Selection of Desirable Starch Pasting Properties in Wheat for Use in White Salted or Yellow Alkaline Noodles

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ABSTRACT

Landraces of wheat may harbor wide diversity in quality-related traits, yet they have been little utilized to improve modern wheat varieties for major end uses such as noodles. Screening for starch physical properties in wheat breeding programs may provide valuable information on the suitability of genotypes for noodle manufacture. The pasting or viscoamylograph characteristics, especially the peak viscosity and the rate of viscosity breakdown after gelatinization, have been widely used to predict the eating quality of Japanese white salted noodles (WSN) and also applied to Chinese yellow alkaline noodles (YAN). We investigated the pasting properties of purified wheat starch and wholemeal from 21 Iranian landrace accessions and five standard cultivars, in water and in salt and alkaline conditions. The peak viscosity of starch with added water or 2% salt and at as-is or alkaline pH (pH 11) were found to be significantly correlated with each other. The results obtained were compared with the pasting profiles of wholemeal under the same treatment conditions. The peak viscosity of wholemeal was significantly correlated with that of starch, especially when 0.5 m*M* silver nitrate was used to suppress the effect of α-amylase. It was confirmed that wholemeal may be used instead of starch during rapid screening of wheat genotypes when sample availability is limited, but wide differences in starch content in unadapted material, such as landraces, will reduce the accuracy of the results. When wholemeal is to be used for screening wheat for desirable end use quality, it is preferable to always use an amylase inhibitor like silver nitrate to eliminate the effect of endogenous amylases, even in nonsprouted material. The differences in pasting profiles resulting from alkaline versus nonalkaline conditions indicate that whenever YAN quality is of particular importance, screening under high pH should also be conducted.

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Rapid screening of lines for potential use in quality improvement in a wheat breeding program requires identification of traits that are easy to measure, highly heritable, and meaningfully related to end use quality. Hence, effective early selection depends on development of reliable screening methods for relevant traits. Various studies (Nagao et al 1977, Moss 1980, Oda et al 1980, Toyokawa et al 1989, Crosbie et al 1990, Crosbie 1991, Konik et al 1991) have shown that variation in the eating quality of noodles is related to the swelling and pasting properties of wheat starch, and that the most convenient method for assessing wheat for noodle quality in a breeding program is by using viscoamylography to measure the starch pasting properties (Crosbie 1991, Panozzo and McCormick 1993).

Pasting properties of starch have traditionally been studied using the Brabender Amylograph/Viscograph (Walker et al 1988, Konik et al 1991). This method can be restrictive because of the large amount of flour or starch required and the long analysis time, limiting application to the later stages of wheat breeding programs (Crosbie 1991, Panozzo and McCormick 1993). The Rapid Visco-Analyser (RVA), which was initially designed to screen for sprout damage in wheat (Ross et al 1987, Deffenbaugh and Walker 1989), has proven to be a versatile and useful instrument for measuring starch pasting properties. The major advantages of the RVA relative to the Brabender Amylograph/Viscograph are that only a small sample of starch, wholemeal, or flour (3–4 g) is required for the test, the analysis takes a short time, and the data is recorded directly by computer.

Moss (1980) stated that amylography of starch rather than wholemeal or flour should be used to assess quality for manufacture of Japanese noodles. However, Panozzo and McCormick (1993) reported that analyzing wholemeal using the RVA was as reliable as testing flour or starch in identifying lines suitable for producing white salted noodles (WSN). Those studies were conducted on wheat samples free from sprout damage, but showed that the pasting properties of flour and wholemeal were comparable with those of starch and, hence, were similarly predictive of Japanese noodle quality.

In genetic resource management and evaluation, and in the early stages of breeding in trying to introduce useful diversity for starch physical properties from unadapted wheat varieties or landraces, the major problems are: 1) limited availability of material, making it difficult to isolate starch or extract flour; 2) the need to screen large numbers of samples; 3) the diversity of end uses of wheat and the effect of processing variables such as salt or pH on starch behavior; and 4) the potential effect of high levels of endogenous α-amylase activity in the samples, and the effect of preharvest sprouting. If wholemeal of such materials were to be screened for pasting properties, the results would be biased by the amylase present in the sample, and the results would not be comparable with those from purified starch. Ideally, the wholemeal samples should be treated to eliminate the effect of α-amylase activity before they are used for screening desirable starch pasting properties associated with noodle quality. Various chemical treatments have been reported to inhibit amylase activity and consequently improve the pasting profile of sprout-damaged wheat, e.g., HCl followed by neutralizaton with NaOH, $AgNO_3$, $HgCl_2$, cycloheptaamylose, and EDTA (Meredith and Pomeranz 1982, Hutchinson 1966, De Haas et al 1978, Kim and Hill 1984, Kickhaefer and Walker 1995). Crosbie and Lambe (1993) found that treatment of severely sprouted grain with 0.5 m*M* $AgNO_3$ gave flour swelling volume (FSV) results that were highly correlated with the eating quality of boiled noodles derived from sound grain.

Furthermore, little information is available on the paste characteristics associated with the eating and textural qualities of YAN. The main ingredients of YAN are flour, water, and an alkaline salt solution called *kansui* or "lye water" which imparts the typical yellow color and the characteristic chewy texture to the noodles. Due to the alkaline salts, the pH of the noodles ranges from 9–11. Thus, the pasting properties of starch in YAN is influenced by the presence of salt and high alkaline conditions.

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Before large-scale screening of many thousands of lines for starch-related traits, it was necessary to establish appropriate methodology for the diverse classes of end uses potentially of interest, including WSN, YAN, and other noodle variants. Hence, the present study aimed at finding whether the pasting profile of starch in plain water is predictive of how the starch would behave in the presence of salt and high pH. The study was also aimed at finding whether the pasting profiles of wholemeal were comparable to those of starch, which would obviate the need for tedious starch purification procedures and increase the rapidity of screening of genotypes for variation in starch pasting properties. To eliminate the possible effect of α-amylase on the pasting characteristics of wholemeal, 0.5 m*M* $AgNO_3$ was used in the RVA analysis.

MATERIALS AND METHODS

Wheat Samples

The samples used for this study comprised 21 Iranian hexaploid wheat landraces and six U.S. commercial wheat samples. The landraces are from a large collection held at the University of California, Davis, and subject to a series of ongoing investigations (e.g., Jafari-Shabestari et al 1995). Five U.S. commercial cultivars (Klasic, Serra, Calorwa, Cavalier, and Yecora Rojo) were supplied by the University of California, Davis. A sample of U.S. hard red winter (HRW) grain with the trade name Red Bicycle, widely used commercially for making noodles in Hong Kong, was obtained from Hong Kong Flour Mills, Kowloon, Hong Kong.

Twenty-one Iranian hexaploid wheat landraces were selected at random from a larger collection of some 250 lines under study in our laboratory. These landraces form part of a large base collection of some 12,000 accessions, known to harbor a wide genetic diversity in quality-related traits, and were also supplied by the University of California, Davis. The landraces used in this study were numbered as accession LR1 to accession LR21 in order of decreasing starch peak viscosity in water.

Sample Preparation

Starch was isolated from wheat grains using a labor-intensive protease digestion method, which according to Morrison et al (1984) and McDonald and Stark (1988), would result in starch granules of high purity with maximum recovery of B-granules, high yields of starch (≈65%), representative particle size distribution, and a low protein content (≈0.1–0.2%). Wholemeal was prepared by grinding in an Udy Cyclone sample mill (Udy Corp., Ft. Collins, CO) fitted with a 0.5-mm sieve.

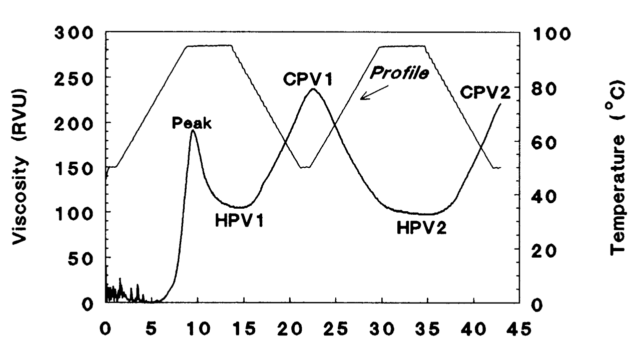

Fig. 1. Double heating and cooling cycle of Rapid Visco-Analyzer pasting profile for wheat starch: peak viscosity (Peak); hot paste viscosity at 95°C in the first and second cycle (HPV1 and HPV2), and cold paste viscosity at 50°C in the first and second cycle (CPV1 and CPV2); and temperature profile.

Proximate Analysis

Duplicate moisture determinations were made using a rapid microwave oven method (Davis and Lai 1984). Protein content (N × 5.7) and diastatic activity of wholemeal were determined in duplicate by standard methods 46-11A and 22-16, respectively, (AACC 1995). Total starch content of wholemeal was analyzed using the Megazyme Total Starch Assay Kit (Megazyme Australia, Warriewood, Australia).

Differential Scanning Calorimetry (DSC)

DSC analyses were performed in duplicate using a Mettler DSC-20 differential scanning calorimeter (Mettler-Toledo AG Instruments, Naenikon-Uster, Switzerland) equipped with a Mettler TC11 data analysis station. Approximately 3.0–3.5 mg (dwb) of starch was weighed directly into a tarred aluminum crucible and distilled water was added to obtain a starch-to-water ratio of 1:2 (w/w, dwb). The crucible was hermetically sealed and allowed to equilibrate for 1 hr before analysis. Samples were heated from 30 to 110°C at the rate of 10°C min^{-1}. An empty crucible was used as a reference. Gelatinization was recorded as onset (T_o), peak (T_p) and completion (T_c) temperatures, and energy of enthalpy (ΔH) was computed using the data processing software supplied with the DSC-20 instrument.

Pasting Profile Determination

A Rapid Visco-Analyser model 3-D (RVA) (Newport Scientific Pty. Ltd., Narrabeen, Australia) was used to study the pasting behavior of wheat starch and wholemeal samples. Wholemeal (4.0 g) or starch (3.0 g), each at 14% mb, were mixed with 25 g of accurately weighed distilled water or treatment solution, in a disposable aluminum RVA sample canister. Four treatments were applied to study the pasting properties of starch and wholemeal for each wheat genotype. 1. *Control.* The samples were mixed with distilled water (14% mb). 2. *Effect of alkaline conditions.* Most of the water was added, the pH of the slurry was adjusted to 11.0 by dropwise addition with constant stirring of 1*N* NaOH, then the rest of the water, corrected for the addition of sodium hydroxide, was added to make up 25 g of solution. 3. *Effect of salt.* 2% (w/v) NaCl solution was added to the samples instead of water. 4. *Combined effect of salt and high pH.* The sample was mixed with 2% NaCl solution to make the sample slurry and the pH of the slurry was adjusted to 11.0 as in treatment 2 by adding 1*N* NaOH. In addition, a further treatment was applied to wholemeal only. 5. *Inactivation of α-amylase in wholemeal samples.* A 0.5 m*M* $AgNO_3$ solution was used instead of distilled water; no pH adjustments were made.

A disposable plastic stirring paddle was placed in the sample canister to mix the contents continuously during the programmed heating and cooling cycle. A double heating and cooling cycle was employed: the sample slurry was held at 50°C for 1 min, heated from 50 to 95°C at the rate of 6°C min^{-1}, held at 95°C for 5 min and then cooled to 50°C at the same rate, where it was held for 1 min before repeating the cycle once again. The mean values for peak viscosity (Peak), hot paste viscosity at 95°C (HPV1), rate of breakdown (Peak – HPV1), cold paste viscosity at 50°C from the first cycle (CPV1), setback (CPV1 – HPV1), and the cold paste viscosity from the second cycle (CPV2) were recorded (Fig. 1). Previous studies in our laboratory indicated that the double heating and cooling cycle might be more effective in some applications in enhancing discrimination among samples with similar first peak viscosity (Corke et al, *in press*). Two replicates were used in each case.

RESULTS AND DISCUSSION

Gelatinization Characteristics of Starch

Table I summarizes the gelatinization behavior of starch obtained from the standard cultivars and the landraces, as examined by DSC. The overall temperature range for gelatinization from T_o to T_c for all genotypes ranged from 52.1 to 76.3°C. This observed range was somewhat narrower than the range 50 to 86°C reported earlier for wheat starch (Wootton and Bamunuarachchi 1979). The GT of the starch of six cultivars did not differ much among samples, with T_o ranging from 54.6 to 56.2°C, T_p from 60.3 to 63.2°C, and T_c from 71.8 to 75.8°C. The landraces displayed a wider range of T_o ranging from 52.1 to 56.8°C, and T_c from 69.1 to 76.3°C, but the range in T_p was only 59.2 to 62.0°C. Accession LR17 showed the lowest T_p and Red Bicycle starch the highest among all the samples. The gelatinization enthalpy (ΔH) varied from 6.6 to 10.0 J/g, which was somewhat lower than the values of 11.1 and 19.7 J/g reported by Wootton and Bamunuarachchi (1979), perhaps reflecting the differences in starch sample preparation (Wootton and Mahdar 1993).

Pasting Profiles of Starch: Effect of Water

The typical RVA profile of starch in a double heating and cooling cycle is shown in Figure 1. The peak viscosity in water of the commercial samples ranged from 92 to 181 RVU (Table II). Klasic starch had the highest peak viscosity, but this was followed by relatively greater breakdown, its setback (CPV1 – HPV1) being the lowest among all the starches. Several studies have shown that starch pasting properties including high peak viscosity (Moss 1980, Crosbie 1991, Crosbie et al 1992, Konik et al 1992, Panozzo and McCormick 1993), high breakdown (Oda et al 1980, Konik et al 1992), and low setback are responsible for superior Japanese noodle quality. In this respect, Klasic starch exhibits paste characteristics desirable for good quality Japanese noodles. The peak viscosity of Red Bicycle starch was not significantly different from that of Klasic starch, but it exhibited the highest shear stability among all the cultivars. Calorwa had an intermediate peak viscosity significantly different from all the other cultivars, while Cavalier, Yecora Rojo, and Serra had lower peak viscosities, lower rates of breakdown, and fairly high setback values. The peak viscosity of all the starches were positively correlated with rate of breakdown ($r = 0.96$, $P < 0.001$, $n = 27$) as well as with setback ($r = 0.45$, $P < 0.05$). Bahnassey and Breene (1994) reported that high setback of some starches was due to higher amylose contents that reinforce the molecular network within the granules by developing an aggregated structure.

The cultivated genotypes represent a wide range of noodle quality and, hence, vary widely in starch properties. As expected, the landraces also displayed a wide diversity in starch pasting characteristics, such as peak viscosity, HPV1, CPV1, and CPV2 (Tables II and III). The pasting profile of accession LR1 was considerably different from all the other samples, with a peak viscosity even exceeding that of Klasic starch. High peak viscosity, high rate of breakdown, and low setback indicates the possible potential in producing good quality WSN. Accession LR2 exhibited the highest shear stability among the landraces, its value being similar to that of Red Bicycle starch. Starch with low paste viscosity is preferred for YAN, presumably to allow for the substantial increase in the viscosity in the alkaline medium (Miskelly and Moss 1985). Accessions LR2–LR9 gave moderately low peak viscosities and high CPV, perhaps appropriate for producing YAN. Accessions LR17–LR21 gave low peak viscosities, negligible rate of breakdown, and comparatively high setback values, which may indicate relatively high amylose content.

The cold paste viscosity of the second cycle, CPV2, was highly correlated with the cold paste viscosity of the first cycle, CPV1 ($r = 0.98$, $P < 0.001$, $n = 27$), with values very similar to each other (Table III). Therefore, when the RVA is used to evaluate starch properties associated with noodle quality, the standard one-cycle pasting profile gives sufficient information for rapid screening of samples. We tested the two-cycle method because of previous experience in process simulation of a canned food operation, where CPV2 was found to enhance the relative differences among the samples and thus provide higher predictive value for end use texture than a single-cycle profile (Corke et al, *in press*).

Pasting Profiles of Starch: Effect of NaCl

The peak viscosity of starches increased dramatically in the presence of 2% NaCl (Fig. 2, Table II). High ionic concentrations are well known to increase the peak viscosity of starch (Ganz 1965, Medcalf and Gilles 1966, D'Appolonia 1972). Ganz (1965), in a study on the effect of NaCl on the pasting of wheat starch granules observed that salt increases and regulates the swelling of

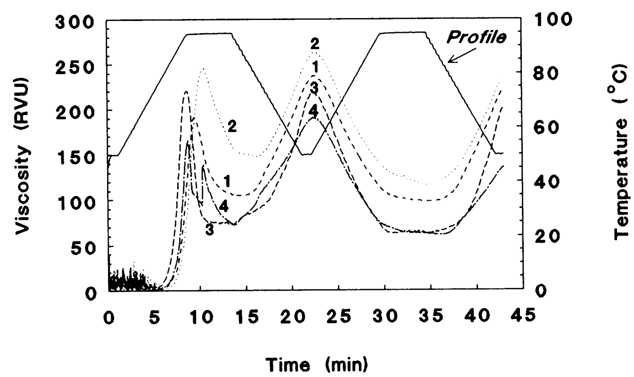

Fig. 2. Typical effect of various treatments on wheat starch in a two-cycle Rapid Visco-Analyzer heating and cooling profile: 1) water; 2) 2% NaCl; 3) pH 11; 4) 2% NaCl + pH 11; and temperature profile.

TABLE I
Gelatinization Characteristics of Purified Starch Determined by Differential Scanning Calorimetry[a]

Genotypes	Gelatinization Temperatures[b] T_o	T_p	T_c	ΔH (J/g)
Cultivars				
Klasic	54.6	61.0	73.7	9.2
Calorwa	56.2	61.5	73.1	7.8
Cavalier	55.7	60.7	71.8	8.5
Yecora Rojo	54.9	60.3	73.3	7.7
Serra	54.6	61.4	73.8	10.0
Commercial flour				
Red Bicycle	56.2	63.2	75.8	9.7
Landrace accessions				
LR1	56.8	61.3	74.1	8.0
LR2	55.6	61.5	76.3	8.8
LR3	55.5	61.2	72.7	8.2
LR4	56.3	61.5	73.1	7.7
LR5	54.6	62.0	74.3	8.3
LR6	56.1	60.8	69.2	6.7
LR7	54.1	59.7	70.4	7.1
LR8	55.1	61.2	72.9	8.6
LR9	55.7	61.3	72.4	7.8
LR10	56.3	61.6	74.4	8.9
LR11	55.9	61.0	75.5	6.6
LR12	54.5	61.0	74.0	9.2
LR13	55.7	61.5	75.4	8.8
LR14	56.5	61.5	75.0	7.0
LR15	55.1	61.5	73.7	9.2
LR16	56.1	61.9	72.5	7.6
LR17	52.1	59.2	69.1	6.8
LR18	54.9	61.0	73.6	7.6
LR19	54.9	61.8	73.0	8.8
LR20	55.1	61.2	74.0	7.4
LR21	55.6	61.2	73.9	8.8
LSD[c]	0.7	0.5	1.4	1.7

[a] Each value is the mean of duplicate measurements.
[b] T_o = onset; T_p = peak; T_c = completion; ΔH = enthalpy.
[c] Least significant difference ($P < 0.05$) for comparison of means within a column.

starch granules. The increase was believed to be due to enhanced maintenance of granule integrity, resulting in the starch granules remaining intact for a longer period of time and swelling to a greater extent, thus increasing the peak viscosity. The present results are also consistent with that hypothesis. The wheat cultivars in this study underwent a rapid breakdown after the initial increase to peak. In contrast, the landraces showed more resistance to breakdown in the presence of salt; with hot paste viscosities being generally quite uniform and higher than the cultivars (Table II). There was a drop in the setback of starches in presence of salt, which may be indicative of the possible role of salt in imparting a soft texture to the noodles.

The starches exhibited higher gelatinization temperature (GT) and took longer to attain peak viscosity in the presence of salt compared to the other treatments (Fig. 2). The ability of salt to modify the gelatinization of starch has been attributed to its influence on the properties of water (Collison 1968). Gough and Pybus (1973) reported that salts at low concentration lower the water activity due to a contribution to osmotic pressure and thus increase the GT. Oosten (1982) reported that NaCl increased the GT of starch by raising the so-called Donnan potential of the starch suspension. When NaCl is added to the starch suspension, some alcoholic groups in the starch granules are converted to sodium alcoholate groups. These compounds are more easily dissociated, causing a rise in the Donnan potential, which more effectively repels the anions (Cl^-) from the granules. Oosten (1990) also suggested that the anion is the gelatinizing agent and could promote the gelatinization by rupturing the hydrogen bond between starch molecules. Thus, the swelling inhibitor, NaCl, raises the Donnan potential in the starch suspension and retards the gelatinization of starch. The delay in the swelling probably gives more shear stability to the starch granules during stirring at 95°C, yielding a higher paste viscosity. Salt, an ingredient in Japanese white salted noodles, results in higher peak viscosity, higher breakdown and lower setback, all desirable for good quality noodles.

The salt treatment viscosity parameters were highly correlated with those obtained in water, in terms of peak viscosity (r = 0.98, P < 0.001), HPV1 (r = 0.90, P < 0.001), CPV1 (r = 0.92, P < 0.001) and CPV2 (r = 0.95, P < 0.001) (n = 27 in each case). Evidently, the RVA profile of starch in water alone can predict the suitability of genotypes in producing WSN and is suitable as a rapid screening test. Among the landraces, accession LR1 again displayed the highest peak viscosity, reconfirming its potential in improving quality of WSN.

Pasting Profiles of Starch: Effect of Alkaline pH

The peak viscosities of starches at pH 11 were found to be much higher than in water (Table II). This could again be attributed to the strengthening of bonding forces within the granules in the presence of Na^+ or OH^- ions and also due to the effects of high pH. It has been suggested that the increase in the swelling and viscosity of starch in the presence of alkali could be because of the anions (OH^-) that associate at the specific sites in the starch and create a large hydration sphere (Medcalf and Gilles 1966, Mistry and Eckhoff 1992). The RVA pasting profiles showed that alkali treatment lowered the temperature and time of gelatinization, and thus accelerated the gelatinization process (Fig. 2). Similar findings were reported by Anker and Geddes (1944) and Moss et al (1986). However, the alkaline pH could not sustain granular integrity for long, resulting in the rapid breakdown of starch granules.

TABLE II
Rapid Visco-Analyser Measurements (RVU) of Purified Starch[a]

	Peak Viscosity				HPV1[b]			
Genotypes	Water	2% NaCl	pH 11	2% NaCl + pH 11	Water	2% NaCl	pH 11	2% NaCl + pH 11
Cultivars								
Klasic	181	236	240	165	86	144	85	74
Calorwa	149	218	230	160	91	148	97	84
Cavalier	120	186	175	171	87	134	102	82
Yecora Rojo	98	153	155	151	74	113	103	76
Serra	92	156	134	139	71	98	83	70
Commercial flour								
Red Bicycle	177	229	240	164	107	168	111	91
Landrace accessions								
LR1	189	244	226	169	107	160	77	74
LR2	158	221	212	183	108	149	113	95
LR3	154	219	224	173	101	143	100	89
LR4	149	211	209	177	105	169	119	90
LR5	144	208	197	166	101	160	86	85
LR6	132	197	186	173	93	145	104	91
LR7	129	196	176	183	91	158	97	103
LR8	126	203	178	155	102	146	121	89
LR9	122	178	189	158	91	129	109	85
LR10	113	167	174	157	82	130	105	91
LR11	109	166	153	154	92	137	109	100
LR12	103	167	152	151	82	133	98	84
LR13	103	159	153	144	77	120	92	76
LR14	101	160	159	161	89	127	99	84
LR15	99	156	160	140	80	127	109	81
LR16	97	153	152	151	76	114	94	81
LR17	92	153	146	140	74	124	100	94
LR18	92	152	138	119	77	120	92	76
LR19	84	141	132	143	76	121	109	80
LR20	80	120	116	127	77	112	102	86
LR21	75	124	114	132	69	112	90	90
LSD[c]	6	5	12	10	4	7	7	9

[a] Each value is the mean of duplicate measurements.
[b] Hot paste viscosity at 95°C (first cycle).
[c] Least significant difference (P < 0.05) for comparison of means within a column.

Accessions LR2–LR9, which had given low peak values in water (158–122 RVU), showed the expected increase in peak viscosities (224–176 RVU) under alkaline conditions. We observed that the alkali treatment enhanced certain minor differences within genotypes that were not evident in the control. Among the commercial samples, Yecora Rojo and Serra gave a similar peak in the control (98 and 92 RVU, respectively), while at pH 11, the peak viscosity of Yecora Rojo was significantly higher than that of Serra (155 and 134 RVU, respectively). Similar differences were also observed in the landraces. Accessions LR14 and LR15, which had lower peak viscosities than LR11 in the control (101 and 99 vs. 109), displayed slightly higher viscosities at pH 11 (159 and 160 vs. 153). This suggests that pasting of starch under alkaline conditions may provide somewhat more accurate information on the potential quality of different genotypes as YAN.

Pasting Profiles of Starch: Effect of Salt and Alkaline pH

Some food systems based on wheat flour, including certain types of noodles, may contain NaCl and high pH in combination, so this combined treatment was included to investigate the effects in relation to wheat genotype. All the starches with this treatment gave uneven jagged peaks, which in some cases appeared as two 'peaks' on the RVA pasting profile (line 4 in Fig. 2). When a few sample runs were interrupted at the onset of the peak, the starch paste was dense and viscous and had formed a top layer of semisolid gel around the paddle, indicating that uneven breaking through the gel by the paddle is responsible for the jagged peak.

The peak viscosity of most of the samples with this treatment were higher than in water, with the exception of Klasic, Red Bicycle, and LR1, which had high peak viscosity in the control, but now showed a decrease in peak viscosity. However, the increase in peak viscosity was not as high as when salt or alkaline condition was used alone, except in the case of Serra and accessions LR7, LR11, LR14, LR19, LR20, and LR21. There was a drastic drop in the HPV and CPV1 and CPV2 of the samples when compared to the other treatments. It is evident that the cumulative effect of salt and alkaline pH causes excessive breakdown of hydrogen bonds between starch chains resulting in the decrease of paste viscosity. This decrease was more pronounced in the second cycle, CPV2 (Table III). Thus, we confirmed that the second heating and cooling cycle further enhanced discrimination in more complex food systems where the presence of certain solutes have a profound effect on the pasting profile of starch.

As discussed earlier, addition of salt increases the GT of starch due to the interaction between starch, water, and the ions. However, when salt was used in combination with alkaline pH, the onset of gelatinization was not as retarded as in the presence of salt, but it was intermediate between that observed with salt or alkaline pH alone (Fig. 2). It has been reported that the absorption of sodium ions by starch is limited, and when the salt concentration increases beyond a certain level, the influence of anions become dominant, resulting in the decrease of the GT of starch (Oosten 1990, Lii and Lee 1993). The addition of NaCl and NaOH to the starch suspension simultaneously, may have increased the anion concentration (Cl^-, OH^-) to a level that assisted the decrease in GT of starch as well as causing a tremendous drop in the paste viscosity by rupturing the hydrogen bonds.

TABLE III
Cold Paste Viscosity for First and Second Cycle Cooling in the Rapid Visco-Analyser Profile (RVU) of Purified Starch[a]

	CPV1[b]				CPV2[c]			
Genotypes	Water	2% NaCl	pH 11	2% NaCl + pH 11	Water	2% NaCl	pH 11	2% NaCl + pH 11
Cultivars								
Klasic	186	224	188	168	177	198	175	123
Calorwa	223	252	227	192	227	251	218	163
Cavalier	217	233	226	176	222	230	202	149
Yecora Rojo	189	204	226	175	189	199	209	140
Serra	175	199	173	147	183	194	161	124
Commercial flour								
Red Bicycle	261	280	230	221	256	276	239	175
Landrace accessions								
LR1	233	256	214	187	226	234	198	136
LR2	263	269	245	197	272	268	221	160
LR3	245	258	235	210	249	253	233	175
LR4	257	262	234	213	258	261	234	175
LR5	251	265	225	214	249	261	219	171
LR6	234	243	221	202	235	243	207	170
LR7	224	243	221	204	224	240	208	166
LR8	246	262	246	215	250	256	223	175
LR9	234	239	238	188	235	241	227	154
LR10	215	211	217	186	213	219	208	151
LR11	232	228	245	206	239	241	229	171
LR12	208	224	219	196	213	230	207	161
LR13	199	206	214	165	203	214	197	134
LR14	221	230	231	196	228	233	223	160
LR15	206	209	228	182	211	218	223	156
LR16	195	197	212	172	201	202	202	151
LR17	194	212	236	190	192	216	223	144
LR18	199	206	214	140	203	214	197	134
LR19	192	209	232	188	201	215	221	160
LR20	189	183	226	179	199	198	218	157
LR21	195	187	221	149	202	199	213	149
LSD[d]	7	5	10	6	8	7	17	6

[a] Each value is the mean of duplicate measurements.
[b] Cold paste viscosity at 50°C for first cycle cooling.
[c] Cold paste viscosity at 50°C for second cycle cooling.
[d] Least significant difference ($P < 0.05$) for comparison of means within a column.

Characteristics of Wholemeal

The characteristics of wholemeal obtained from the cultivars and the landraces are shown in Table IV. The protein content in the cultivars ranged from 10.1 to 13.7% (dwb). The protein content in the landraces ranged from 9.3 to 13.9% (dwb). Total starch content of the cultivars ranged from 61.9 to 69.7% (dwb), while the landraces showed wider differences in starch content, ranging from 54.6 to 75.8% (dwb). The standard cultivars had lower diastatic activity values, ranging from 1.44 to 6.62, while landraces displayed higher α-amylase activity, from 6.05 to 11.30 me/g of wholemeal sample.

Pasting Profiles of Wholemeal: Effect of Water

Panozzo and McCormick (1993) and Konik et al (1994) found significant correlation between the peak viscosity of starch, flour, and wholemeal. Based on these observations, they suggested that isolation of starch is not necessary to identify potential noodle quality wheat in the early stages of a wheat breeding program, when only small quantities of grain are available. In this present study, the availability of landrace material was limited, precluding the possibility of flour extraction, and therefore only wholemeal samples were available for comparison with starch. Among the standard cultivars, the peak viscosity of wholemeal in water showed strong correlation with the peak viscosity of starch (r = 0.95, $P < 0.001$, $n = 6$).

The peak viscosity of wholemeal from landraces when compared to the starch component, however, showed low correlation in presence of water ($r = 0.54$, $P < 0.05$, $n = 21$). This discrepancy in results can be attributed to the high α-amylase activity in the landraces and to the wider range in starch content. When α-amylase inhibitor $AgNO_3$ at a concentration of 0.5 mM was used instead of water, the correlation with starch dramatically increased ($r = 0.84$, $P < 0.001$, $n = 21$). When the concentration of $AgNO_3$ solution was increased to 1, 1.5, and 2 mM, viscosity was slightly increased at 1 mM and then remained constant at higher concentrations (results not shown). Significant negative correlation was observed between the peak viscosity in presence of silver nitrate and amylase activity of wholemeal (Table V). Holmes (1995) observed that the peak viscosity of malt reached the maximum at 0.1 mM/g and thereafter remained constant up to 1.25 mM/g. He reported that silver nitrate was the enzyme inhibitor of choice for irreversible inhibition, as 10-fold increases in the control did not significantly affect the viscograms.

The peak viscosity of wholemeal increased at pH 11, which could be attributed to the influence of alkaline pH on the starch-protein complex. Protein and starch form complexes while being gelatinized, which is due to the attraction of opposite charges (Takeuchi 1969). The protein in flour or wholemeal complexes with the starch molecules on the granule surface, preventing escape of exudate from the granule and, therefore, interfering with the increase in the viscosity (Olkku and Rha 1978). Dahle (1971) observed that maximum protein-starch interaction occurred at pH 6.5. At more alkaline pH, the positive charge on the protein is reduced and it complexes less with the negatively charged starch, resulting in the starch granules swelling to a greater extent and increasing the paste consistency. The pH range of the wholemeal slurry in presence of water was 6–6.5. This is optimal for complexing to take place, preventing the granules from swelling and resulting in low viscosity values. At alkaline pH, the peak viscosity and the hot paste viscosity of wholemeal was as high as that of pure starch.

TABLE IV
Physical Characteristics of Wholemeal[a]

Genotypes	Protein (%, dwb)	Total Starch (%, dwb)	Diastatic Activity (me/g)
Cultivars			
Klasic	10.1	69.4	6.62
Calorwa	13.0	64.2	4.39
Cavalier	12.4	62.0	2.59
Yecora Rojo	13.0	68.1	4.32
Serra	11.4	69.7	2.30
Commercial flour			
Red Bicycle	13.7	65.4	1.44
Landrace accessions			
LR1	9.3	67.0	7.06
LR2	12.4	56.3	9.36
LR3	9.9	55.8	9.14
LR4	12.4	73.4	9.07
LR5	10.3	64.7	7.78
LR6	12.1	72.9	8.71
LR7	11.0	55.8	8.78
LR8	9.8	63.3	7.06
LR9	12.4	58.7	9.50
LR10	13.7	54.6	7.06
LR11	13.9	57.4	9.36
LR12	11.9	74.3	11.23
LR13	11.3	65.1	6.05
LR14	9.6	67.2	8.78
LR15	11.4	73.6	8.14
LR16	10.0	75.8	7.20
LR17	12.4	55.3	8.78
LR18	12.4	57.2	6.70
LR19	10.6	61.7	7.49
LR20	12.0	60.5	11.30
LR21	10.6	71.1	7.34
LSD[b]	0.3	5.0	0.30

[a] Each value is the mean of duplicate measurements.
[b] Least significant difference ($P < 0.05$) for comparison of means within a column.

Pasting Profiles of Wholemeal: Effect of Salt

The viscosity of wholemeal in the presence of 2% salt, at as-is pH and at pH 11, was higher than that observed in presence of water. The pasting profile of wholemeal in the presence of NaCl showed a characteristic bump-like pattern in the heating stage of the second cycle (Fig. 3). The bump was not prominent in the cooling stage of the first cycle, nor was it evident in the absence of NaCl. The combined effect of salt and high pH, however, suppressed the bump height. Similar bump-like patterns during the cooling cycle of the amylogram have been reported before (Xu et al 1992, Kim and Seib 1993). During the cooking stage the solubilized amylose interacts with the flour lipids, mainly polar lipids, to form an amylose-monoacyl lipid complex, which increases the paste consistency; the crystallization of the helices results in a decrease in viscosity, thus forming a bump (Xu et al 1992). Though this bump is reported to be well correlated with noodle

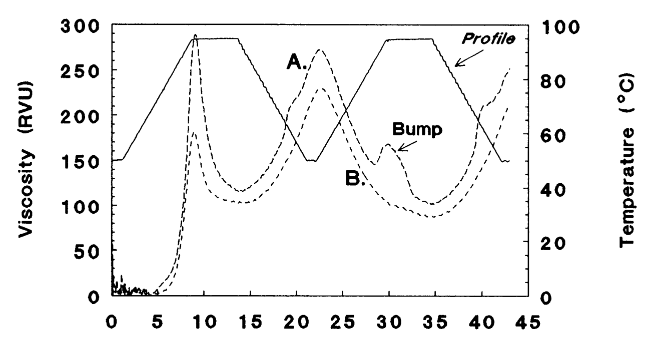

Fig. 3. Double heating and cooling cycle Rapid Visco-Analyzer pasting profile for wheat wholemeal: A) characteristic bump-like pattern in the second cycle in the presence of 2% NaCl; B) pasting profile in water that does not show bump; and temperature profile.

TABLE V
Correlation Coefficients for Rapid Visco-Analyser Peak Viscosities[a]

	Peak (Starch)				Peak (Wholemeal)				
	Water	NaCl	pH 11	NaCl + pH 11	Water	$AgNO_3$	NaCl	pH 11	NaCl + pH 11
Peak (starch)									
NaCl	0.98 ***								
pH 11	0.97 ***	0.96 ***							
NaCl + pH 11	0.75 ***	0.79 ***	0.75 ***						
Peak (wholemeal)									
Water	0.65 ***	0.57 **	0.61 ***	0.30 ns					
$AgNO_3$	0.84 ***	0.80 ***	0.75 ***	0.46 *	0.80 ***				
NaCl	0.77 ***	0.73 ***	0.69 ***	0.44 *	0.85 ***	0.94 ***			
pH 11	0.76 ***	0.75 ***	0.67 ***	0.50 **	0.53 **	0.86 ***	0.85 ***		
NaCl + pH 11	0.76 ***	0.76 ***	0.68 ***	0.52 **	0.57 **	0.87 ***	0.88 ***	0.90 ***	
Starch HPV1[b]	0.82 ***	0.85 ***	0.80 ***	0.77 ***	0.33 ns	0.60 ***	0.55 **	0.67 ***	0.64 ***

[a] $n = 27$. ***,**,*, = $P < 0.001$, < 0.01, < 0.05, respectively. ns = not significant.
[b] Hot paste viscosity at 95°C (first cycle).

quality (Bason and Booth 1994), the exact role in noodle texture remains unclear.

The correlation matrix for peak viscosity of starch and wholemeal under different treatments (Table V) showed an overall good correlation between all treatments. Treatment of wholemeal with silver nitrate gave the best correlation with starch when compared to other treatments. These results reconfirm that testing wholemeal is nearly as reliable as testing starch during the early generation screening of wheat. With even more diverse material than these landraces, we note that the increased variation in starch content will make the results from wholemeal evaluation less and less reliable. Breeders should then weigh the costs and benefits of routinely measuring starch content or extracting starch. Furthermore, for screening landraces or other early generation lines, the use of silver nitrate solution as a replacement to water will rule out the confounding effects of α-amylase activity, and thus provide more valuable information to wheat breeders.

CONCLUSION

Viscosity profiles of starch were studied in salt and alkaline conditions to simulate the conditions prevailing in two major classes of noodles. High correlation was observed between all the treatments. Wholemeal samples from the commercial cultivars were low in amylase activity and showed significantly higher correlation with the peak and hot paste viscosity of starch than did the landraces. Treatment of the landraces with 0.5 m*M* $AgNO_3$ solution substantially improved the correlation with starch. Diverse wheat genotypes, such as landraces used at early stages of breeding, should be treated with 0.5–1 m*M* $AgNO_3$ to eliminate the possible effects of amylase when screening wheat for noodle quality. The double heating and cooling cycle enhanced the differences between genotypes where salt and high pH was used in combination. However, in rapid screening of early generation wheat, a single cycle was found to be the method of choice for predicting noodle quality.

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