Effect of Starch on Pasta Dough Rheology and Spaghetti Cooking Quality[1]

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ABSTRACT

A collection of cereals comprising seven wheats, four barleys, three corns, rye, triticale, oats, and buckwheat served as a source of starches to investigate the effect of starch properties on pasta dough rheology and spaghetti cooking quality. The diverse nature of the starches was reflected by significant differences in their water absorption, amylose contents, microscopic structure, and amylograph pasting properties. A wide range in mixing properties was obtained for starch and gluten blends when absorption was held constant at 36% (14% moisture basis). These differences appeared to be mainly attributable to variations in starch water absorptions. Waxy maize and waxy barley starches were detrimental to spaghetti cooking quality, but high-amylose corn starch appeared to impart a slight improvement in cooked spaghetti firmness. Assessment of the cooking quality of starches with more normal amylose content suggested that other starch properties may supersede amylose content as a spaghetti cooking quality criterion once a threshold level of amylose is attained.

Protein content (Dexter and Matsuo 1977b, Matsuo et al 1972, Matweef 1967) and gluten properties (Dexter and Matsuo 1977a, 1978a; Matsuo and Irvine 1970; Sheu et al 1967; Walsh and Gilles 1971) have been shown to be the main factors contributing to pasta cooking quality and pasta dough rheology. The amount of information currently available on the role of starch in determining pasta quality is very limited, although it has been shown that interchange of starch isolated from a durum wheat and a hard red spring wheat had little effect on cooking quality (Sheu et al 1967). Starch is the major component of semolina, and firmness in cooked spaghetti must, in part, be influenced by gelatinized starch properties. Accordingly, this investigation was undertaken to study the effect on spaghetti cooking quality of some starches isolated from various cereals in relation to their physiochemical properties. In addition, the effect of the starches on pasta dough farinograph mixing properties was also investigated.

MATERIALS AND METHODS

Starch Source

An assortment of Canadian cereals and two commercial corn starches served as a starch source. The samples are listed below:

1. Seven wheat samples:
   a. An amber durum wheat semolina milled from a 1 CWAD composite in an Allis-Chalmers laboratory mill (Dexter and Matsuo 1978b).
   b. Two amber durum cultivars, Wakooma and Stewart 63.
   c. A hard red spring composite.
   d. An Alberta red winter composite.
   e. A soft white spring composite.
   f. An Eastern soft white winter composite.
2. A rye composite.
3. A hexaploid triticale cultivar, Welsh.
4. Four barley samples:
   a. A six-row barley cultivar, Bonanza.
   b. Two near isogenic lines of Manchuria 6-row barley, one with waxy character.
   c. A two-row barley composite.
5. An oat composite.
6. Three maize samples:
   a. An Eastern yellow corn composite.
   b. Commercial waxy maize starch (Corn Products).
   c. Commercial amylomaize-7 starch (American Maize Products).
7. A buckwheat composite.

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Preparation of Starch and Gluten from Semolina

Gluten was prepared from the semolina on three occasions by the method of Doguchi and Hlynka (1967). Each gluten was freeze-dried and humidified to about 12% moisture prior to use. The protein content (N × 5.7) of the isolated glutens, as determined by the modified micro-Kjeldahl method of Mitcheson and Stowell (1970), varied from about 65 to 75% on an as-is moisture basis.

Some of the starch and wash water remaining after gluten preparation was retained as a source of starch. The starch water slurry was poured through a fine cloth sieve, centrifuged (2,500 × g), and the supernatant discarded. The surface layer of tailings was removed and the prime starch remaining was freeze-dried and sieved through a U.S. 40 sieve. To minimize starch damage during rehydration (Williams and Hlynka 1968), the starch was humidified to about 11% moisture prior to use in reconstitution studies.

Preparation of Starch from Cereal Grains

Starch was prepared from the various Canadian cereals by the wet-milling procedure of Adkins and Greenwood (1966) with some modifications. Washed kernels (500 g) were steeped in 0.01*M* mercuric chloride buffered to pH 6.5 by 0.02*M* acetate for 48 hr at 4°C with four changes of steeping medium. The softened kernels were drained, rinsed, and ground in a Waring Blendor with twice their apparent volume of water. The grists were kneaded under water before screening successively through U.S. 40, 200, and 400 sieves. The grinding, kneading, and screening were repeated until the grist appeared to be free of starchy endosperm particles. The screened slurries were centifuged (2,500 × *g*) and the surface layer of tailings was removed. The prime starch was reslurried in water and deproteinated by successive stirrings in toluene-water (1:2, v/v). The denatured proteins were removed from the toluene layer by suction and the process repeated until the toluene layer was virtually free of protein. The purified starches were filtered by suction, washed with ethanol, and air-dried. Although yields were not quantitated, it is estimated that starch yields ranged from 30 to 50% for the various grains.

Starch Properties

Protein contents (N × 5.7) for all starches were estimated by the modified micro-Kjeldahl method of Mitcheson and Stowell (1970). Starch damage was determined as described by Farrand (1964) and amylose content by the amperometric procedure of Williams et al (1970). An estimate of the water absorption capacity of each starch was obtained by performing the ultracentrifuge flour absorption method of Preston and Tipples (1978) on starch-gluten mixtures prepared at fixed protein contents.

The pasting properties of each starch were investigated with a Brabender amylograph according to the procedure of D'Appolonia and MacArthur (1975). Pasting temperature, peak height, peak temperature, 15 min height, and setback were measured as described by Medcalf and Gilles (1966).

Each starch was examined under a Cambridge "Steroscan" MK IIa scanning electron microscope in order to gain a qualitative estimate of granule size. Samples were mounted and photographed as previously described (Dexter et al 1978).

Preparation of Reconstituted Samples

Three series of starch-gluten blends were prepared. The first series comprised semolina starch and commercial waxy maize starch blended in varying proportions; the second series comprised blends of semolina starch and commercial amylomaize-7 starch. Another series was prepared from the laboratory-prepared cereal starches. Within each series the protein content was maintained at a constant level. Since different lots of dry gluten were used for each series, it was not possible to make direct comparisons of cooking quality between two samples from different series.

Farinograms

Farinograms were obtained by the method of Irvine et al (1961). Fifty grams of starch-gluten blend (14% moisture basis [mb]) was mixed with distilled water in a stainless-steel farinograph bowl (59 rpm drive), using the rear sensitivity setting. All samples were mixed at 36% absorption. Mixing time was the time required to reach the peak of the curve (maximum consistency) and tolerance index was the decrease in consistency measured in Brabender units four min past the peak.

Spaghetti-Making

Fifty grams of sample (14% mb), with sufficient distilled water to achieve optimum absorption, was mixed under vacuum in a 50-g farinograph bowl and made into spaghetti as described by Matsuo et al (1972). Spaghetti was dried with a controlled decrease in relative humidity for 29 hr at 39°C.

TABLE I
Some Properties of the Various Starches[a]

Starch Source	Protein Content[b] (%)	Water Absorption (%)	Amylose (%)
Wheats:			
Amber durum semolina	0.5	58	26.3
Amber durum (cv. Wakooma)	0.3	58	26.3
Amber durum (cv. Stewart 63)	0.2	64	25.6
Hard red spring	0.2	65	25.0
Alberta red winter	0.2	56	25.6
Soft white spring	0.1	62	22.0
Soft white winter	0.2	70	25.0
Rye	0.1	70	28.2
Triticale (cv. Welsh)	0.2	62	22.7
Barleys:			
6-Row (cv. Bonanza)	0.2	65	25.6
6-Row (cv. Manchuria)	0.2	57	21.2
6-Row (Waxy Manchuria)	0.3	100	3.8
2-Row	0.2	70	21.8
Oats	0.3	88	19.0
Buckwheat	0.4	86	27.7
Corns:			
Eastern yellow corn	0.2	83	22.6
Waxy maize	0.4	105	...[c]
Amylomaize-7	0.6	116	51.9

[a]All values expressed on dry matter basis.
[b]Expressed as % N × 5.7.
[c]Value was below detectable limit.

Spaghetti Cooking Quality

Spaghetti was cooked to normal cooking time and to 5 min past normal cooking time as previously described (Dexter and Matsuo 1978a). Cooking quality data were obtained on the GRL spaghetti tenderness testing apparatus (Dexter and Matsuo 1977b, Matsuo and Irvine 1969, 1971). Superior cooking quality is characterized by low values for tenderness index (Matsuo and Irvine 1969) and compressibility (Matsuo and Irvine 1971) concomitant with a high value for recovery. Thus, as cooking quality improves, the cooking quality parameter (Dexter and Matsuo 1977b) increases.

RESULTS AND DISCUSSION

Starch Properties

The commercial corn starches and all the starches prepared in the laboratory by the wet-milling procedure had no detectable starch damage, whereas starch prepared from the semolina had starch damage of 9.3 Farrand units. All prepared starches had very low protein contents (Table I).

Water absorption of the various starches differed considerably both between cereal species and within species (Table I). Starch water absorption would be expected to be an important factor in determining processing absorption requirements and in influencing pasta dough rheology.

Amylose contents for the various starches (Table I) were in good agreement with the results of Williams et al (1970), who reported on the amylose content of a wide range of cereal starches. Previous reports (Berry et al 1971, Klassen and Hill 1971) have shown triticale to have a lower amylose content than either of its parental species, durum wheat and rye, while durum wheat has been shown to have slightly greater amylose content than other classes of wheat (Berry et al 1971, Klassen and Hill 1971, Medcalf and Gilles 1965). Both these findings are corroborated by our results (Table I).

Pasting characteristics of the various starches in the amylograph showed large interspecies differences (Fig. 1, Table II), reflecting the physicochemical differences in the makeup of the granules. As noted previously by Kulp (1972), starch consistency maxima from hard wheats were reached only during the holding period subsequent to peak temperature (Table II). A similar behavior was also observed for the normal barley starches and the rye starch (Fig. 1, Table II). The waxy barley and waxy maize starches gave pasting curves typical of waxy starches (Goering et al 1973) exhibiting very high pasting peak, instability, and very little setback on cooking (Table II, Fig. 1). Since high-amylose corn starch is composed primarily of linear molecules so highly associated that some of the granules will resist gelatinization at low concentrations even in boiling water (Leach 1965), no gel formation was observed for the amylomaize-7 starch during pasting in the amylograph.

A qualitative estimate of granule size variability was obtained by examining each starch under the scanning electron microscope (Fig. 2). As noted previously by other workers (Hoseney et al 1971, Klassen and Hill 1971), wheat, rye, barley, and triticale starch granules were of comparable size, whereas oat and corn granules were somewhat smaller. Buckwheat starch (Fig. 2) was composed exclusively of small granules. The amylomaize starch (Fig. 2) possessed irregularly shaped granules characteristic of high-amylose corn starch (Badenhuizen 1965).

Farinograms

The farinograms shown in Fig. 3 are representative of the range in mixing characteristics observed for the various starch-gluten mixtures. The triticale and wheat starches produced mixing curves characterized by very short mixing times. The rye, normal barley, and Eastern yellow corn starches gave curves that were wilder (wider band width) and had slightly longer mixing times. The waxy barley and waxy maize starches gave very wild curves with relatively long mixing times and high maximum consistencies. The oat, buckwheat, and amylomaize curves were also very wild and exhibited long mixing times of about 30 min. As might be expected, those

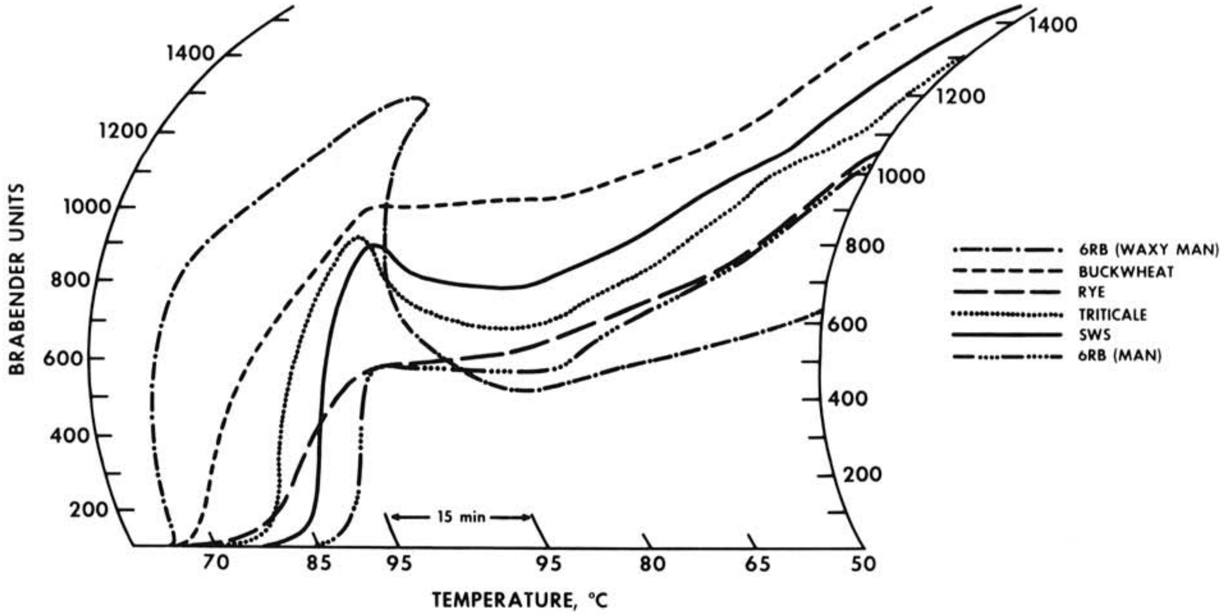

Fig. 1. Amylograph pasting curves for starches prepared from some Canadian cereals. 6RB = six-row barley, SWS = soft white spring.

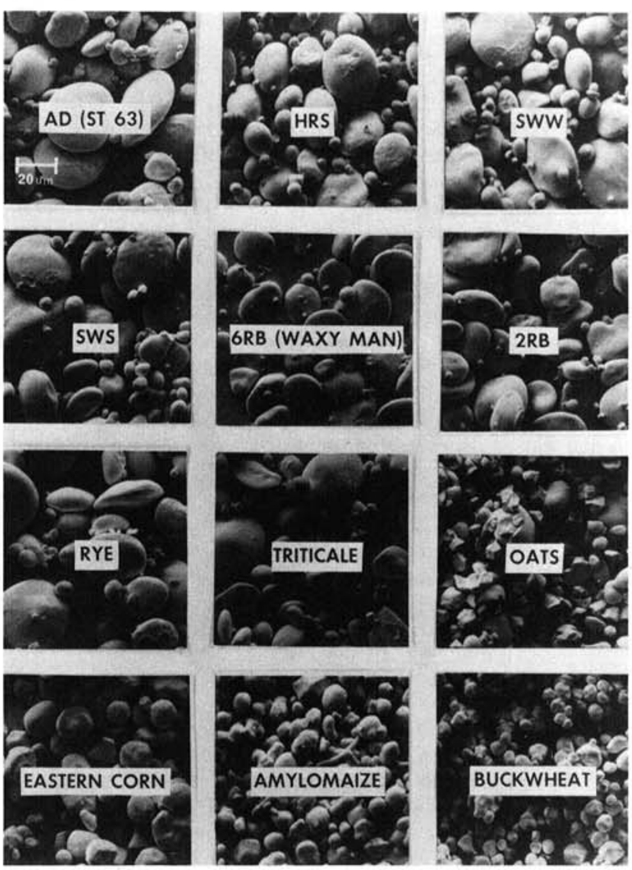

Fig. 2. Scanning electron micrographs of starches prepared from various cereal sources. AD = amber durum, HRS = hard red spring, SWW = soft white winter, SWS = soft white spring, 6RB = six-row barley, 2RB = two-row barley.

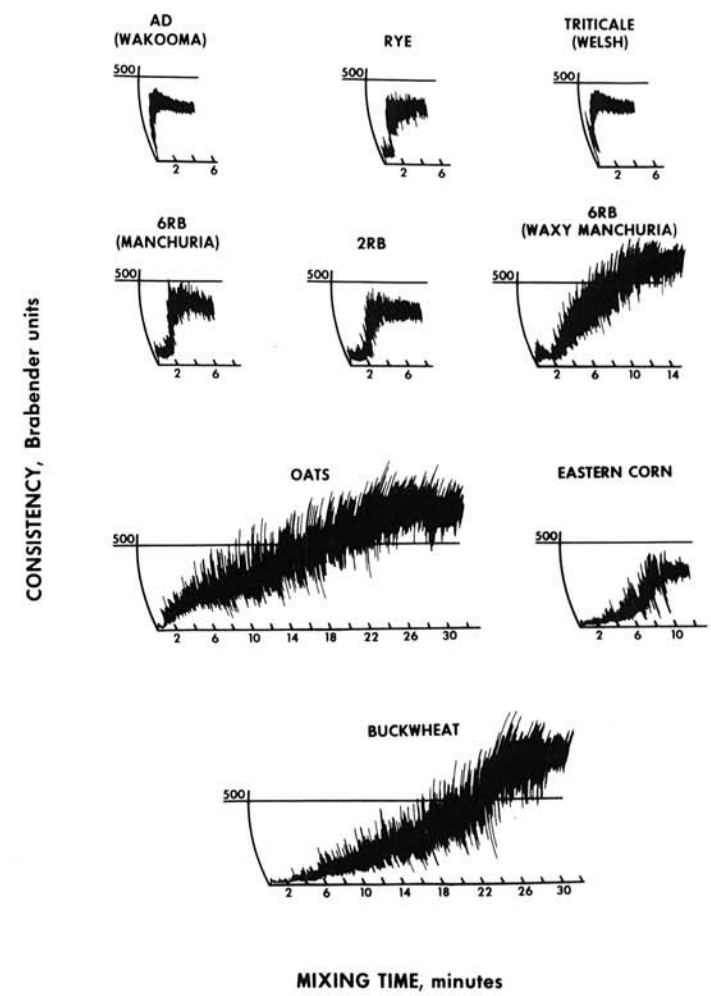

Fig. 3. Farinograph mixing curves obtained from some starch-gluten blends obtained by the method of Irvine et al (1961) at 36% absorption (14% moisture basis) and 12% protein. AD = amber durum, 6RB = six-row barley, 2RB = two-row barley.

TABLE II
Amylograph Pasting Properties of Some Cereal Starches

Starch Source	Pasting Temperature (°C)	Peak Height (BU)[a]	Peak Temperature (°C)	15 min Height (BU)[a]	Setback (BU)[a]
Wheats:					
Amber durum semolina	84	410	95 (1 min)	430	610
Amber durum (cv. Wakooma)	83	480	95 (4 min)	500	610
Amber durum (cv. Stewart 63)	83	450	95 (3.5 min)	470	590
Hard red spring	85	410	95 (3 min)	430	620
Alberta red winter	83	380	95 (2 min)	400	610
Soft white winter	83	420	95 (4 min)	410	510
Barleys:					
6-Row (cv. Bonanza)	82	450	95 (2 min)	470	560
2-Row	84	560	95 (2 min)	540	590
Oats	85	810	95	560	580
Corns:					
Eastern yellow corn	74	880	93	680	630
Waxy maize	69	1650	75	460	180
Amylomaize-7	...	0	...	0	0

[a]BU = Brabender units.

TABLE III
Cooking Quality of Spaghetti Prepared from Reconstituted Samples Containing Amber Durum Wheat Gluten and Various Mixtures of Amber Durum Wheat Starch and Waxy Maize Starch[a]

Proportion of Waxy Maize Starch (%)	Processing Absorption (%)	Normal Cooking Time[b] C (%)	R (%)	TI mm/sec × 10^3	CQP	Overcooked 5 min C (%)	R (%)	TI mm/sec × 10^3	OQP[b]
100	36	100	0	49[c]	...	100	0	61[c]	...
83	36	94	16	48[c]	4	100	0	62[c]	...
67	35	81	42	47[c]	11	100	0	58[c]	...
50	35	81	39	50	10	100	0	58	...
33	34	73	56	45	17	100	0	54	...
17	34	67	58	43	20	75	33	53	8
0	33	63	61	42	23	64	42	50	13

[a]All samples were prepared at 11.5% protein.
[b]Cooking time about 16 min. C = Compressibility, R = recovery, TI = tenderness index, CQP = cooking quality parameter, OQP = overcooking quality parameter.
[c]Blade did not completely sever strand due to starch gel fluidity at high proportions of waxy maize starch.

TABLE IV
Cooking Quality of Spaghetti Prepared from Reconstituted Samples Containing Amber Durum Wheat Gluten and Various Mixtures of Amber Durum Wheat Starch and Amylomaize -7 Starch[a]

Proportion of Amylomaize Starch (%)	Processing Absorption (%)	Normal Cooking Time[b] C (%)	R (%)	TI mm/sec × 10^3	CQP	Overcooked 5 min C (%)	R (%)	TI mm/sec × 10^3	OQP[b]
0	35	57	72	38	33	69	59	44	19
6	35	56	71	38	33	68	62	45	20
13	35	56	71	38	33	66	61	40	23
20	35	51	73	35	41	65	58	39	23
27	37	47	74	33	48	65	56	38	23
34	37	46	72	32	49	59	61	37	28
40	40	48	69	33	44	59	59	38	26

[a]All samples were prepared at 12.5% protein.
[b]Cooking time about 16 min. C = Compressibility, R = recovery, TI = tenderness index, CQP = cooking quality parameter, OQP = overcooking quality parameter.

TABLE V
Cooking Quality of Spaghetti Prepared from Reconstituted Samples Containing Amber Durum Wheat Gluten and Starches Isolated from Various Canadian Cereals[a]

Starch Source	Processing Absorption (%)	Normal Cooking Time[b] C (%)	R (%)	TI mm/sec × 10^3	CQP	Overcooked 5 min C (%)	R (%)	TI mm/sec × 10^3	OQP[b]
Wheats:									
Amber durum (cv. Wakooma)	34	63	54	45	19	100	0	50	...
Amber durum (cv. Stewart 63)	34	54	63	42	28	100	0	45	...
Hard red spring	34	61	48	46	17	100	0	48	...
Alberta red winter	34	55	67	40	30	90	13	46	3
Soft white spring	34	57	67	40	29	78	33	42	10
Soft white winter	34	62	50	46	18	100	0	48	...
Rye	36	57	63	46	24	100	0	53	...
Triticale (cv. Welsh)	34	60	70	39	30	100	0	43	...
Barleys:									
6-Row (cv. Bonanza)	33	54	61	40	28	57	54	43	22
6-Row (cv. Manchuria)	34	53	72	37	37	65	52	44	18
6-Row (Waxy Manchuria)	40	74	58	50[c]	16	100	0	65[c]	...
2-Row	34	54	56	40	26	59	60	44	23
Oats	50	63	73	41	30	86	12	46	3
Eastern yellow corn	42	83	23	44	6	100	0	55	...
Buckwheat	48	65	85	44	30	100	0	51	...

[a]All samples were prepared at 12% protein.
[b]Cooking time about 15 min. C = Compressibility, R = recovery, TI = tenderness index, CQP = cooking quality parameter, OQP = overcooking quality parameter.
[c]Blade did not completely sever strand due to the fluidity of gelatinized waxy starch.

starches with high water absorption values (Table I) gave the wildest curves with the longest mixing times. It has been reported that starch properties have a significant effect on bread dough-mixing properties (D'Appolonia and Gilles 1971, Hoseney et al 1971, Medcalf and Gilles 1968). The great diversity in the mixing properties of the reconstituted samples from this study illustrates that starch properties also can have an important influence on pasta dough-mixing properties.

Spaghetti Cooking Quality

In view of the importance of amylose content in determining rice cooking properties (Alary et al 1977, Juliano et al 1965, Webb and Adair 1970, Williams et al 1958), a series of reconstituted samples was prepared at various amylose contents by blending durum wheat starch with waxy maize starch. As the proportion of waxy maize starch was increased (amylose content decreased), cooking quality deteriorated (Table III). The cooked strands that contained a high proportion of waxy maize starch lacked resilience as reflected by their poor performance during the compression test. Due to the high fluidity of amylopectin-rich gels, the strands were not easily severed by the blade during the tenderness index test. The texture imparted by waxy maize to these samples would not be desirable for pasta where a firm, resilient, cooked product is preferred. In Japan, however, the blending of up to 30% waxy maize starch in soft wheat flours is considered to have a desirable effect on the organoleptic properties of Japanese noodles.

Further evidence for the importance of amylose in imparting firmness to cooked pasta was gained from the cooking quality trends of some amylomaize-semolina starch blends (Table IV). As the proportion of amylomaize starch was increased, the cooked pasta became firmer as evidenced by a progressive decrease in compressibility and tenderness index. However, the cooking quality improvement brought about by enrichment of the blends by amylomaize starch was not nearly as great as that which has been achieved previously by manipulation of gluten proteins (Dexter and Matsuo 1977b, 1978a; Matsuo et al 1972; Matsuo and Irvine 1970; Sheu et al 1967).

The effect on spaghetti cooking quality of each of the cereal starches prepared by wet milling in the laboratory was also assessed (Table V). Some significant variations in cooking quality were observed. As would be expected from the results with waxy maize blends (Table III), the waxy barley starch performed very poorly (Table V). The three normal barley starches appeared to impart superior cooking quality compared with all other laboratory-prepared starches. Of the wheat starches examined, the soft white spring appeared to convey the best cooking quality.

There did not appear to be a relation between the amylose content (Table II) of the various starches examined and their spaghetti cooking quality, with the exception that both the waxy maize and waxy barley starches, which contained negligible amylose, performed poorly. The results suggest that other starch properties may supersede amylose content in imparting superior cooking quality to spaghetti once a certain threshold level of amylose is present.

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