Effect of Starch Granule Size Distribution and Elevated Amylose Content on Durum Dough Rheology and Spaghetti Cooking Quality

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ABSTRACT

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To obtain an indication of the effect of increasing the starch amylose content above normal levels (27–74%) and increasing the percentage of B-type starch granules (11–60%) on durum dough properties and the quality of the spaghetti derived from these doughs, the reconstitution approach was used. Reconstituted flours were prepared from a common Wollaroi gluten, solubles and tailings fraction combined with starches containing varying B-granule contents, or with starches from maize with varying amylose content. An increased B-granule content increased farinograph water absorption. Cooked spaghetti firmness was highest with B-type granules at 32–44% (volume percentage basis), which is ≈10–15% higher than normally found in durum starch. Increasing the amylose content in the starch caused the dough to be more extensible, increased spaghetti firmness, and decreased water absorption with optimum quality of amylose at 32–44%. The information indicates there would be benefit in producing durum wheats with slightly elevated B-granule and amylose contents.

Starch is the main carbohydrate in the endosperm of wheat grain. It is an important determinant of the textural and processing properties of many foods (Thomas and Atwell 1999). During grain development, starch is deposited in the endosperm as discrete semi-crystalline aggregates known as starch granules. Starch is composed of two types of polysaccharide molecules, amylose and amylopectin, that normally occur in a ratio of ≈1:3, by weight. In mature wheat grain, the starch is deposited in two types of granules, small B-type granules (average diameter of 3–5 μm) and larger A-type granules (average diameter of 13–16 μm) (Soulaka and Morrison 1985). Differences in starch granule size distributions have been identified within durum wheat cultivars and tetraploid species (Vansteelandt and Delcour 1998; Stoddard 1999). Wheat A- and B-type starch granules have different physical, chemical, and functional properties (Maningat and Seib 1997). These differences result in the two starch granule types being used differently in industrial food and nonfood applications. Starch has several roles in the breadmaking process, and starch granule size affects a range of properties (Sahlström et al 1998, 2003). A survey of studies looking at the effects of starch granule size on baking performance was summarized by Park et al (2005) and found to be contradictory. This is probably due to the differences between the experimental approaches used to prepare granule fractions and in the baking methods used by researchers. Soulaka and Morrison (1985) report an optimum proportion of B-type granules (25–35%, by weight) for breadmaking, beyond which loaf volume decreases. Using fractionated potato and sweet potato starches, Chen et al (2003) found that noodles made from small granule fractions (<20 μm) had better processibility for noodle making and were of higher quality than noodles made from large granule fractions. More recently, Park et al (2005), using granule fractions that were isolated from bread wheat flour, prepared reconstituted flours that contained different proportions of B-type granules (0–82%). In this study, as the proportion of small granules increased in the reconstituted flour, the bread made from these flours was softer but with an extended storage life. Little is known about the effect that variation in the starch granule distribution on the technological quality of durum wheat. In one study, Delcour et al (2000) used reconstitution to substitute durum starch with starch that was enriched with small or large starch granule populations (no information provided about their purity) and found no effect on pasta cooking quality. However, there is insufficient information to demonstrate the effect of variation in starch granule size on durum quality to provide breeders with direction on whether to develop durum genotypes with widely varying B-granule content for commercial applications.

Amylose accounts for ≈25% of total starch in starch granules, and durum wheat starches have slightly higher amylose than common wheat starches (Vansteelandt and Delcour 1998). The quality of white salted noodles is improved when amylopectin content is slightly elevated (Crosbie 1991; Wang and Seib 1996; Batey et al 1997; Martin et al 2004). In contrast, for pasta, lowering the amylose content to near zero results in a much softer and inferior pasta (Gianibelli et al 2005; Vignaux et al 2005). Little is known about the effect of increased amylose content above normal levels (≈24–28%) on pasta technological quality. Recent reports using high-amylose wheat flour (37% amylose) indicate that the substitution of up to 50% high-amylose flour in breadmaking provides an acceptable loaf with higher fiber content (Hung et al 2005), while use of 100% high-amylose flour produces inferior breadmaking quality (Morita et al 2002). In the absence of genetic material with either high-amylose or varying B-granule percentage in the starch, the reconstitution method provides an alternative approach. In this system, substitution of one component of a dough at a time while maintaining the remaining components, allows the evaluation of an increase in just the amylose content in the starch, while maintaining a constant gluten content and composition as used in other studies (Delcour et al 2000; Grassberger et al 2003; Uthayakumaran and Lukow 2003; Gianibelli et al 2005, Sissons et al 2005).

The objectives of this study were to investigate the influence of varying the ratio of A- to B-type starch granules and increasing the starch amylose content on durum dough rheology and pasta quality using the reconstitution method.

MATERIALS AND METHODS

B-Granule Starch

Starches were extracted through hand-washing (Sissons et al 2002) from a subset of a Vulcan × Kewell hexaploid wheat double-haploid population that varied in B-granule content (27–44%). This population was grown at Forbes, NSW, in 2001. Starch was also isolated from Wollaroi and two purified fractions of A- and B-granule starches isolated from commercial semolina (kindly provided by Ian Batey, Food Science Australia). The double-haploid

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starches were used to form samples with B-granule contents from 27 to 44.0%. Samples with lower B-granule contents were generated by combining starch from Wollaroi with a purified A-granule fraction, and a sample containing 59.7% B-granules was achieved by combining the double-haploid starch of 44% B-type granules with a purified B-granule fraction derived from semolina. The volume distribution of large and small starch granules was measured on each of these eight samples. Wollaroi was used as donor semolina to form bulks of gluten, solubles, and tailings. This bulk was combined with various starch samples to prepare the reconstituted flours as described previously (Sissons et al 2002).

Variable Amylose Starch

Normal maize starch (amylose ≈27%) and high-amylose maize starch (amylose ≈74%) were obtained from Penford Australia (Tamworth, Australia). These starches were combined to create samples with amylose percentages of 27.2 (normal maize), 34.7, 41.1, 55.2, and 74.1 (Hi-Maize). The Wollaroi semolina used in the B-granule study was also the source of the gluten, solubles, and tailings for reconstitution with the maize starches. A reconstituted control sample (ReSem) consisting of only Wollaroi components was also tested, this had an amylose content of 28.5%.

B-Granule Determination

B-granule content was determined using a slightly modified method as detailed in Stoddard (1999). The samples were evaluated using a laser diffraction particle size analyser (Malvern Mastersizer 2600C) and the flow-through module for particles in liquid with a 100-mm focus length lens. This provides information of 32 size bands with diameters of 1.9–188 μm, each representing a size class. Two 100-mg replicates of each starch sample were sonicated and vortexed in a microfuge tube and then added to the distilled water in the circulating system. Duplicate results were obtained from each replicate. The results obtained were volume percentages of material in each of the 32 bands. Mean values of the A- and B-granule contents were calculated. Some samples contained small amounts of large aggregated particles (>100 μm) and results were recalculated to exclude them. Particles of 10 μm are commonly used for discrimination of A- and B-type granules. Particles <9.8 μm were considered B-type granules and those >9.8 μm were considered A-type granules. All reference to % B-type granules throughout is on a volume percentage basis.

Amylose Determination

The amylose content of each sample was determined using the Megazyme amylose and amylopectin assay kit (AM/AMP 7/98). The average standard deviation obtained on the samples tested was 3.3%.

Rapid Visco Analyser (RVA)

Starch properties were tested using an RVA and data analyzed using Thermocline software (Newport Scientific Pty Ltd, Warriewood, Australia). Before analysis, all samples were corrected to 14% moisture content to eliminate the effect of variation in sample moisture which affects RVA results (Batey and Curtin 2000). The formulae used were

$$M_2 = (100–14) \times M_1 / (100 - W_1)$$

$$W_2 = 25 + (M_1 - M_2)$$

where M_1 = sample mass for material as recommended (i.e., 3 g), M_2 = corrected sample mass, W_1 = actual moisture content of sample, and W_2 = corrected water volume (mL).

Starch was added to ≈25 mL of distilled water in an aluminum canister. With constant stirring, the mixture was heated and cooled with the following temperature profile: hold at 50°C for 1 min, heat to 95°C for 8.5 min, hold at 95°C for 5 min, cool to 50°C in 7.7 min. RVA parameters were measured in RVU units.

Gelatinization Properties of B-Granule Samples

Differential scanning calorimetery (DSC) characterizes the process of starch gelatinization by measuring the temperature at which different stages of the process occur. Department of Primary Industries, Yanco, conducted the DSC testing (Randzio et al 2002) using a Mettler Toledo DSC 822e for all samples. Before testing, the samples were equilibrated overnight to obtain similar moisture content within the samples. Sample (3 mg) was placed into a hermetic DSC pan and 3 mg of water was added by syringe. The pan was then covered with a lid, crimped together with the pan to create a hermetic environment, and allowed to equilibrate overnight at room temperature. An empty pan and lid pressed together were used as a reference. During testing, each sample was cooled or heated to 25°C before slowly ramping up to 150°C at a rate of 5°C/min. A DSC heating or cooling curve was generated in this process. Gelatinization temperatures of onset (T_o), peak (T_p), completion (T_c) and enthalpy (ΔH) are obtained in the process.

Fractionation and Reconstitution

Semolina reconstitution was conducted according to Sissons et al (2002). Substitution of semolina starch was made by replacing the starch with the test starches prepared as described above. A constant amount of gluten, residue, and water-soluble fractions from the durum wheat cultivar Wollaroi were used and mixed with test starches. The gluten and residue fractions contain a small amount of starch. A reconstituted sample using all durum wheat components was included as a control (ReSem). A summary of the prepared reconstituted flours is shown in Table I.

Chemical Analyses

Moisture was determined by drying a sample for 1 hr at 130°C according to Approved Method 44–16 (AACC International 2000). Protein content was determined by nitrogen combustion using an NC soil analyser (Flash 1112 series EA) using Approved Method 46–30.

Dough Mixing Properties

A 10-g farinograph (Brabender Farinograph-E) was used according to Approved Method 54–21 (AACC International 2000) to determine the water absorption of the flour. Each of the farino-

TABLE I
Preparation of Reconstituted Samples

Sample[a]	%B-Granule or Amylose Content	Amount of Component Needed to Form 100 g of Reconstituted Sample: Starch (g)	Bulk Fraction[b] (g)	Water (g)
Semolina	22.7	–	–	–
1	11.4	59.4	33.7	6.8
2	17.0	58.1	33.6	8.4
3	22.7	56.8	33.4	9.8
4	27.0	56.4	33.5	10.1
5	32.4	57.2	33.4	9.4
6	40.1	56.4	33.3	10.3
7	44.0	56.1	33.6	10.3
8	59.7	59.0	33.6	7.3
9 (ReSem)	28.5	56.8	33.4	9.8
10	27.2	62.2	32.8	5.0
11	34.7	62.7	32.7	4.6
12	41.1	62.7	32.7	4.6
13	55.2	63.2	32.6	4.2
14	74.1	63.2	32.6	4.2

[a] Samples 1–8 contain starch from durum and common wheat with varying %B-granules. Sample 9 is the ReSem control for the amylose study consisting of only durum components. Samples 10–14 contain maize starch with varying amylose content.

[b] Bulk fraction refers to gluten, soluble components (albumin, globulins, water-extractable pentosans) and tailings fraction isolated from Wollaroi semolina (Sissons et al 2002).

graphs was run for 20 min. Two to three replicates were used to achieve farinograms that had a maximum resistance centered on the 500-BU line. A 10-g mixograph (National Manufacturing, Division of TMCO, Lincoln, NE) was used to determine the mixing properties of each sample according to Approved Method 54–40A (AACC International 2000). All samples were corrected for moisture content to generate a constant dough mass of 17 g using the optimum farinograph water absorption obtained from the original semolina. Each mixograph was run for 10 min with two replicates per sample with the mean value provided. Mixing parameters such as peak time (MPT), peak height, width at peak, and width 3 min after peak were read from manual mixograph traces. The dough resistance to breakdown (RBD) was also calculated as % RBD = [(width at peak – width 3 min after peak)/width at peak] × 100.

A Kieffer rig and a TA.XT2 texture analyzer (Stable Micro Systems, Godalming, UK) were used to measure the extensibility of the dough adapted from Smewing (1997). Semolina (20 g) and NaCl (0.4 g) were mixed with distilled water (adjusted to optimum farinograph water absorption) at 30°C in a 50-g farinograph bowl for 5 min. After mixing, the dough was allowed to rest for 20 min in an airtight container. The dough was then pressed into a Teflon mold and allowed to relax for 40 min in a humidified chamber at 30°C. Ten dough strips per sample were tested using a Kieffer dough and gluten extensibility rig (A/KIE) on the TA.XT2 texture analyzer with a hook speed of 3.3 mm/sec. The texture analyser produces two measurements: force and distance. The average of 10 replicate measurements per sample was calculated. Maximal extensigraph dough resistance (*R*max) is the maximum resistance achieved before the dough breaks. Distance, refers to the extensibility (Exten) of the dough before rupture. The force correlates well with the 300-g extensigraph *R*max measurement on durum doughs (Soh et al 2003).

Pasta Preparation and Cooking Quality

Semolina (25 g) was used for making pasta using a micro-scale extruder with addition of 30% of water and dried using a low temperature (50°C) cycle (Sharma et al 2002; Sissons et al 2002). Cooking quality was evaluated with a suite of tests. The optimum cooking time (OCT) is the time taken for the white core in the middle of the strand to disappear when squashed between two slides). Pasta was cooked to OCT and the firmness and stickiness were measured as described previously (Wood et al 2001). Testing was done in triplicate, cooking each set of five strands of pasta separately. Cooking loss (CL%) was based on measuring the iodine binding materials lost into the boiling water during cooking (Matsuo et al 1992). After cooking, the pasta was blotted dry and weighed immediately to obtain a measurement of water uptake [% water uptake = {(cooked pasta weight – original dried pasta weight) / dried pasta weight} × 100.]

Statistical Analysis

S-Plus 2000 (MathSoft, Data Analysis Productsn, 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 Variation in % B-Granules in Starch on Technological Properties of Reconstituted Durum Flours

Properties of the starches. The B-granule starches contained <1% protein and the amylose contents were 25.1–28.9%. The amylose content was generally higher in samples with lower B-granule contents. Some studies reported A-type granules have a 4–10% higher amylose content than the B-type granules (Peng et al 1999; Bertonlini et al 2003; Shinde et al 2003), while others have found only minor differences (1–2%) in amylose content (Ames et al 1999; Yun et al 2000) and this may reflect different botanical sources and methods to measure amylose. Our data supports the latter studies, although the sample size is small.

The semolina sample has higher viscosity than the starches due to the presence of gluten and other flour components (Table II). As the percentage of B-type granules in the starch increased, peak viscosity and trough decreased with a tendency for final viscosity to decrease. A possible explanation is that B-type granules absorb water more rapidly and swell more than A-type granules (Chiotelli and Le Meste 2002). This may be due to higher surface area to volume ratio, and also the presence of more amorphous regions more accessible to water in the less crystallized arrangement in B-type granules. Therefore, a high percentage of B-type granules in the starch might be expected to prevent complete starch swelling by restricting complete swelling of A-type granules due to competition for water by the B-type granules and result in a reduced peak viscosity and breakdown. Setback reflects the reassociation of the starch molecules, especially amylose, and there was no obvious trend in this data. It has been reported that A-type granules have higher swelling ability and occupy a greater volume when swollen (Shinde et al 2003) and this would cause an increase in peak viscosity as B-granule content decreased. For the starch sample containing the highest B-granule content (59.7%), a reduction in breakdown occurred compared with the other samples.

Gelatinization onset (T_o) increased steadily from 52 to 56.7°C with increasing B-type granules up to 44% with similar trends for T_p and T_c (Table III). These results are consistent with reports of higher gelatinization temperatures for B-type granules compared with A-type granules (Kulp 1973; Peng et al 1999; Chiotelli and Le Meste 2002). However, in other reports, either no change or a lower T_o for B-type granules has been reported (Eliasson and Karlsson 1983; Soulaka and Morrison 1985). There were no differences in gelatinization enthalpy with changing granule composition, consistent with Stevens and Elton (1971), who found similar gelatinization enthalpies of wheat starch granules of different size

TABLE II
Rapid Visco Analyser Measurements (RVU) of Semolina and Starches with Varying B-Granule Content

%B-Granule Content of Starches	Peak Viscosity	Trough	Breakdown	Final Viscosity	Setback
Semolina (22.7)	326	216	110	418	202
11.4	218	183	35	269	86
17.0	203	171	31	248	76
22.7	195	145	50	232	87
27.0	188	156	32	241	86
32.4	167	130	36	222	92
40.1	177	139	38	233	94
44.0	175	138	38	239	101
59.7	151	128	23	201	73
LSD	2.3	2.3	1.1	2.0	1.6

TABLE III
Differential Scanning Calorimetry (DSC) Measurements, Onset (T_o), Peak (T_p), and Completion Temperatures (T_c) and Gelatinization Enthalpies (ΔH) of Isolated Starches with Varying B-Granule Content

%B-Granule Content of Starches	T_o (°C)	T_p (°C)	T_c (°C)	ΔH (J/g)
11.4	52.0	58.9	65.5	–6.2
17.0	53.0	60.2	67.0	–6.7
22.7	54.8	61.8	68.2	–7.1
27.0	55.7	61.2	67.3	–6.9
32.4	55.3	61.0	67.2	–6.9
40.1	56.7	61.4	66.9	–5.9
44.0	56.4	61.6	67.8	–7.4
59.7	52.9	60.7	68.0	–6.3
LSD	0.7	0.5	0.5	1.1

classes. However, a decrease in enthalpy was obtained at 40.1% B-type granules. Others have found that the gelatinization enthalpy of B-type granules is lower than that of the A-type granules, probably because there is a reduction in the ordered arrangement or lower stability in crystalline regions in small granules (Eliasson and Karlsson 1983; Soulaka and Morrison 1985; Peng et al 1999).

Dough Properties of Reconstituted Samples

These starches were reconstituted with Wollaroi gluten, tailings, and soluble fraction to achieve a relatively constant protein content of 17.55 ± 0.44% (mean ± SD), which was higher than the original Wollaroi semolina (15.20%). The appropriate control sample is the ReSem, which is reconstituted using the Wollaroi starch with 22.7% B-type granules present with a water absorption of ≈66%. Generally, farinograph water absorption increased with increasing B-granule content up to 32.4%, above which there was no further change (Fig. 1) except for a higher absorption in the 11.4% B-granule sample. B-type granules have a higher surface to volume ratio and are able to hydrate and swell more efficiently and bind more water than A-type granules (Vasanthan and Bhatty 1996; Chiotelli and Le Meste 2002); therefore increased B-granule content should increase flour water absorption as observed by others (Kulp 1973; Stoddard 1999; Yun et al 2000; Chiotelli and Le Meste 2002).

Mixograph analysis of the reconstituted samples indicated no significant differences in peak time and resistance breakdown and was not sufficiently discriminating (data not shown). However, the micro-extensigraph test on the dough was more informative. The *R*max increased with up to 32% B-type granules, followed by a decrease at higher B-granule levels (Table IV). There were no significant changes in extensibility. Due to an error in water addition, no results could be obtained for the first two samples (11.4 and 17%). Sebecic and Sebecic (1995, 1999) studied the influence of wheat starch granule size on the rheological properties of flour-water dough using an extensigraph and farinograph. They found that small to intermediate size granules (6.5–19.5 μm) significantly increased the extensibility of the dough and decreased resistance to extension. It is not possible to draw a definite conclusion from Sebecic and Sebecic (1995, 1999) as no clear indication of the %B-granule content was reported before the reduction in resistance was observed. The data in Table IV do not support this, except at the highest B-granule level (59.7%) where *R*max was reduced compared with the ReSem. An increase in the %B-granules, which absorb more water, might be expected to limit the amount of water available for gluten formation as more of the water will be bound by the starch resulting in an increase in dough stiffness. Sebecic and Sebecic (1999) reported that the starch fraction of very small granules (5–16 μm) causes dough weakening as measured by farinograph. However, Park et al (2005) proposed that more small granules could interact more intimately as filler particles with the continuous gluten phase in dough, which causes a corresponding increase in resistance to mixing. It could be speculated that too many B-type granules causes a high demand for water by the starch, creating an imbalance of water distribution in the dough, resulting in a weaker dough.

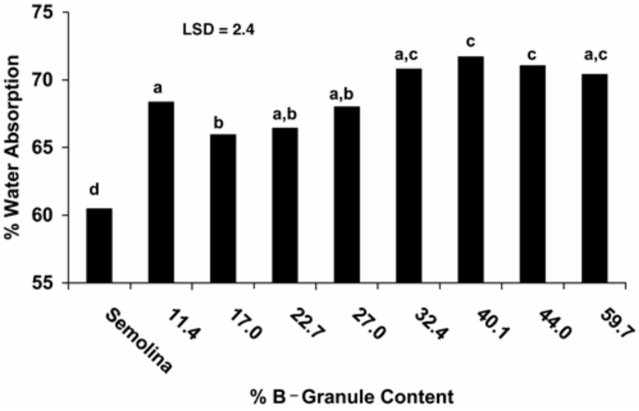

Fig. 1. Farinograph water absorption of semolina and reconstituted samples containing varying B-granule content. Bars with same letters are not significantly different ($P < 0.05$).

Pasta Quality of Reconstituted Samples

Spaghetti was made from each of the reconstituted starch samples and subjected to texture testing to measure firmness, stickiness, and resilience (Table V). The ReSem sample can be used as control. At the lowest level of %B-granules compared with ReSem, there were no differences in pasta quality except for a higher water absorption for the 11.4 %B-granules. Cooked pasta firmness was similar for samples with 11.4–27% B-granules. However, an increase in firmness was observed in samples containing 32.4 and 40% B-type granules, which then decreased at the higher B-granule levels but was still higher than ReSem and samples with <27% B-type granules. A similar trend was observed for resilience with the most resilient pasta coming from the 32 and 40% B-granule samples. At higher B-granule contents (>40%), pasta resilience decreased significantly, yielding very poor values that indicated the pasta does not recover well from an initial compression.

There were few differences in pasta stickiness, except that B-granule samples with 32.4 and 44% had the lowest stickiness. There were no obvious trends in pasta water uptake, although the 11.4% sample had the highest water uptake. There was no significant change in cooking loss until %B-granules was >27%, declining to 4.6–4.7% and not falling with further increases in %B-type granules (Table V). Smaller granules have a greater surface area, so increasing the percentage of these might be expected to extend

TABLE IV
Micro-Extensigraph Measurements Obtained Using Kieffer Rig and TA.XT2 Texture Analyzer on Reconstituted Samples with Varying B-Granule Content

%B-Granule Content	*R*max (AU)	Extensibility (mm)	Protein (%)
11.4	i.s.[a]	–	16.8
17.0	–	–	17.7
22.7[b]	115	39.2	17.4
27.0	117	34.1	17.5
32.4	129	30.1	17.6
40.1	114	32.9	18.1
44.0	110	31.5	18.1
59.7	78	40.4	17.2
LSD	2	15.4	–

[a] Insufficient sample.
[b] ReSem control sample.

TABLE V
Pasta Cooking Quality of Reconstituted Samples with Varying B-Granule Content

%B-Granule Content	Firmness (g)	Resilience	Stickiness (g)	% PWU[a]	%CL[b]
11.4	494	0.26	14.1	173	5.3
17.0	505	0.20	15.3	164	5.2
22.7[c]	488	0.25	14.7	163	5.2
27.0	485	0.23	14.6	167	5.0
32.4	716	0.32	13.6	166	4.6
40.1	746	0.38	13.4	168	4.7
44.0	645	0.11	13.4	162	4.7
59.7	557	0.07	14.8	159	4.7
LSD	33	0.09	1.3	4	0.1

[a] Pasta water uptake.
[b] Cooking loss.
[c] ReSem control sample.

the interactions between the starch granules and gluten and this may decrease the loss of amylose, reducing cooking loss (Vasanthan and Bhatty 1996). This might also explain a reduced stickiness in some of the samples because both measurements are a reflection of the leaching of amylose from starch granules. Delcour et al (2000), used the reconstitution method, substituting starch with enriched small and large starch granule fractions and found no effect on pasta viscoelasticity. In that study, the purity of the enriched preparations was not specified. More recently, Chen et al (2003) using potato starches, found that noodles containing more small granules have firmer cutting properties, consistent with the results presented here. While there are no studies in pasta, other research has indicated an optimum large-to-small granule ratio of 7:3 (w/w) wheat starch granules for breadbaking using reconstitution (Park et al 2005). A higher proportion of smaller granules in the starch of wheat flour maintained a softer bread crumb grain during storage. In summary, variation in the A-to-B-granule ratio affects dough water absorption, strength, and pasta quality. Improved pasta quality was obtained with a %B-granule content of 32–44%, which is higher than the normal %B-granule content in cultivated durum wheat.

Effect of Elevated Amylose Content in Starch on Durum Technological Quality

The effect of lowering the amylose content below the normal range (22–27%) on durum quality has been examined using two approaches, reconstitution (Gianibelli et al 2005) and the development of genetic lines lacking one or both Wx loci (Sharma et al 2002; Grant et al 2004; Vignaux et al 2005). This research showed that spaghetti made from durum wheat with almost no amylose in the starch produced pasta with quality inferior to that of normal durum wheat. The question of whether increasing the amount of amylose in the starch can improve pasta quality and nutrition, especially resistant starch, is of great interest to pasta processors. This study has some limitations and assumptions. First the use of the reconstitution technique increases the dough strength (*R*max and Exten) of the reconstituted sample compared with the unrecosntituted sample (Sissons et al 2002). Second, the maize starch used as a source of high-amylose may not interact with the durum gluten in the same manner as durum starch.

Starch Properties of Amylose Samples

The starches used for the study had an amylose content range of 27.2–74.1% with protein contents of ≈0.5%. Each of the maize and Wollaroi durum starches were examined by RVA. Wollaroi starch had different viscosity from the maize starch of similar amylose content (Table VI). In general, as amylose content increased, all the RVA parameters decreased. Similar results were reported for high-amylose (37.5%) wheat flour (Hung et al 2005). High-amylose starches do not gelatinize fully at the maximum temperatures (<95°C) in which RVA is performed (Tam et al 2004). Therefore, very low pasting viscosity profiles were obtained for the 55 and 74% amylose samples (Table VI). Without gelatinization, the amylose molecules are not released and can not participate in the retrogradation process; therefore virtually no setback was observed in those samples. Gelatinization refers to the thermal disordering of crystalline structures in the starch granules (Tester and Morrison 1990). Amylopectin defines the crystallinity of starch which raises the gelatinization temperature and endothermic enthalpy of starch (Grant et al 2001). With a reduction in amylopectin content, there are more amorphous and fewer crystalline regions within the starch granules, therefore a decrease in the gelatinization temperature and enthalpy may be expected. Indeed, the enthalpy change decreased with increasing amylose content in these starches (Table VII), but the changes in gelatinization temperature were minimal. In contrast, the gelatinization temperatures of high-amylose maize starches have been reported to be higher than normal and waxy maize starches (Casey et al 1997), whereas Morita et al (2002) report lower gelatinization temperatures for high-amylose wheat dough compared with normal wheat dough. No data was obtained at 74% amylose content because no gelatinization occurred at the DSC temperature (≈95°C).

Dough Properties of High-Amylose Reconstituted Flours

The farinograph water absorption measured on the reconstituted Wollaroi sample was lower than the reconstituted sample of similar amylose content consisting of maize starch (Fig. 2). Increasing the amylose content of the samples resulted in an almost linear increase in farinograph water absorption going from ≈66% to a very high 80% (Fig. 2). Morita et al (2002) also reported significantly higher water absorption in high-amylose wheat flour and attributed the increase in water absorption to the higher dietary fiber content of their starch. In another study, as the proportion of high-amylose wheat flour was increased in the dough, farinograph water absorption increased but dough stability and development time decreased (Hung et al 2005). In our study, the results for mixograph and micro-extensigraph testing were less clear. The ReSem sample had higher MPT, *R*max, and extensibility than the maize reconstituted samples (Table VIII). There was a tendency for MPT and RBD to decrease as amylose content increased. The dough *R*max was unchanged except at 74% amylose where it was significantly higher and RBD was lowest, indicating a stronger dough. The observed dough strengthening in sample E here can not be explained. However, dough extensibility showed a progressive and significant decrease with increase in amylose, consistent with a reduced dough elasticity reported in high-amylose wheat flour (Hung et al 2005).

TABLE VII
Differential Scanning Calorimetry (DSC), Onset (T_o), Peak (T_p), and Completion Temperatures (T_c) and Gelatinization Enthalpies (ΔH) of Isolated Starches with Varying Amylose Content

Starch Sample	% Amylose	T_o (°C)	T_p (°C)	T_c (°C)	ΔH (J/g)
A	27.2	65.9	70.6	76.3	–10.3
B	34.7	65.8	70.6	75.1	–7.8
C	41.1	65.9	70.4	75.4	–5.9
D	55.2	66.2	70.4	75.4	–2.2
E	74.1[a]	–	–	–	–
LSD		0.2	0.3	0.5	1.9

[a] No data was obtained at 74% amylose content because no gelatinization occurred at DSC temperature (≈95°C).

TABLE VI
Rapid Visco Analyser Measurements (RVU) of Maize Starches (A–E) and Durum Starch (Wollaroi) with Varying Amylose Content

Starch Sample	% Amylose	Peak Viscosity	Trough	Breakdown	Final Viscosity	Setback
A	27.2	198	112	86	183	71
B	34.7	116	83	32	108	25
C	41.1	104	79	25	98	19
D	55.2	9	6	3	8	2
E	74.1	–2	–3	1	–3	1
Wollaroi	28.5	194	147	47	231	84
LSD		0.6	1.3	1.3	2.6	3.7

TABLE VIII
Mixograph and Micro-Extensigraph Measurements of Reconstituted Samples with Varying Amylose Contents

			Mixograph		Kieffer Rig	
Reconstituted Sample	Amylose (%)	Protein (%)	MPT (min)	RBD (%)	*R*max (g)	Extensibility (mm)
ReSem	28.5	17.4	6.8	9.3	114.7	39.2
A	27.2	15.9	4.9	31.9	89.1	33.0
B	34.7	15.6	4.8	25.7	77.8	28.9
C	41.1	15.4	3.7	22.1	86.3	27.5
D	55.2	16.4	2.9	20.4	87.2	21.9
E	74.1	15.8	3.4	7.9	97.8	19.8
LSD			1.0	15.0	6.9	2.7

TABLE IX
Pasta Quality of Reconstituted Samples with Varying Amylose Contents

Reconstituted Sample	%Amylose	Firmness (g)	Resilience	% Water Uptake	% Cooking Loss
ReSem	28.5	426	0.48	nd[a]	nd
A	27.2	337	0.20	188	5.1
B	34.7	366	0.07	169	5.2
C	41.1	377	0.0	151	5.5
D	55.2	398	0.0	142	5.8
E	74.1	377	0.0	131	5.7
LSD		48.1	0.1	7.5	0.2

[a] Not determined.

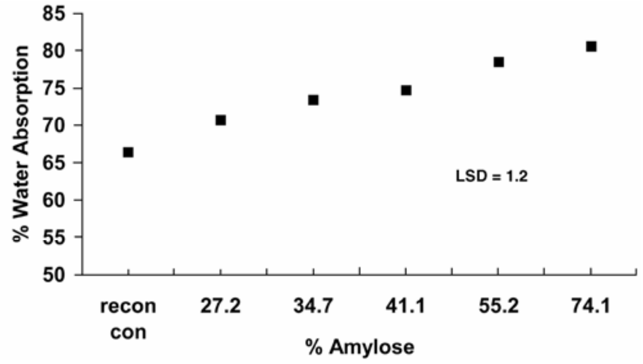

Fig. 2. Farinograph water absorption of reconstituted samples with varying amylose contents. Reconstituted samples prepared from only Wollaroi components: recon con.

Pasta Quality of High-Amylose Reconstituted Flours

Although pasta was prepared from doughs corrected to the same water absorption, dough consistency varied in appearance. The higher amylose samples had drier doughs and did not form coffee-bean-size crumbs, probably due to their higher water absorption. The ReSem prepared from all Wollaroi components was firmer and had higher resilience than the samples with maize starch (Table IX) reported previously (Gianibelli et al 2000). There was a tendency for firmness to increase as amylose content increased, but only the 55% amylose sample was significantly higher in firmness. In support of these findings, Dexter and Matsuo (1979) used blends of semolina starch and amylomaize-7 starch (a high-amylose starch, ≈52%) and found the cooked pasta became firmer as the proportion of amylomaize starch was increased. In contrast, decreasing the amylose below normal levels causes a decrease in pasta firmness (Gianibelli et al 2005; Vignaux et al 2005). In high-amylose starches, the granules are more tightly packed and, on swelling, have more resistance to rupture and deformation. This might explain the increased tendency to produce firmer pasta. Samples had very low or no resilience, which means there was no second peak during the compression test as the pasta was very soft and did not resist the initial compression well.

There were no significant changes in pasta stickiness (data not shown) with increasing amylose, which contrasts to the increase in stickiness when amylose content is lower than the normal levels (Gianibelli et al 2005). Pasta water uptake decreased and cooking loss increased with elevation of amylose content (Table IX). The ability of amylose to restrict swelling probably contributed to this drop in water uptake. This could affect the mouthfeel of the pasta and provide a unique consistency of unknown desirability. The increase in cooking loss is probably a result of an increased availability of amylose to leach during cooking.

CONCLUSIONS

The results obtained in this study show that variation in the starch granule distribution and amylose content while maintaining protein content and composition the same, affects pasta quality. An increase in the B-granule content increased farinograph water absorption. A significant increase in pasta firmness and a slight reduction in stickiness, reflecting improved pasta quality, was also observed with an increase in B-granule content, with an optimum at ≈32–44% B-type granules. This is ≈10–15% higher than normally found in durum starch. Increasing the amylose content in the starch caused the dough to be more extensible, increased cooked pasta firmness, and decreased pasta water uptake. The latter might alter the sensory perception of the pasta in an undesirable way. Based on the results of this study using maize starches, the optimum amylose content for improved pasta quality is 32–44%. Further studies are needed to confirm these results using durum wheat starch of variable amylose content. This suggests that developing durum wheat with slightly enhanced amylose content and the %B-granules would provide new starch types with potential food applications.

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