determined.

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