

## Physicochemical Properties of Australian Flours Influencing the Texture of Yellow Alkaline Noodles

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### ABSTRACT

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Flour properties of 25 Australian wheat cultivars were examined for their relationship to alkaline noodle quality. Rapid Visco Analyzer (RVA) analyses of flours showed that RVA breakdown and final viscosity determined in both water and dilute sodium carbonate were significantly related to the alkaline noodle firmness, elasticity, and surface smoothness. Flour swelling volume (FSV) of flours was negatively correlated with alkaline noodle firmness and elasticity, and positively correlated with surface smoothness of cooked noodles. Use of a dilute sodium carbonate solution led to overall increases in both paste viscosity and FSV. High FSV and low RVA final viscosity values were associated with both

the softest noodles and with cultivars containing a null allele for granule-bound starch synthase on chromosome 4A. Flour protein content and SDS sedimentation volumes were significantly related to noodle texture. The relationship between protein content and noodle firmness was dependent on the Null4A status of the flours and suggested an interaction between starch and protein in determining noodle texture. Multiple regression analysis using flour protein and FSV accounted for 76% of the variation in alkaline noodle firmness. A speculative model of noodle structure was developed based on a concept of the cooked noodle as a composite material.

Alkaline noodles are popular foods in Southeast Asia, Southern China, and Japan. A variety of types is manufactured with different ingredient additions (salts, egg, etc.). They also differ in their optimum protein content and in the type of processing (e.g., steaming, drying, frying, or parboiling) used before being supplied to the consumer. The most common alkaline salts used in noodle production are sodium and potassium carbonates and sodium hydroxide. These can be used alone or in combination, with or without sodium chloride (Miskelly and Moss 1985). The inclusion of alkaline salts at 1.0% (w/w, flour basis) in noodle formulations produces noodle doughs with pH values in the 9.9–11.4 range (Moss et al 1986).

Texture of cooked alkaline noodles should be firm and elastic (or springy) with a smooth surface. Both higher flour protein content (Miskelly and Moss 1985, Moss et al 1987, Shelke et al 1990) and high protein quality (dough strength, SDS sedimentation volume) (Miskelly and Moss 1985, Huang and Morrison 1988, Baik et al 1994) have been associated with firmer bite, increased cutting stress, and increased hardness of alkaline noodles. Flour protein content and high dough strength have also been positively related to more elastic alkaline noodles (Miskelly and Moss 1985) and flour protein content has been negatively related to both noodle surface smoothness (Moss et al 1987) and visual brightness (Miskelly and Moss 1985).

Starch attributes also play a role in determining texture of alkaline noodles. This was illustrated by Konik et al (1994), who showed that the inclusion of starch (or flour) pasting or swelling characters with protein content in multiple regression analyses was needed to account for a majority of the variation in alkaline noodle texture. In particular, high starch or flour peak viscosities (Moss 1982, Miskelly and Moss 1985) and swelling power (Konik et al 1994) have been negatively related to alkaline noodle firmness, producing softer and less desirable noodles. Consistent with their association with less firm alkaline noodles, wheat starches that confer high peak paste viscosities (Moss 1979, Crosbie 1991, Konik et al 1992) or high swelling power (Toyokawa et al 1989,

Crosbie 1991, McCormick et al 1991, Crosbie et al 1992, Konik et al 1993, Yun et al 1996) have been associated with the desirable soft and elastic eating quality of Japanese white salted noodles and to high quality Korean white salted noodles (Lee et al 1987). These high-swelling starches have also been associated with a null allele for the granule-bound starch synthase (GBSS) protein encoded on chromosome 4A (Null4A) (Zhao et al 1995) and to lower amylose contents (Yamamori et al 1992, Nakamura et al 1993, Miura and Tanii 1994, Zeng et al 1997). However, up to this point, no studies have reported a relationship between the GBSS Null4A status of wheats and their suitability for alkaline noodle manufacture.

This study set out to confirm and clarify earlier work relating flour pasting and swelling properties and flour protein content and quality to alkaline noodle texture. The study also intended to determine whether the Null4A status of wheats has any influence on suitability for alkaline noodle production. An additional aim was to develop a model for the internal structure of cooked noodles. The results of this article are based on observations of Cantonese-style noodles manufactured using sodium carbonate as the sole alkaline salt.

### MATERIALS AND METHODS

#### Flour Samples

Sixty-two Australian wheat samples made up of 25 wheat cultivars and advanced breeders' lines grown at three different sites (Narrabri and Condobolin, New South Wales, and Norwin, Queensland) from the 1993–94 season (Australian Interstate Wheat Variety Trials, 23B series; IWVT23B) were selected for this study. Thirty-seven samples, representing 15 lines were normal for the GBSS gene on chromosome 4A (Plus4A) and 25 samples, representing 10 lines were Null4A. All wheat samples were milled to 60% extraction using a Buhler experimental mill. Data from the different sites was pooled because the effect of growth site within a crop year is the least influential of the factors influencing FSV (cultivar, crop year, and growth location) (Morris et al 1997). The average, range, and standard deviation of selected analytical data for the 62 flour samples are shown in Table I.

#### $\alpha$ -Amylase Determinations

$\alpha$ -Amylase was determined by the method of McCleary and Sheehan (1987) (Megazyme, Ireland). The method is based on the release

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of the chromophore, *p*-nitrophenol, from a blocked *p*-nitrophenol maltoheptaoside, by the combined action of  $\alpha$ -amylase extracted from flour and glucoamylase and amyloglucosidase in the reagent mixture.

### Rapid Visco Analyzer (RVA) Testing

The pasting properties of flour were determined using a method reported previously (Konik et al 1994). Flour (4 g) was added to deionized water (25 mL) and placed in the RVA. While stirring, the mixture was equilibrated to 65°C for 2 min before the block temperature was ramped to 95°C at 15°C/min and held at that temperature for a further 6 min. Block temperature was reduced to 50°C at 15°C/min and held at that temperature for a further 5 min.

Definitions of terms used include: peak viscosity (PV), highest viscosity during 95°C heating stage; holding viscosity (HV), lowest viscosity during 95°C heating stage; breakdown (BD), difference between peak and holding viscosity; final viscosity (FV), highest viscosity at during 50°C cooling stage.

The effect of alkaline conditions on RVA pasting properties was examined by the use of a 3.125% (w/v) sodium carbonate solution (alkaline RVA [ARVA]). This was equivalent to the concentration of sodium carbonate used in the dough water during noodle manufacture (1%, w/w, flour basis). RVA parameters measured in alkali will be termed APV, AHV, ABD, and AFV and defined in the same way as the parameters above.

### Flour Swelling Volume

Flour swelling volume (FSV) was determined using a previously published method (Crosbie et al 1992) and its modification (Crosbie and Lambe 1993). The effect of alkaline conditions on FSV was examined by the use of a 0.4% (w/v) sodium carbonate solution (alkaline FSV [AFSV]). The 3.125% solution used in RVA testing was not used as it caused the flour samples to swell to such an extent that they could not be contained within the tubes used for the determinations.

### SDS Sedimentation Testing

Sodium dodecyl sulfate sedimentation determinations were performed following the method of Axford et al (1979).

### Noodle Preparation and Quality Evaluation

Alkaline noodles were made from the flours using a previously published method (Moss et al 1987). Sodium carbonate was used as the sole salt. For sensory evaluations of noodle texture, three

samples were tested at each panel session along with known firm and soft reference samples. The firm reference sample was a 60% extraction flour milled from grain of the cultivar Sunco. The soft reference sample was a low protein, straight-run flour milled from grain of the cultivar Rosella. Both reference samples were milled on the BRI Australia pilot mill. Sensory evaluations were performed by a trained panel of at least five members. Panelists were asked to rate the intensity of each of three textural parameters: firmness, elasticity, and surface smoothness. The relative intensity of each parameter was marked on a separate 15-cm unstructured line scale on which the relative positions of the reference samples were indicated. Scores were calculated as the distance in centimeters from the origin of each line. Panelists were isolated from each other in neutral-colored booths lit with daylight (6,400 K) fluorescent tubes. Samples were presented in room temperature water in white dessert bowls exactly 15 min after cessation of cooking. The only sample identification known to the panelists was a random three digit code number. Noodles were dipped momentarily in a warm thin soy soup (dashi) immediately before assessment to aid palatability.

### Typing for GBSS Null-4A Waxy Allele

Samples were typed for the GBSS Null-4A waxy allele using the method of Zhao and Sharp (1995).

### Other Analytical Methods

Protein content ( $N \times 5.7$ ) of flour and grain hardness (particle size index) were determined by near-infrared reflectance (Konik et al 1993).

### Statistical Analyses

Statistical analyses were made using MSUSTAT 4.0 (E. Lund, Montana State University, Bozeman, MT) and the data analysis tools of Microsoft Excel 5.0. Residual errors were determined using analyses of variance (ANOVA). Multiple comparisons were made using Student's *t* test (least significant difference [LSD] values) and were calculated using the residual mean squared from ANOVA. LSD values were calculated using a probability level of  $P = 0.01$  unless otherwise specified. Linear correlation coefficients were calculated and significance for *r* is given at a probability level of  $P = 0.001$  unless otherwise specified.

TABLE I  
Analytical Data of 62 Wheat Flour Samples

	Mean	Range	Standard Deviation
Flour protein (%)	10.8	8.9–12.6	0.8
Particle size index (grain hardness)	16.7	10–26	4.5
SDS sedimentation volume (mL)	63.5	47.5–74.5	6.7
Flour swelling volume (mL/g)	15.7	12.2–22.7	2.6
Alkaline swelling volume ( $n = 19$ )	25.5	21.4–31.9	3.3
Flour color			
<i>L</i> *	92.5	90.2–93.9	0.6
<i>a</i> *	-0.4	-0.9–0.0	0.2
<i>b</i> *	9.6	7.6–12.1	1.1
$\alpha$ -amylase (Ceralpha units)	0.054	0.036–0.084	0.013
Flour paste viscosity (RVU) <sup>a</sup>			
Water			
Peak	274	197–331	28.7
Holding	131	70–169	17.5
Setback	283	161–359	25.6
Alkaline solution			
Peak	433	367–479	25.1
Holding	158	130–186	14.6
Setback	333	274–411	36.3

<sup>a</sup> Rapid Visco Analyser units measured on 65°C–95°C–50°C profile.

TABLE II  
Mean Values<sup>a</sup> of Protein Content, Flour Swelling Volume (FSV), Flour Paste Viscosity (RVA)<sup>b</sup>, and Noodle Textural Parameters as Categorized by Null4A Status

Parameters <sup>c</sup>	Null4A	Plus 4A	LSD	<i>P</i>
Flour protein (%) <sup>d</sup>	10.4	11.1	0.5	0.000
FSV (mL/g)	18.3	14.1	1.1	0.000
RVA				
PV	282	269	19.8	0.076
HV	119	140	9.9	0.000
FV	246	308	19.0	0.000
BD	163	129	13.5	0.000
ARVA				
APV	439	429	17.6	0.148
AHV	146	166	7.7	0.000
AFV	296	357	12.5	0.000
ABD	293	264	15.2	0.000
Noodle texture scores				
Firmness	6.6	8.5	0.7	0.000
Elasticity	6.6	8.7	0.6	0.000
Surface smoothness	12.2	10.8	0.5	0.000

<sup>a</sup> Mean, least significant difference (LSD), and *P* values ( $P \leq 0.01$ ) from analysis of variance (ANOVA).

<sup>b</sup> Measured in Rapid Visco Analyser units.

<sup>c</sup> PV = peak viscosity; HV = holding viscosity; BD = breakdown; FV = final viscosity. Parameters measured in alkali are APV, AHV, ABD, and AFV, respectively.

<sup>d</sup>  $N \times 5.7$ .

## RESULTS AND DISCUSSION

### Noodle Texture

Sensory testing of noodle texture indicated highly significant correlations between the three noodle texture parameters:  $r = -0.86$  between smoothness and firmness;  $r = -0.82$  between smoothness and elasticity; and  $r = 0.94$  between firmness and elasticity. The results were in line with previous results showing indirectly that as noodles (either alkaline or salted) become firmer they generally become less smooth (Konik et al 1992, 1993, 1994). The relationship between firmness and elasticity of alkaline noodles seen in this study is very strong. A positive relationship between these two parameters has been observed previously in alkaline noodles, although again, indirectly (Miskelly and Moss 1985). In contrast to the relationships observed between alkaline noodle firmness and elasticity, the results of both Crosbie (1991) and Konik et al (1992) have indicated a negative relationship between firmness and elasticity (positive between softness and elasticity) in white salted noodles. To simplify the discussion from this point on, noodle firmness alone will be referred to unless otherwise specified. This was due to the strong correlations observed between the three textural parameters.

### RVA Pasting Properties

ANOVA showed that all RVA pasting properties except PV and APV were significantly dependent on Null4A status of the samples (Table II). Addition of alkali to the solution used for flour pasting increased the mean values for APV, AHV, and AFV of heated flour suspensions (Table I) when compared to the same parameters measured in water. This concurs with earlier results that showed increased Brabender Visco/Amylograph peak viscosity after addition of carbonates (Moss et al 1986). The same RVA parameters determined in water and dilute alkali were highly correlated, with the exception of PV and APV. This lack of correlation between PV and APV may have been due to very low but detectable levels of  $\alpha$ -amylase (Table I) in these flour samples, which were considered to be sound and had predicted grain Falling Number values  $>430$  sec (McCleary and Sheehan 1987). How-

ever, despite the low levels of  $\alpha$ -amylase activity present, they were sufficient to have a significant effect on PV ( $r = -0.498$ ,  $P \leq 0.01$ ) but had no significant effect on APV. Previous studies have highlighted the necessity to inactivate  $\alpha$ -amylase activity in flour or wholemeal when screening samples for potential noodle quality (Crosbie and Lambe 1993, Bhattacharya and Corke 1996). This work has served to highlight the large impact that even very low levels of  $\alpha$ -amylase activity can have on interpretation of pasting data from flour samples. Inactivation of  $\alpha$ -amylase can also be achieved at pH values  $>8.5$  (Greenwood and Milne 1968, Barnes and Blakeney 1974). As a result of this, and due to the relevance to the product under investigation, only ARVA results will be used for comparisons with alkaline noodle texture results (Bhattacharya and Corke 1996).

Significant correlations were observed between all ARVA flour pasting parameters and surface smoothness, firmness and elasticity of alkaline noodles (Table III). Comparison with similar work where flour pasting was performed in water (Konik et al 1994), shows a high degree of alignment, both in the magnitude and sign, of the  $r$  values obtained (Table III). The best RVA parameters for prediction of alkaline noodle texture in the current study were AFV and ABD. In particular, decreasing AFV was correlated with smoother, less firm and less elastic noodle texture. However, the correlations between AFV and alkaline noodle firmness may be misleading as they result from a basically two-point regression (Fig. 1). In addition, there were no significant correlations between AFV and noodle firmness when the correlations for the two populations (Null4A, Plus4A) were calculated separately. The division into two discrete populations was not so pronounced for the relationships between noodle firmness and ABD, and BD and FV in water. In the current study, RVA parameters were also related to noodle elasticity, in contrast to the earlier study of Konik et al (1994).

### Flour Swelling Volume

ANOVA showed that FSV was significantly dependent on the Null4A status of the samples (Table II). These results were in accordance with earlier results (Zhao et al 1995) which indicated a strong genetic component in determining FSV. Flour swelling characteristics may also be considered to give a good approximation of starch swelling characteristics as Konik et al (1994) indicated a high degree of agreement between both starch and flour swelling properties suggesting that FSV is largely determined by the swelling capacity of the starch.

Mean FSV observed in AFSV testing were higher than those observed when FSV was determined in water only (Table I).

TABLE III  
Correlation Coefficients for Noodle Texture Parameters and Flour Pasting Properties<sup>a</sup>

	Smoothness	Firmness	Elasticity
RVA flour paste viscosity <sup>b</sup>			
Water			
Peak	0.26*	-0.12	-0.06
Holding	-0.48***	0.52***	0.56***
Final	-0.63***	0.61***	0.63***
Breakdown	0.63***	-0.50***	-0.45***
Water <sup>c</sup>			
Peak	0.41	-0.34	-0.38
Holding	-0.65***	0.64**	0.40
Final	-0.66***	0.66***	0.40
Breakdown	0.59**	-0.56**	0.38
Alkaline solution			
Peak	0.33**	-0.32**	-0.37**
Holding	-0.37**	0.39**	0.36**
Final	-0.69***	0.65***	0.59***
Breakdown	0.53***	-0.54***	-0.56***
Flour swelling volume (mL/g)	0.79***	-0.82***	-0.78***
Alkaline FSV (mL/g) <sup>d</sup>	0.92***	-0.86***	-0.81***
Flour swelling power <sup>c</sup>	0.58**	-0.43*	-0.25
Flour protein content (%)	-0.65***	0.71***	0.68***
SDS sedimentation volume (mL)	-0.38**	0.42**	0.42**

<sup>a</sup> \*, \*\*, \*\*\* indicate  $P \leq 0.05$ , 0.01, and 0.001, respectively.

<sup>b</sup> Measured in Rapid Visco Analyser units ( $n = 60$ ). Determinations performed in both water and dilute sodium carbonate solutions.

<sup>c</sup> Data from Konik et al (1994).

<sup>d</sup> FSV = flour swelling volume. Determinations performed on 19 samples from the Narrabri site only.

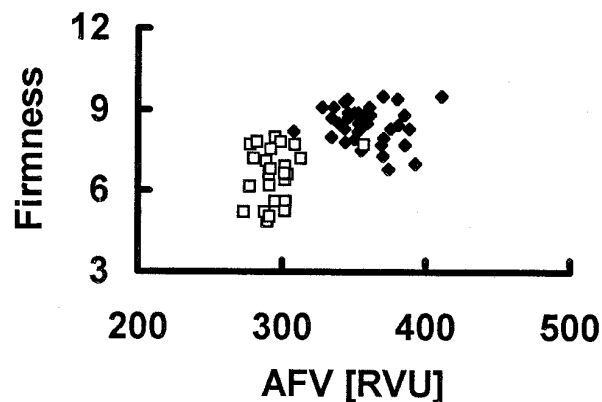


Fig. 1. Rapid Visco Analyzer (RVA) alkaline final viscosity (AFV) vs. sensory firmness scores for 60 flour samples representing 25 genotypes from the 1993-94 Australian Interstate Wheat Variety Trials (23B series). Null4A samples indicated by open symbols; Plus4A samples indicated by closed symbols.

There was a highly significant correlation between the results of the FSV and AFSV tests (Table IV). This result was a further indication of the relative insensitivity of the FSV test to low levels of  $\alpha$ -amylase that had been observed previously by Crosbie and Lambe (1993). FSV was significantly related to all RVA pasting properties except PV in water (Table IV).

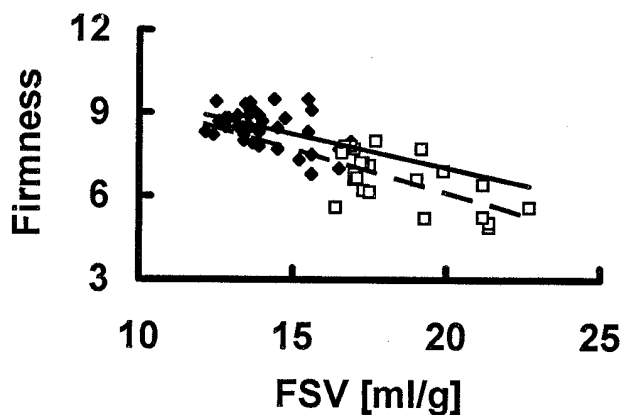
Increasing FSV was correlated with less firm (Fig. 2), less elastic and smoother noodles (Table III). However, in contrast to the relationship between AFV and firmness, the correlations between FSV and noodle firmness were both significant when calculated separately for the Null4A ( $P \leq 0.001$ ) and Plus4A ( $P \leq 0.05$ ) populations. In addition, the regression coefficients and intercepts of the two populations were not significantly different (Table V). This suggests that the FSV values, despite arising from two genetically distinct populations, form a single continuous population in terms of the effects of FSV on noodle firmness.

Previous work has also related high swelling volumes to smoother and less firm alkaline noodles (Konik et al 1994). In addition, Miskelly and Moss (1985) indicated that lower Brabender Visco/Amylograph peak viscosity, in the absence of  $\alpha$ -amylase activity, was desirable for alkaline noodles. They considered that the increased peak viscosity observed in alkaline solution would lead to overly soft noodles at high pH, and that this softening would be accentuated with high peak viscosity genotypes. The results of the FSV determinations in this study and the increased

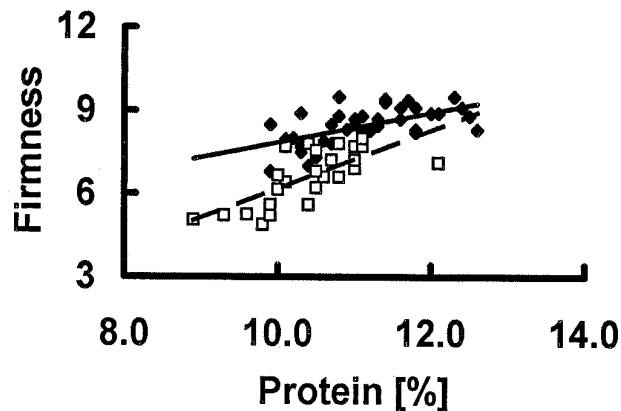
volume occupied by the gels in alkaline conditions support the hypothesis of Miskelly and Moss (1985). However, the structure of the starch in the flour gel produced in the FSV test, or other static starch-flour gels, may more closely describe the structure of the starch in a noodle (Wang and Seib 1996) than pasting analyses. The latter are often determined in conditions of high shear, where granule integrity can be completely disrupted leading to amylopectin dissolution, which may not occur with intact gelatinized granules. As a consequence, it may be possible to learn more of the structure-function relationships of starch in noodles from investigations of gels produced in conditions of low shear, rather than pastes. This is despite potential limitations of low shear starch or flour gels, such as being produced in excess water and also in the absence of the swelling and water restrictions imposed by the developed gluten network and the compressed nature of a noodle dough.

**Protein Content and SDS Sedimentation Volumes.**

Increased protein content gave significantly firmer (Fig. 3), more elastic, and less smooth alkaline noodles (Table III). In addition, SDS sedimentation volumes were also significantly and positively related to alkaline noodle firmness and elasticity, and negatively to surface smoothness (Table III). However, the magnitude of the correlation coefficients and the level of significance were both lower than those observed for protein content. This



**Fig. 2.** Flour swelling volume (FSV) vs. sensory firmness scores for 61 flour samples representing 25 genotypes from the 1993-94 Australian Interstate Wheat Variety Trials (23B series). Null4A samples indicated by open symbols and dashed regression line; Plus4A samples indicated by closed symbols and solid regression line.



**Fig. 3.** Flour protein content (%) vs. sensory firmness scores for 62 flour samples representing 25 genotypes from the 1993-94 Australian Interstate Wheat Variety Trials (23B series). Null4A samples indicated by open symbols and dashed regression line; Plus4A samples indicated by closed symbols and solid regression line.

**TABLE IV**  
Correlation Coefficients<sup>a</sup> Between Flour Pasting Properties<sup>b</sup> and Flour Swelling Volume (FSV) Determinations<sup>c,d</sup>

	Water			Alkaline Solution					
	HV	FV	BD	APV	AHV	AFV	ABD	FSV	AFSV
Water									
PV	0.47***	0.24	0.78***	0.36**	-0.01	-0.16	0.36**	0.34**	0.36
HV		0.95***	-0.15	0.00	0.56***	0.59***	-0.31	-0.45***	-0.53
FV			-0.38**	-0.03	0.64***	0.76***	-0.38**	-0.57***	-0.71***
BD				0.41***	-0.39**	-0.58***	0.62***	0.70***	-0.80***
Alkaline solution									
APV					0.25	0.08	0.84***	0.43***	0.39
AHV						0.79***	-0.33	-0.49***	-0.62**
AFV							-0.37**	-0.64***	-0.83***
ABD								0.70***	0.69***
FSV									0.89***

<sup>a</sup> \*\*,\*\*\* indicate  $P \leq 0.01$  and  $0.001$ , respectively.

<sup>b</sup> Measured in Rapid Visco Analyser (RVA) units. Determinations performed in both water and in 3.125% (w/v) sodium carbonate solutions ( $n = 60$ ).

<sup>c</sup> FSV = flour swelling volume ( $n = 60$ ). Alkaline FSV determinations were performed in 0.4% w/v sodium carbonate solutions on samples from the Narrabri site only ( $n = 19$ ).

<sup>d</sup> PV = peak viscosity; HV = holding viscosity; FV = final viscosity; BD = breakdown. Parameters measured in alkali are APV, AHV, AFV, and ABD, respectively.

suggests that protein content had a more substantial role in determining noodle texture than protein quality for this sample set. Previously, both Huang and Morrison (1988) and Baik et al (1994) had demonstrated a stronger relationship between SDS volume and noodle texture (cutting force and texture profile analysis, respectively) than the relationship they observed between protein content and noodle texture. This discrepancy is not necessarily at odds with the current results, given the divergent genetic backgrounds of the sample sets used in the three studies. However, the range of SDS volumes observed in this study (Table I) was narrower than those in the studies of Huang and Morrison (1988) and Baik et al (1994) (42–88 and 17.3–87.2 mL, respectively), possibly leading to the emphasized relationship with protein content. When regression coefficients were calculated for protein content versus noodle firmness with the Null and Plus4A populations considered separately (Fig. 3, Table V), the regressions were significantly different from each other ( $P \leq 0.05$ ), in contrast to the FSV results (Fig. 2). This indicated a faster rise in perceived noodle firmness with unit increases in protein content in the Null4A group when compared to the Plus4A group, which could indicate a potential physical interaction between starch characteristics and protein content not previously observed. Flour protein content was negatively and significantly related to FSV for this sample set ( $r = -0.51$ ,  $P \leq 0.01$ ). Nevertheless, a partial correlation coefficient of  $-0.76$  ( $P \leq 0.01$ ) was calculated for FSV and noodle firmness while holding flour protein constant. This indicated a fundamental link between FSV and noodle firmness, independent of any influence of flour protein content.

#### Multiple Regression Analyses.

Multiple regressions were calculated using flour protein content and FSV as the independent variables and noodle texture parameters as individual dependent variables. The  $r^2$  values for the multiple regressions using FSV were 0.76, 0.70, and 0.69 for firmness, elasticity, and surface smoothness, respectively. These results compared favorably with the results of Konik et al (1994), who were able to account for a similar amount of variation in noodle firmness, but who used the additional independent variables Falling Number and particle size index. The results of both studies suggest that alkaline noodle firmness is determined by flour protein content and starch characteristics acting in concert.

#### GBSS Null4A Status.

The Null4A samples were lower in mean flour protein content, higher in FSV, lower in AFV, and produced smoother, softer, and less elastic noodles (Table II). High FSV lines were associated with softer alkaline noodles (Fig. 2) and were almost all of the Null4A type. The physical relationship of FSV, or starch swelling, to noodle texture seems evident. More swollen granules with a diffuse gel structure will be softer than less swollen, more condensed, granules leading to the differences in noodle texture observed. More swollen granules should also fill the surface of the noodle more completely, leading to the smoother surface characteristics also observed in the Null4A group. The presence of a discrete, and probably causative, genetic marker for these traits is

fortuitous. However, there is a range of FSV values within each of the types (Fig. 2), suggesting other starch characteristics may have an influence.

The data appear to present a case that the low FSV lines, which are almost all Plus4A, are potentially more appropriate as raw material for manufacture of Cantonese noodles. Nonetheless, some pragmatism is needed during selection of raw materials for alkaline noodle production. Selection of wheats with extremely low FSV values for alkaline noodle production may be undesirable due to the potential for unacceptably low levels of surface smoothness (Table III). However, as adequate levels of firmness could be achieved at lower protein contents when using low FSV flours, the potential deterioration of surface smoothness associated with low FSV values could be partially offset by the use of lower protein flour. These results are an initial indication only and further investigations are required.

#### Speculative Model of Internal Structure of Cooked Noodles

This model is essentially an extension of a “working model for wheat starch in noodles” developed by Wang and Seib (1996) and focuses on the core region of cooked noodles, which determines the bulk rheology of the product. The core region can be visualized as a composite material made up of two distinct but interconnected phases (Fig. 4). One phase is polymeric and continuous and is made up of a three-dimensional (3D) lattice of gluten proteins and amylose exuded from gelatinized starch granules. The second phase is a discontinuous particulate phase made up of remnant starch granules “glued” into the continuous phase by partly exuded amylose molecules.

The major component of the continuous phase is gluten. During processing of noodle dough, the commonly accepted attributes conferred by the gluten (strength, cohesiveness, and extensibility) are still operational and function to allow the processing of a well-defined and discreet dough piece of sufficient integrity to survive the sheeting process intact. However, the role of the gluten proteins in cooked noodles may differ from their roles in both noodle dough formation and breadmaking. In breadmaking, film forming and interfacial properties of dough related to gas retention and the ability of the dough to allow biaxial extension of gas cells without rupture are critical. Of additional importance is the transfer of water from the gluten to the gelatinizing starch at the end of oven spring, leading to the partial dehydration and subsequent denaturation of the proteins. In noodle manufacture and cooking there is no requirement for gas retention, and the transfer of water from gluten to starch during gelatinization may be very different during boiling of noodles. Even in the core region where water penetration is more limited, it may still be available to the granules in sufficient quantities to enable gelatinization without dehydration of the proteins. However, it may be the propensity of the gluten to form fibrils, their thickness, extent, and integrity of the 3D lattice that may be of primary importance, rather than film-forming capacity. Earlier experimentation has supported these speculations. Moss et al (1986) showed by microscopy that one of the reasons for the softer eating quality of alkaline noodles made from sodium hydroxide was the visible discontinuity of the protein network in the noodle dough, even before boiling.

TABLE V  
Regression Coefficients and Upper and Lower 95% Confidence Limits for Flour Swelling Volume and Flour Protein Content vs. Sensory Firmness of Alkaline Noodles

	Samples	Slope	Lower	Upper	Intercept	Lower	Upper	<i>r</i>
Flour swelling volume								
Null4A	37	-0.31	-0.49	-0.14	12.4	9.1	15.7	-0.62***
Plus4A	23	-0.24	-0.41	-0.07	11.8	9.4	14.2	-0.44*
Flour protein content								
Null4A	37	1.1	0.62	1.5	-4.5	-9.1	0.16	0.72***
Plus4A	25	0.54	0.30	0.78	2.4	-0.27	5.2	0.61**

<sup>a</sup> \*, \*\*, \*\*\* indicate  $P \leq 0.05$ , 0.01, and 0.001.

Amylose found in the polymeric phase will contribute to the rigidity of the polymeric network through retrogradation with other amylose molecules as well as, at the simplest level, through steric entanglements with protein polymers. The existence of more stable interactions between protein and amylose may be possible through hydrogen bond stabilized junction zones, although these have never been demonstrated experimentally. New evidence of the water solubility of internal repetitive regions of some glutenin subunits in the absence of their N and C terminals (Bekkers et al 1996) is suggestive that hetero-polymeric junction zones between glutenin and amylose may be possible. Dexter et al (1979), when observing Japanese noodles using scanning electron microscopy, observed that open areas in the noodles were connected by gluten fibrils and material leached from the starch granules during gelatinization. Their observations are consistent with the model presented for the continuous polymeric phase of the noodle.

The discontinuous phase consists of expanded starch granules that have become enriched in amylopectin due to the loss of amylose during cooking. The gelatinized starch granules, despite their intrinsically polymeric nature, can be thought of as particulate inclusions due to their discrete nature in the core zone (Moss et al 1987). The volume fraction taken up by these inclusions is large in comparison to the surrounding polymeric network. As a consequence, the relative consistency of the granules should have a large effect on the overall texture of the composite. More swollen granules where the internal gel structure is more diffuse should be softer, leading to a softer overall consistency in the composite. The evidence presented in this article seems to support this concept.

Wang and Seib (1996) suggested that low levels of amylose exuded from the granules would produce good elasticity when the continuous amylose phase gelled in white salted noodles. However, they also said that the low-swelling starches of hard wheats, which are probably higher in amylose (Zeng et al 1997), would produce starch gels that are hard and highly elastic in alkaline noodles. It is not clear how to reconcile the two ideas. However, struggles with the term "elasticity" and the physical genesis of its expression are understandable. We believe that a more sophisticated understanding of the architecture of the polymeric components in a noodle strand and of the sensory descriptor "elasticity" in relation to noodle mouthfeel are required before a good conceptual model of the basis of noodle elasticity can be achieved. In a more complete model of noodle structure, modifying factors other than starch swelling and protein content will clearly need to be addressed. These other modifying factors may include protein composition, the effect of alkaline conditions on the gluten proteins (Feeney and Whitaker 1988; Terada et al 1978, 1981), AM/AP ratio, itself affected by the dosage of the *waxy* alleles (Zeng et al 1997), the average molecular weights, polydispersities, and fine structures of all of the polymeric components of the flour, as well as the impact of both the lipid fraction and component interactions.

### CONCLUSIONS

Alkaline noodle texture was influenced by both the protein and starch components of flour. The influence of the starch component

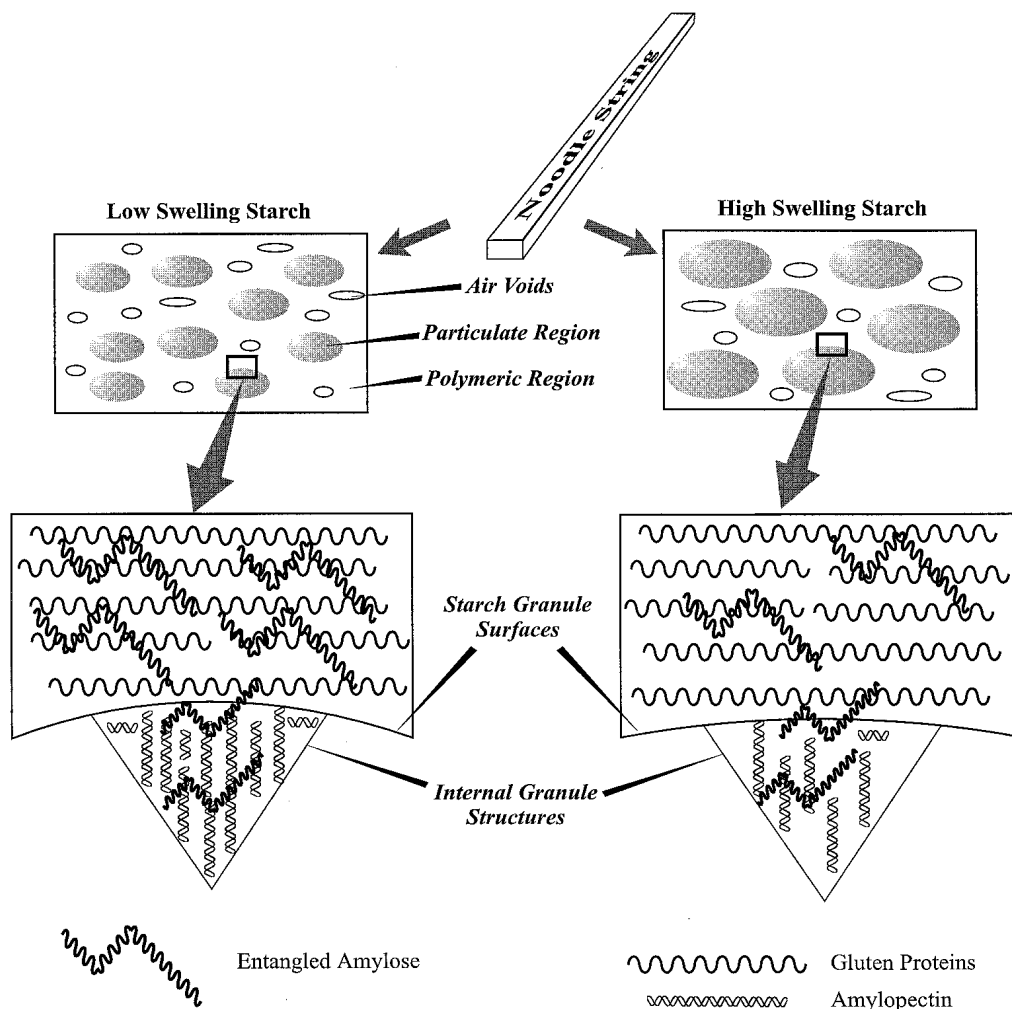


Fig. 4. Schematic representation of a model for the molecular structure of the core region of cooked wheat flour noodles.

on noodle texture was best characterized by the swelling volume of the flour. ARVA pasting characteristics were also related to noodle texture with AFV and ABD being the most valuable parameters. Flour protein content was better related to alkaline noodle texture than protein quality (as indicated by the SDS sedimentation test) for this set of samples. The Null4A status of the wheats used also influenced alkaline noodle texture, primarily due to its effect on FSV. Null4A samples were almost all higher in FSV than the Plus4A group and were responsible for the softest noodles, an undesirable trait for this type of noodle. Significantly different regressions between protein content and noodle firmness for the Null and Plus4A groups may indicate an interaction between the starch and protein components, in their influence on alkaline noodle texture, not previously observed.

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