

Contribution of Wheat Flour Fractions to Peak Hot Paste Viscosity

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ABSTRACT

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The quality of many baked products, noodles, gravies, and thickeners is related to the pasting properties of wheat (*Triticum aestivum* L.) flour, yet different flours vary markedly in their pasting performance. The objective of the present research was to assess the role of the wheat flour fractions, gluten, water solubles, prime and tailing starches, in the contribution to peak hot paste viscosity among three selected wheat cultivars. Straight-grade flours were fractionated and reconstituted. Fractions were examined independently and were deleted in otherwise fully reconstituted flours. Fractions were exchanged between cultivars for reconstituting flours, and fractions were substituted individually into a common starch

base. The flours from the cultivars Klasic, McKay, and Madsen differed markedly in their peak hot paste viscosities, and were fractionated and reconstituted with only a small effect on paste viscosity. Results clearly showed that prime starch was the primary determinate of flour paste viscosity, but the other fractions all exerted a significant effect. Tailing starch increased paste viscosity directly due to pasting capacity of starch or indirectly through competition for water. Gluten also increased paste viscosity through competition for water. The water-soluble fraction from different cultivar flours was more variable in effect.

The quality of many baked products, noodles, gravies, and thickeners is related to the pasting properties of wheat (*Triticum aestivum* L.) flour. Pasting refers to the temperature-dependent changes in the viscosity of highly hydrated systems such as doughs and batters during baking, boiling, cooking, or other processing (Atwell et al 1988). Although it is well recognized that flours milled from sound, unspouted wheats exhibit differences in pasting behavior, the variation among wheat flour fractions and wheat cultivars has not been well characterized.

Hutchinson (1966) was among the first to clearly demonstrate that different flours exhibited markedly different inherent peak hot paste viscosities (amylograph maxima). Hutchinson showed that differences remained beyond those that could be accounted for by α -amylase. Flours of Australian origin were noted for inherently high paste viscosity. Moss (1967) characterized further the variation for peak paste viscosity among Australian cultivars grown at various locations and found that a number of cultivars had consistently higher peak paste viscosity. Moss' data indicated that high paste viscosity was a cultivar trait and therefore genetically controlled. Meredith, Loney and co-workers (Meredith 1970, Loney and Meredith 1974, Loney et al 1975) continued the study of the differences among cultivars, particularly differences between New Zealand and Australian cultivars. In a 1970 report, Meredith provided data that indicated that differences in peak paste viscosity remained after amylase inactivation, and pointed out that in rice, amylose content was related to flour and starch paste viscosity. Later, Loney and Meredith (1974) demonstrated that the paste viscosity of isolated starch corresponded to the inherently different paste viscosities of flours. Then in 1975, Loney et al demonstrated that cultivars with high flour paste viscosity possessed starch with high paste viscosity. These higher pasting starches had lower amylose contents.

Since these reports, differences in paste viscosity among wheat cultivars especially Australian, have been widely noted, as well as the role of prime starch and its amylose-amylopectin content (Moss 1980, Moss and Miskelly 1984, Crosbie 1989, Endo et al 1989, Batey et al 1993, Zeng et al 1997).

With the exception of amylases and starch, other flour components that contribute to overall flour paste viscosity have not been studied in much detail. Anker and Geddes (1944) measured the peak paste viscosity of a commercial wheat starch with various levels of substituted gluten. Increasing amounts of substituted gluten progressively decreased peak paste viscosity. However, viscosities were always greater than that produced by an equivalent amount of starch alone. The results of Allen et al (1991) using corn (maize) starch with added wheat gluten (1–10%) were similar.

Hutchinson (1966) found that when treated with silver nitrate, the amylograph maxima of a number of Australian flours correlated with protein content, whereas among a number of English flours, no significant correlation was present. Moss (1967) found that amylograph peak viscosity was correlated with grain protein within five of six Australian cultivars grown at a single location, but fertilized differently to achieve a range in protein. In a second set of samples comprising cultivars grown at several locations, peak viscosity and protein were also positively correlated ($r = 0.32$, $P < 0.001$). Moss (1980) and Moss and Miskelly (1984) reported positive correlations between starch peak paste viscosity and flour protein content, but interpreted this relationship as indirect—higher pasting and higher protein coinciding when adverse growing conditions were encountered during grain development. Meredith (1970), on the other hand, found that flour protein content did not improve correlations with amylograph peak viscosity, and Šebečić (1989) concluded that protein content did not significantly influence peak paste viscosity.

Yasunaga et al (1968) studied the effect of papain on flour and starch paste viscosity and found that although most of the effect of papain could be attributed to its liberation of β -amylase, the hydrolysis of gluten produced some reduction in peak paste viscosity. Also, when isolated gluten was mixed with starch, viscosity was greater than with starch alone.

Balint and Momirović-Čuljat (1976) concluded that peak paste viscosity was directly attributable to the quantity of starch in the sample (and inversely but indirectly to protein content). They also concluded that although protein had no direct effect on paste viscosity, papain reduced paste viscosity by disturbing “. . . the equilibrium of starch-protein in [the] complex system caused by protein degradation.” In a companion article, Momirović-Čuljat and

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Balint (1976) included a table which predicted the starch content of flours based solely on the peak paste viscosity. However, Loney et al (1975) found that starch content and composition (amylose-amylopectin) were poor predictors of the pasting capacity of flours.

Jelaca and Hlynka (1971) showed that both water-soluble and insoluble pentosans increased the paste viscosities of flour, though the insoluble fraction had the greater effect. Endo et al (1988, 1989) found that prime starches from different grain lots and cultivars had inherently different peak paste viscosities. Substituting 30% tailing starch in a common prime starch base reduced peak paste viscosity relative to prime starch alone, although different tailing starch fractions exhibited variable levels of reduction.

In the course of evaluating wheat breeding lines for potential use in Asian noodles, considerable variation in peak hot paste viscosity has been observed (G. E. King and C. F. Morris, *unpublished data*). Experience suggests that this variation is fairly consistent among given cultivars, and as such, may be largely under genetic control. The objective of the present research was to assess the contribution of the wheat flour fractions, gluten, water solubles, and prime and tailing starches, to peak hot paste viscosity among a select group of wheat cultivars known to encompass much of the variation encountered in our cultivar development work. A preliminary report of our findings appeared in *Agronomy Abstracts* (King et al 1994).

MATERIALS AND METHODS

Samples

Klasic hard white spring, McKay hard red spring, and Madsen soft white winter wheat cultivars were selected a priori to encompass much of the total range in peak paste viscosity observed during the routine analysis of breeding samples as part of the cultivar development activities of the Western Wheat Quality Laboratory (cf. Zeng et al 1997). The peak hot paste viscosity of Klasic, McKay, and Madsen prime starch have been previously characterized (Batey et al 1993, Zeng et al 1997).

Grain samples were tempered to 14% moisture content (wb) and milled on a Bühler MLU-202 pneumatic flour mill (AACC 1995). A straight-grade flour was produced by combining the six flour streams.

Fractionation

Flours were fractionated into prime and tailing starches, water solubles, and gluten following the dough-ball method of Wolf (1964). The procedure entailed mixing 250 g of flour at optimum water absorption (60% for Klasic and McKay, 53% for Madsen) for 30 sec in a pin-type mixer (National Manufacturing, Co., Lincoln, NE) and washing the dough with five to seven volumes of water until the wash water was clear. Wash water was pooled and centrifuged (1,000 × g). The supernatant from the first centrifugation was recovered and designated as the water-soluble fraction. The starch pellet was washed two times more, the supernatants were discarded, and the starch was subdivided into prime and tailing starches based on the appearance and texture of the prime

starch and tailing starch interface. All fractions were lyophilized. Prime and tailing starches and gluten were ground in a Tecator Cemotec 1090 Sample Mill (Tecator, Sweden) at setting no. 1.

To assess the effect of the wetting and fractionation process per se, two procedures were examined. In the first, slurry, parent flours were hydrated with five volumes of water. In the second, dough, parent flours were hydrated and mixed with a quantity of water equal to that needed for optimum water absorption. After these two hydration steps, the slurry or dough was lyophilized and ground in the Tecator mill as above.

Reconstitution and Substitution

Reconstitution of flour fractions was accomplished by either simply mixing the dry fractions immediately before starch paste viscosity analysis or by mixing the dry fractions followed by the dough hydration, lyophilization, and grinding procedure. In both instances an appropriate proportional composition based on fraction yield was used. When interchanging fractions, substitution was based on the fraction yield of the parent flour. Substitution of a common commercial wheat starch (Sigma, St. Louis, MO) base involved deleting 3, 6, or 12% of the base starch and replacing it with an equivalent amount of isolated flour fraction.

Analytical

Flour ash was determined by Method 08-01 at 550°C (AACC 1995). Nitrogen was determined by the Dumas combustion method (Method 46-30, AACC 1995) using ≈0.25 g of sample (model FP-428, Leco Corp., St. Joseph, MI). Moisture content of flours and flour fractions was determined by a modified Method 44-16 (AACC 1995) (130°C for 20 min). Hot paste viscosity was determined using the Rapid Visco Analyzer (RVA) (Newport Scientific, Pty. Ltd., Warriewood, NSW, Australia) following the procedures described previously (Ross et al 1987, Walker et al 1988). The specific temperature program used was 60°C, from start to 2 min (elapsed time of run); heat at a constant rate to 93°C, 2–8 min; and hold at 93°C, 8–12 min. Samples were added to 25 mL of distilled water in the RVA vessel, dispersed with the aid of the mixing paddle, and immediately analyzed for peak hot paste viscosity. Generally, 2.58 g dwb (3.0 g, 14% mb) of parent or reconstituted flour, or flour fraction was used unless otherwise indicated. RVA units (RVU) reflect apparent viscosity and are approximately equal to centipoise (cP)/11.6 (K. Albertson, *personal communication*).

RESULTS

Flour yields for the three cultivars ranged from 66.9 to 69.6 g/100 g of grain (Table I). Ash and nitrogen contents are also listed in Table I. These flours were fractionated into the four components, prime and tailing starches, water solubles, and gluten. Fraction yields and nitrogen contents are reported in Table II. Yield of prime starch generally inversely paralleled differences in flour nitrogen content (Table I) and gluten yield. Starch-gluten separation was similarly efficient for all three cultivars as evidenced by the low nitrogen content of the prime starch fractions

TABLE I
Flour Yield, Ash and Nitrogen Content (g/100 g, dwb) of Bühler-Milled Flours Used to Examine the Role of Flour Fractions in Variation for Peak Hot Paste Viscosity^a

Cultivar	Flour Yield	Ash Content	Nitrogen Content
Klasic	66.9	0.44	3.12
McKay	67.9	0.51	3.14
Madsen	69.6	0.45	2.05

^a Flour yield calculated as recovery of straight-grade flour per 100 g grain, ash and nitrogen contents as per 100 g of flour. All calculations on a dry weight basis.

TABLE II
Yield and Nitrogen Content (g/100 g, dwb) of Prime and Tailing Starches, Water Solubles and Gluten Fractionated from Bühler-Milled Flours^a

Cultivar	Prime Starch		Tailing Starch		Water Solubles		Gluten	
	Yield	N	Yield	N	Yield	N	Yield	N
Klasic	66.1	0.05	8.3	0.66	6.3	3.0	19.3	14.3
McKay	63.9	0.05	8.9	0.48	6.5	3.6	20.7	13.6
Madsen	71.1	0.04	9.8	0.43	5.7	3.8	13.4	12.9

^a Fraction yields and nitrogen contents based on grams of fraction or nitrogen per 100 g of parent flour, dry weight basis.

(Table II). Tailing starch fractions represented less than one-tenth the original flour, but contained about 10-fold higher nitrogen content than did the prime starch. Water solubles represented the smallest fraction of the four and ranged from ≈19–25% protein (N × 6.25). Gluten yields were consistent with flour nitrogen content (≈12–18% protein, N × 5.7). Even though Madsen, the soft wheat cultivar, yielded ≈6–7 g of gluten/100 g of flour less than the two hard wheat cultivars, this yield was consistent with the relative nitrogen content of its parent flour. Madsen did, however, exhibit the highest concentration of nonprotein constituents (based on N content) in the gluten fraction and the highest nitrogen concentration in its water-soluble fraction. The yields and protein contents of the gluten and prime starch fractions were within the ranges expected (Anker and Geddes 1944, Loney et al 1975).

Before examining the role of individual flour fractions in hot paste viscosity, the possible effect of the fractionation procedure itself was assessed. Adding sufficient water to a flour to form a slurry, freeze-drying and regrinding had a negligible or small effect on peak hot paste viscosity (Table III). McKay and Madsen appeared to be little affected, while paste viscosity of Klasic was slightly reduced. Reducing the quantity of water such that a dough was developed, produced similar results.

Next, two approaches to reconstituting the fractionated flours were examined. For McKay and Madsen, reconstituting the dry fractions into a dough, freeze drying, and grinding produced paste viscosity similar to or slightly less than the parent flour (Table III). Klasic exhibited a significant reduction in paste viscosity. Simply reconstituting the dry fractions immediately before conducting RVA pasting resulted in a slight reduction in paste viscosity for McKay and Madsen, but similar results for Klasic when compared to the reconstituted dough method. We concluded from these data that although the fractionation procedure had some effect on paste viscosity, the ranking of cultivars did not change, the reduction was not great, and the reduction was generally proportional to the peak viscosity of the original parent flour (the greatest reduction was in Klasic, which was also the highest viscosity). Additionally, rehydrating the fractions into a dough and then relyophilizing provided no benefit and was considerably more labor-intensive. Consequently, reconstituting the dry fractions directly was adopted for the remainder of the research.

The primary objective of assessing the relative role of the flour fractions in variation in peak hot paste viscosity was first investi-

gated by deleting individually each of the four fractions from an otherwise completely reconstituted flour. As expected a priori, deleting the prime starch fraction essentially eliminated measurable hot paste viscosity (Table IV). Although not as dramatic in effect, deleting the tailing starch fraction also markedly reduced paste viscosity for all three flours. The effect of deleting the water-soluble fraction was most variable. Deleting the water solubles from Klasic and McKay had only a slightly positive or neutral effect. Deleting the water soluble fraction from Madsen, however, markedly increased peak viscosity. Surprisingly, deleting the gluten fraction also markedly reduced peak paste viscosity, somewhat similar to the effect obtained by deleting tailing starch. Although these series of experiments were hampered by the fact that variable amounts of sample were pasted using a constant amount of water (25 mL), they clearly indicated that: 1) prime starch is the major contributor to peak hot paste viscosity, 2) tailing starch and gluten fractions also significantly contribute to flour paste viscosity, and 3) the water solubles of Madsen reduced flour paste viscosity. The effects of tailing starch, gluten, and water solubles were noteworthy, especially tailing starch and water solubles, because they are relatively minor flour components (5–10%, by weight). Consequently, in the next series of experiments, a constant amount of each fraction was examined independently.

The first strategy sought to examine the temperature-dependent change in viscosity of each individual fraction on an equal sample weight basis. Consequently, 2.58 g (dwb) of each fraction was individually analyzed in the RVA using 25 mL of water. In all cases, peak viscosity of prime starch exceeded the reconstituted sample (Tables IV and V), indicating that on a per unit dry weight basis, prime starch possesses inherently greater capacity for hot paste viscosity than the sum total of the constituents of flour. Assuming that prime starch is the primary contributor to peak hot paste viscosity, then based on the yield of prime starch (Table II), these results seem reasonable. For example, 2.58 g of reconstituted flour contains only 1.65–1.83 g of prime starch, depending on the cultivar, compared to 2.58 g of prime starch used here.

Although tailing starch represents a minor flour fraction, this fraction exhibited pasting viscosity similar to McKay and Madsen prime starch (Table V). In the case of Klasic, tailing starch and prime starches differed substantially. Even at the relatively large quantity of 2.58 g, water solubles and gluten exhibited no temperature-dependent increase in viscosity. In comparing these re-

TABLE III
Effect of Various Wetting, Fractionation and Reconstitution Treatments on Flour Peak Hot Paste Viscosity (RVU)^a

Cultivar	Flour			Reconstituted	
	Control	Slurried	Dough	Dough	Dry Fractions
Klasic	232	221	210	191	200
McKay	144	143	146	136	121
Madsen	114	120	125	116	103

^a Rapid Visco-Analyser units ≈ cP/11.6. Standard deviations ranged from 0 to 18.5 RVU with an overall average standard deviation of 6.2 RVU for replicate analyses (two or three replicates per mean).

TABLE IV
Effect of Deleting Individual Flour Fractions on Peak Hot Paste Viscosity (RVU)^a

Cultivar	Control ^b	Prime Starch ^c	Tailing Starch ^c	Water Solubles ^c	Gluten ^c
Klasic	200	<10	140	215	158
McKay	121	<10	68	129	75
Madsen	103	<10	74	151	60

^a Rapid Visco-Analyser units ≈ cP/11.6.

^b Control equals reconstituted dry fractions.

^c Fraction that was omitted from an otherwise proportionally reconstituted flour, i.e., 2.58 g (dwb) minus the deleted fraction.

TABLE V
Peak Hot Paste Viscosity (RVU)^a of Individual Flour Fractions at a Constant Sample Weight^b

Cultivar	Prime Starch	Tailing Starch	Water Solubles	Gluten
Klasic	238	139	<10	<10
McKay	155	122	<10	<10
Madsen	139	156	<10	<10

^a Rapid Visco-Analyser units ≈ cP/11.6. Standard deviations for tailing starch fractions ranged from 1.4 to 4.2 RVU with an overall average standard deviation of 3.0 RVU for replicate analyses (two replicates per mean).

^b Sample weight: 2.58 g (dwb) per 25 mL of water.

TABLE VI
Line of Best-Fit Equations^a that Describe the Relationship Between Peak Hot Paste Viscosity and Prime Starch Concentration, and 95% Confidence Limits (CL) for Equation Parameters

Cultivar	95% CL		95% CL		95% CL	
	a ₀	Lower Upper	a ₁	Lower Upper	a ₂	Lower Upper
Klasic	-79	-117 -40	52	35 69	1.94	1.73 2.15
McKay	-90	-161 -18	25	6 44	2.50	2.01 2.99
Madsen	-143	-238 -48	32	7 58	2.35	1.85 2.85

^a $y = a_0 + a_1(x^{a_2})$, where y is the peak hot paste viscosity and x is the quantity of starch (dwb).

sults with those described earlier, two main issues emerged. First, prime and tailing starches exhibited either similar or markedly different inherent pasting properties, depending on the flour source. Secondly, the combined results on water solubles and gluten fractions (Tables IV and V) indicated that the various fractions were interacting in their pasting behavior.

The first of these two issues, inherent differences in pasting among prime and tailing starch fractions from different flour sources, was examined in more detail by characterizing the peak hot paste viscosity over a series of concentrations. Figure 1 shows the concentration-dependent increase in paste viscosity for prime starches of the three flours. As seen earlier, Klasic prime starch exhibited significantly higher hot paste viscosity when compared to McKay and Madsen prime starch. However, the graphic presentation suggested that Klasic prime starch exhibited a different concentration and pasting response function, and that at the highest concentrations examined (3.9 and 4.2 g, dwb), viscosity of all three starches were similar. Fitting line equations to the data indicated that indeed Klasic starch had a flatter response curve (lower power function of the exponent, a_2 , Table VI). Comparison of the 95% confidence intervals for the equation coefficients indicated that McKay and Madsen prime starches did not differ significantly in their concentration-dependent pasting response, whereas Klasic did. As an alternative means of simplifying the comparisons among starches, data were also log-transformed and plotted on a log-log scale. However, the extent to which linear equations de-

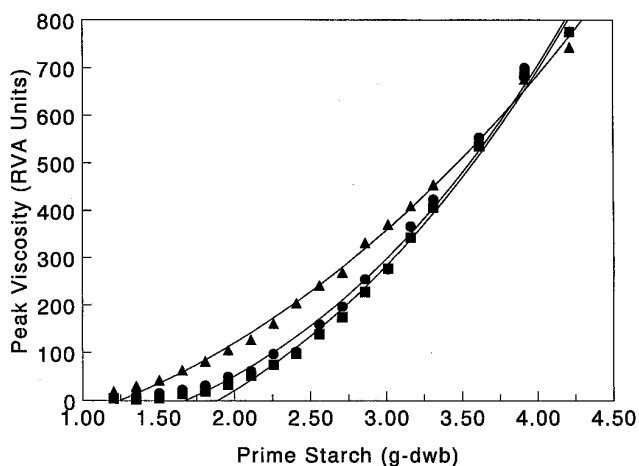


Fig. 1. Peak hot paste viscosity of Klasic (▲), McKay (●), and Madsen (■) prime starches at various concentrations (grams dwb in 25 mL of water) measured by the Rapid Visco Analyzer (RVA).

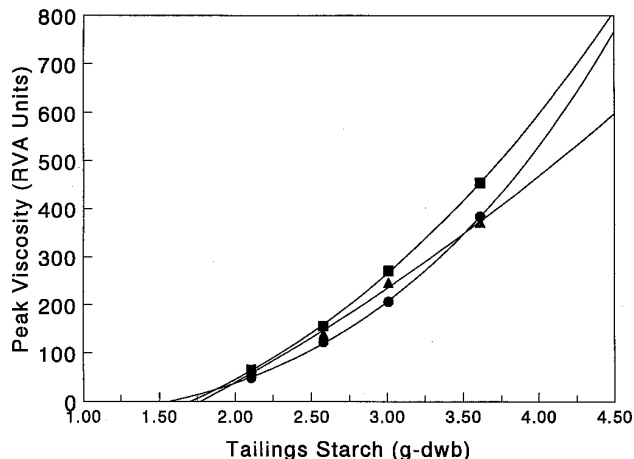


Fig. 2. Peak hot paste viscosity of Klasic (▲), McKay (●), and Madsen (■) tailing starches at various concentrations (grams dwb in 25 mL of water) measured by the Rapid Visco Analyzer (RVA).

scribed the transformed data was deemed to be insufficient to warrant this approach (*data not shown*).

The concentration-dependent response of the tailing starch fractions was also examined (Fig. 2) and found to be in general agreement with the results presented in Table V. Again, the response curve for Klasic was relatively flatter than that of McKay and Madsen.

To assess the importance of these results in determining the overall pasting properties of the parent flours, a concentration series was first conducted for the parent flours (Fig. 3). Next, the peak paste viscosity data for the parent flours were plotted on the basis of the quantity of prime starch contained in the flours along with the curves for the respective prime starch fraction (Fig. 4). For example, 3 g of Klasic flour contains 66.1 g starch/100 g of flour (Table II), or 2 g of prime starch. As can be seen from the plots, a large difference in peak hot paste viscosity between the parent flours and prime starch existed for all three cultivars. Although the prime starch curves of McKay and Madsen were similar, with Klasic being markedly different (Fig. 1), here the adjusted flour curves for Klasic and McKay were nearly identical, whereas Madsen was markedly different. For ease of comparison, all three adjusted flour curves are presented in Figure 4D.

For each flour, a considerable amount of peak hot paste viscosity remained beyond that which could be accounted for simply by the contribution of the prime starch alone. Consequently, the contribution of tailing starch was assessed. Considering the concentration series presented in Figure 2, the fraction yield data of Table II, and the line equations in Table VI, it appeared that tailing starch, although a minor fraction in terms of flour composition, could make a significant, additive contribution to flour peak hot paste viscosity. The yield of tailing starch ranged from 8.3 to 9.8 g/100 g of parent flour (Table II). As such, at a given level of flour (e.g., 3.0 g), the quantity of tailing starch would be 0.25–0.29 g. Given that this same 3.0 g quantity of flour contains ≈ 67 g/100 g of prime starch, or 2.0 g (average yield of the three cultivars) (Table II), then the difference in hot paste viscosity between 2.0 g of prime starch and 2.0 g of prime starch plus 0.25 g of tailing starch may be calculated from the equations given in Table VI. The result predicts 2.0 g of Madsen prime starch produces a peak hot paste viscosity of 20, whereas 2.25 g produces a viscosity of 72. Using 4.0 g of flour and the same assumptions, the result is 181 and 283 RVU (without and with tailing starch, respectively). In general agreement with this assessment were the results presented in Table IV, which indicated that deleting the tailing starch fraction from an otherwise reconstituted flour produced a marked reduction in paste viscosity.

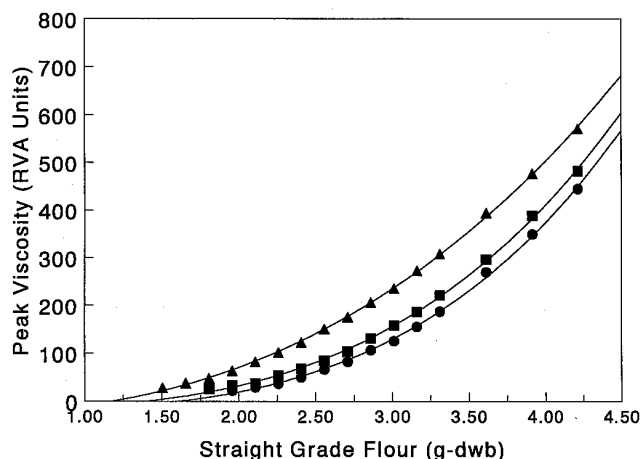


Fig. 3. Peak hot paste viscosity of Klasic (▲), McKay (●), and Madsen (■) straight-grade flours at various concentrations (grams dwb in 25 mL of water) measured by the Rapid Visco Analyzer (RVA).

To further explore the nature of the interaction of flour fractions in peak hot paste viscosity, flours were reconstituted by substituting, singly, the same fraction from a different cultivar. Substituting Klasic prime starch with Madsen prime starch substantially decreased the peak viscosity of the reconstituted Klasic flour (Table VII). Substituting McKay and Madsen prime starches with Klasic prime starch substantially increased the peak hot paste viscosity of the reconstituted flours over that obtained by simply reconstituting McKay and Madsen (controls). Substituting Klasic tailing starch with Madsen tailing starch slightly increased the paste viscosity compared to the Klasic reconstituted control, whereas substituting Madsen and McKay tailing starch fractions with that of Klasic appeared to have little effect.

The fraction deletion and individual fraction constant-weight results presented in Tables IV and V, respectively, indicated that water soluble and gluten fractions, in particular, while contributing no temperature-dependent increase in paste viscosity themselves, profoundly influenced the pasting behavior of the other flour fractions in a reconstituted flour. Substituting Klasic water solubles with Madsen water solubles decreased peak hot paste viscosity of the reconstituted Klasic flour (Table VII). Conversely, substituting McKay and Madsen water solubles with those of Klasic increased peak hot paste viscosity of both flours. Interchanging the gluten fractions of Klasic and Madsen had little effect, whereas substituting the gluten fraction of McKay with that of Klasic increased paste viscosity somewhat.

To summarize this series of experiments, we concluded that there was a positive effect of Klasic prime starch and water solubles when compared to the prime starch and water-soluble fractions of Madsen and McKay, and that tailing starches were more or less similar in effect. Likewise, with the possible exception of McKay, the gluten fractions were also similar among the flours of the three cultivars. These experiments had the advantage over the simple fraction deletion series in that the weight of material and the general composition of the flours were held constant.

As a final means of examining the issue of interaction of fractions and differences among flours, 3, 6, or 12% of a common starch was replaced with each of the fractions derived from the parent cultivar flours (Table VIII). The peak hot paste viscosity of the base starch was 252 RVU. Deleting 3, 6, or 12% of the base starch decreased peak hot paste viscosity in line with what would be expected from Figure 1 and predicted from Table VI. Substituting prime starch from the three cultivar flours had little effect, although a trend of a slight decrease with increasing substituted amount of Madsen and McKay was present. A similar trend was observed with substitution by tailing starch, although the decrease was more pronounced. With water solubles, the decrease in peak hot paste viscosity with increasing level of substitution was pronounced, producing lower viscosities than the base starch without substitution. Again, Klasic appeared to be less deleterious than Madsen and McKay (Table IV).

The addition of gluten, although not producing the level of peak

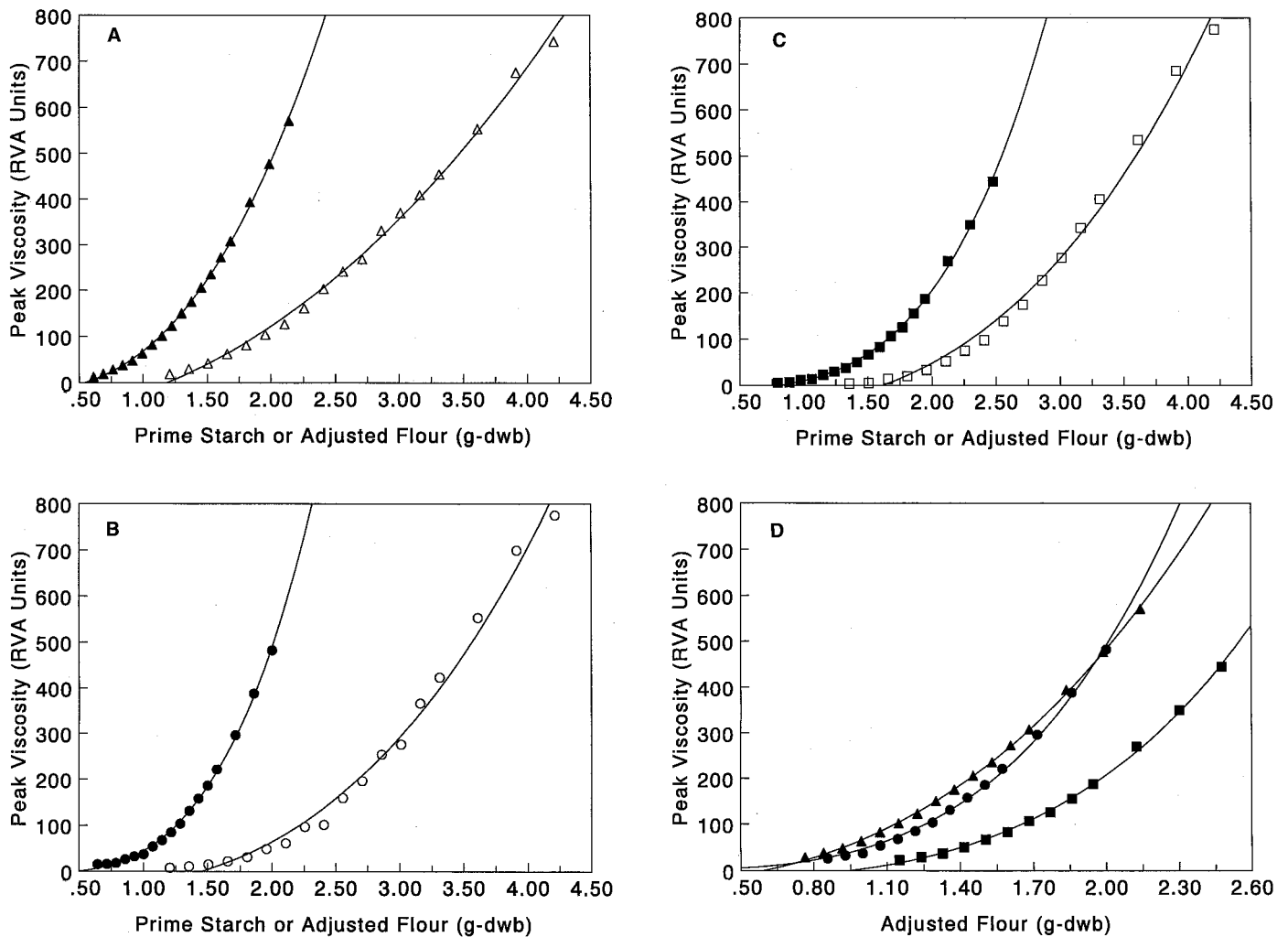


Fig. 4. Peak hot paste viscosity of Klasic (A), McKay (B), and Madsen (C) prime starches (open symbols) and flours (closed symbols). Prime starches at various concentrations (grams dwb in 25 mL of water); flours plotted on the basis of calculated prime starch content of straight-grade flours (66.1, 63.9, and 71.1 g of prime starch/100 g of flour for Klasic, McKay, and Madsen, respectively). Klasic (▲), McKay (●), and Madsen (■) flours plotted on the basis of prime starch content (D) as described for A–C. Viscosity measured by the Rapid Visco Analyzer (RVA).

hot paste viscosity of the original 2.58 g of base starch, did compensate somewhat for the removal of base starch. Since gluten exhibited no intrinsic pasting viscosity of its own (Table V), the combined data from this series of experiments and those illustrated in Table VI suggested that the role of gluten was probably related to altered water relations, i.e., a sequestration of system water such that the effective starch concentration was increased.

DISCUSSION

The inherent peak hot paste viscosity of sound (nonsprouted) wheat flours is due first and foremost to the pasting potential of the prime starch fraction (Table IV) (Loney and Meredith 1974, Loney et al 1975), which is largely determined by the relative content of amylose and amylopectin (Loney et al 1975, Moss 1980, Moss and Miskelly 1984, Endo et al 1989, Zeng et al 1997). The lower amylose content of Klasic prime starch makes the starch from this cultivar inherently higher pasting (Zeng et al 1997). However, this higher peak hot paste viscosity may be concentration-dependent, because Figure 1 shows that all three cultivar starches exhibited similar peak viscosities at ≈16% slurry concentration (4 g/25 mL). It is conceivable that beyond this concentration, given sufficient mechanical shear, that Klasic prime starch (and possibly flour) would be lower pasting relative to starch of the other cultivars. The results of Allen et al (1991) also suggest convergence of different starch pasting response curves at higher concentrations.

In addition to inherent differences in peak hot paste viscosity among prime starches of different cultivars, tailing starch and water solubles seem to exert a significant differential effect. Clearly, water relations per se are a crucial consideration as evidenced by the effect of gluten. It seems reasonable to assume that competition for water during gelatinization in the high-concentration slurries used here would be considerable, and the highly hygroscopic nature of soluble and insoluble pentosans is noteworthy in this context (Jelaca and Hlynka 1971). Additionally, water solubles may contain varying amounts of amylases and proteases, even in the absence of sprout (Moss 1967).

In summary, flours with markedly different peak hot paste viscosities can be fractionated and reconstituted without much adverse effect on paste viscosity. Clearly, prime starch is the primary determinant of flour paste viscosity. However, tailing starch, water solubles, and gluten fractions all exert an effect. For tailing starch and gluten, this effect is positive either due directly to pasting capacity of starch (in tailings) or through competition for water, as in the case of gluten and deduced to be the case with pentosans. The water-soluble fraction from different cultivar flours was more variable in effect, possibly due to various combinations or levels of soluble pentosans and other constituents that compete for water, versus amylases or proteases.

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TABLE VII
Effect of Substituting Individual Flour Fractions from Another Flour on Peak Hot Paste Viscosity (RVU)^a

Reconstituted Flour	Fraction Substituted	Control	Fraction Substituted			
			Prime Starch	Tailing Starch	Water Solubles	Gluten
Klasic	Madsen	191	115	210	161	190
McKay	Klasic	115	172	124	132	137
Madsen	Klasic	104	186	105	140	101

^a Rapid Visco-Analyser units ≈ cP/11.6.

TABLE VIII
Effect of Substituting 3, 6, or 12% of a Common Starch Base with an Equivalent Amount (RVU)^a of Each of the Individual Flour Fractions

Source of Flour Fraction	% Substituted	Control ^b	Fraction Substituted			
			Prime Starch	Tailing Starch	Water Solubles	Gluten
Klasic	0	252	...	...	...	...
	3	225	248	229	211	231
	6	201	243	226	174	209
	12	153	242	219	139	180
McKay	0	252	...	...	...	...
	3	225	248	224	197	226
	6	201	239	220	161	211
	12	153	232	213	106	190
Madsen	0	252	...	...	...	...
	3	225	249	228	183	231
	6	201	241	225	146	213
	12	153	237	218	110	186

^a Rapid Visco-Analyser units ≈ cP/11.6.

^b Control equals the peak hot paste viscosity obtained by removing 0, 3, 6, or 12% of the base starch without substitution. Standard deviation for the 0% substituted control (base starch) was 15.8 RVU (four replicates).

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