Effect of *Amaranthus* and Buckwheat Proteins on Wheat Dough Properties and Noodle Quality

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ABSTRACT

Isoelectric protein concentrates (IPC) were prepared from one buckwheat (*Fagopyrum esculentum*) and five *Amaranthus* genotypes. Their effect on the mixing properties of a wheat flour was studied. Mixograph and dynamic oscillatory measurements showed significant increases in dough strength with the addition of 2 and 4% IPC, correlated to the water-insoluble fraction level of the IPC. The same IPCs were used at 2% level to supplement a wheat flour in making Chinese dry noodles. Measurable changes in both the raw and cooked noodle color were observed, and the change caused by addition of buckwheat IPC was substantial. Some of the IPCs caused an increase in cooking loss and only one caused an increase in weight, while increase in volume of the cooked noodles was not significantly affected. The changes in the rheological properties of cooked noodles due to addition of IPCs were measured. Overall, their effects were favorable, but the changes were statistically significant in only a few cases. The substantial dough-strengthening effect of the IPCs was hence not effectively translated into improved cooked noodle quality, and possible reasons for this are discussed.

Cereal Chem. 75(2):171–176

Numerous studies have been made on using additives or substituting some portion of the wheat flour with other ingredients for making products like bread and noodles, with varying objectives such as improvement of dough and product properties, nutritional supplementation, or for cost considerations. In our laboratory, composite flours of wheat and sweetpotato were used for making yellow-alkaline and white-salted noodles (Collado and Corke 1996). Rayas-Duarte et al (1996) evaluated the quality of spaghetti containing buckwheat, amaranth, and lupin flours.

In breadmaking, the physical properties of dough directly affect the quality of the finished product. Test instruments based on mixing characteristics and strength of wheat dough such as the mixograph, farinograph, extensigraph, and alveograph are commonly used to assess such attributes. Lang et al (1992) evaluated the effects of different additives on flour-water dough mixograms. Khatkar and Schofield (1996) found a significant correlation between gluten quality as measured in a 2-g mixograph and bread loaf volume. Yasumatsu et al (1972) studied how addition of soy proteins affects wheat dough properties using a farinograph.

Dough rheology tests have also been used to relate to noodle quality. Oh et al (1986) noted that the amount of water used in noodle dough preparation plays a critical role in predicting noodle quality. Dough properties largely depend on flour protein (mainly gluten) quality. Wheat protein quality determined through mixograph, alveograph, and SDS-sedimentation was found to be highly correlated to cooked noodle texture (Baik et al 1994). The same conclusion was also reached by Huang (1996) comparing farinograph and extensigraph results with noodle quality.

In a previous study, we found that both *Amaranthus* and buckwheat isoelectric protein concentrates (IPCs) prepared in our laboratory had favorable functional properties, being comparable in foaming ability but better in both solubility and emulsifying ability than commercially prepared soy proteins (Bejosano 1997). We also showed (Bejosano and Corke 1998) that these proteins are of desirable nutritional quality. Thus *Amaranthus* and buckwheat protein concentrates, normally treated as a waste product of specialty starch wet-milling, have potential as functional as well as nutritional food additives.

The aim of this study was to: 1) determine the effect of *Amaranthus* and buckwheat protein concentrates on wheat dough properties and 2) test their possible utilization in noodle processing by assessing the effect on noodle quality.

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Publication no. C-1998-0210-01R.

MATERIALS AND METHODS

Materials

Isoelectric protein concentrates were prepared by alkaline wet-milling as described in Bejosano and Corke (1998). One was made from buckwheat (*Fagopyrum esculentum*), a supermarket sample of grain purchased in Hong Kong, but produced in China. Four were made from *Amaranthus cruentus* genotypes (K112, K350, K459, and R104) and one from an *A. hybridus* genotype (No. 3). All the *Amaranthus* genotypes were varieties or advanced breeding lines grown in Beijing and supplied by S. X. Yue (Chinese Academy of Agricultural Sciences). For the purpose of comparison, a soy protein isolate was also used (Protein Technologies International, St. Louis, MO). A commercial wheat flour sample was used ("D" flour; Shekou Lam Soon Flour Mills, Hong Kong) with a moderate protein content (10%) and 13% wb moisture content, considered suitable for commercial noodle production.

Mixograph

Approved Method 54-40A (AACC 1995) was used, employing a 2-g mixograph with the Mixsmart program for data acquisition and analysis (National Manufacturing Co., Lincoln, NE). Two grams of flour (14% mb) was weighed in the mixing bowl, and water (58% on flour weight) was added based on the flour protein content following the standard procedure. When protein additive was used, the amount of water was readjusted for the increase in the solids content (i.e., based on 58% of the flour weight plus the dry weight of the protein additive). Protein concentrates were dispersed in water, pH was adjusted to 7.0, and then added to flour. The mixograph was operated for 10 min. The experiment was conducted in three replicates. The parameters reported are time to peak in minutes (TP), width at peak (WP), and width after 8 min of mixing (W8).

Protein concentrates were added to the flour at 2 and 4% levels (based on flour weight). We previously (Bejosano 1997) analyzed the solubility of the same protein concentrates and determined the levels of the Osborne solubility fractions (i.e., albumins, globulins, prolamins, and glutelins). That data was used to help explain the results obtained in this experiment.

Dynamic Oscillatory Measurements on Dough

Flour dough was again prepared by the mixograph procedure, but the instrument was stopped when peak was reached. The dough was quickly transferred to a rheometer (Stresstech Controlled Stress/Strain Rheometer, Reologica Instruments AB, Lund, Sweden). Oscillation frequency sweep was performed using a constant stress of 10 Pa at frequencies of 0.01–7.0 Hz. The experiment was done in three replicates. All tests were done at 25°C. The elastic modulus (G') and phase degree (δ) were measured and used to characterize the dough and determine the effect of the added proteins.

Noodle Making

The same flour and protein additives were used for noodle making. The procedure of Rho et al (1988) in making an Oriental-type dry noodle was followed. This type is the most popular commercially produced noodle in China known as *Gua Mian*, favored for its long shelf life, ease of cooking and low cost (Huang 1996). The level of water used was 35% based on flour weight or on flour + dry protein weight. Salt at a level of 1.5% based on flour weight was also added. The protein additive was dispersed in water, pH was adjusted to 7.0, and then added to the flour. Only one level of protein (2% based on flour weight) was used in this experiment. Drying of the noodles was done in a forced convection oven at 45°C and 65 ± 5% rh. The actual drying period was 3 hr. The moisture content of the dried noodles was 16.8 ± 1.1% wb. The procedure was done in two replicates.

Noodle Properties

The noodles were cooked in boiling water for 10 min. Increase in weight, increase in volume (by measurement of noodle dimension), and cooking loss were determined. Cooking loss was calculated according to Approved Method 16-50 (AACC 1995). Color of both raw and cooked noodles was determined using a chromameter (CR-300, Minolta Camera Co., Osaka, Japan). All tests were done in three replicates. The viscoelastic properties of cooked noodles were also determined. The raw noodle sheets were cut into 20-mm disks, then dried and cooked. The cooked noodle disks were recut to 20-mm diameter, kept in sealed plastic bag, held for 1 hr at 25°C (to standardize of the holding time after cooking until the actual testing period), and then subjected to dynamic oscillatory measurements using the rheometer. The noodle disks had an approximate thickness of 2 mm. Stress sweep showed the linear viscoelastic region to be in the 30–70 Pa range. Thus, frequency sweep was done using a constant stress of 40 Pa at 0.01–10 Hz. The elastic modulus (G') and phase degree (δ) were recorded. The tests were done in three replicates.

Statistical Analysis

Analysis of variance (ANOVA) and correlation analysis were done using the SAS System for Windows release 6.10 software (SAS Institute Inc., Cary, North Carolina). Comparison of means was made using the least significant difference (LSD) test at $P < 0.05$.

RESULTS AND DISCUSSION

Mixograph Results

The mixograph parameters of the wheat flour sample were obviously affected by the addition of IPCs (Table I). Time to mixing peak (TP), peak width (WP), and width after 8 min (W8) all increased in proportion to the percentage of proteins added. Comparing mixograms of the control wheat flour and that with 4% K112 IPC added (Fig. 1) showed that with the IPC, TP was delayed from 2.84 to 4.00 min, WP was broadened from 17.3 to 21.9% torque and W8 from 4.8 to 11.0% torque (all differences significant at $P < 0.05$) (Table I). The K112 IPC (the least soluble *Amaranthus* sample) had the most pronounced effect, while No. 3 (the most soluble) showed the least. The effect was not positively related to protein solubility (dispersibility) unlike many other protein functional properties.

Conversely, the amount of insoluble protein fraction added to flour was highly correlated to TP ($r = 0.90$, $P < 0.001$), WP ($r = 0.74$, $P < 0.05$), and W8 ($r = 0.82$, $P < 0.001$). Because this protein fraction largely contains glutelins, the coefficients between the mixograph parameters and the amount of the glutelin fraction were similar for TP ($r = 0.80$, $P < 0.001$), WP ($r = 0.73$, $P < 0.05$), and W8 ($r = 0.71$, $P < 0.05$). Lang et al (1992) studied the effect of the addition of three types of vital gluten (standard, modified, and enhanced) on the mixogram of wheat dough. They found that peak height and area under the peak were increased by all three glutens compared with the control. However, it was also found that mixing time decreased with increased concentrations of modified or enhanced glutens. Yasumatsu et al (1972) found that soybean products (flours, protein concentrates and isolates) increase both the stability and water absorption of wheat dough as meas-

TABLE I
Effect of *Amaranthus* and Buckwheat (BW) Protein Concentrates and Soy Protein Isolate (SPI) on Mixograph Properties,[a] and on Dynamic Oscillatory Rheological Properties[b] of Wheat Flour Dough

Treatment	Protein Added (%) Soluble	Protein Added (%) Insoluble	TP (min)	WP (%)	W8 (%)	G' (kPa)	δ
Control	0	0	2.84e[c]	17.27g	4.83d	9.36gh	22.98ab
2% Protein additive							
SPI	0.66	1.34	3.06de	18.45e–g	5.15cd	11.74e–g	22.55a–c
BW	1.28	0.72	2.96de	19.57b–e	5.63b–d	13.25c–f	22.46a–c
K112	0.40	1.60	3.36bc	19.67b–e	6.87bc	11.20fg	23.04ab
K350	1.13	0.87	3.14c–e	18.50ef	5.10cd	10.75fg	22.16b–d
K459	0.84	1.16	3.16cd	19.15c–e	5.75b–d	9.42hg	23.24ab
R104	0.94	1.06	3.16cd	19.60b–e	5.80b–d	14.95b–d	22.01b–d
No. 3	1.22	0.78	2.93de	17.43fg	5.23cd	7.80h	24.46a
4% Protein additive							
SPI	1.32	2.68	3.18cd	19.85b–d	6.80bc	17.50ab	22.08b–d
BW	2.56	1.44	3.18cd	20.40bc	6.40b–d	15.00b–d	22.16b–d
K112	0.80	3.20	4.00a	21.85a	11.00a	18.60a	21.53cd
K350	2.26	1.74	3.11c–e	20.35bc	5.80b–d	14.45c–e	22.18b–d
K459	1.68	2.32	3.46b	18.45e–g	6.10bcd	12.35d–g	22.80ab
R104	1.88	2.12	3.52b	20.55b	7.10b	15.95a–c	20.32d
No. 3	2.22	1.56	2.98de	18.95de	5.10cd	13.00c–ef	21.68b–d
LSD[d]			0.23	1.07	1.57	2.72	2.13

[a] TP = time to peak (min); WP = width at peak; W8 = width after 8 min of mixing.
[b] G' = elastic modulus (kPa); δ = phase degree.
[c] Means in the same column with different letters are significantly different; ($n = 3$).
[d] Least significant difference ($P < 0.05$).

ured in a farinograph. The study, however, claimed that the water absorption of dough with soy protein isolate directly correlates with the degree of protein denaturation and not with protein dispersibility. Another early study on soy protein addition to wheat bread formulation also noted the apparent advantages it confers on dough properties (Jakubczyk and Haberowa 1974). The study found that when the water-insoluble fraction was added, water absorption was increased and dough softening was reduced.

Our results and those from the literature (Yasumatsu et al 1972, Jakubczyk and Haberowa 1974, Chen and Rasper 1982) indicate that the effect of a protein additive on wheat dough properties varies depending on the characteristics of the protein. Chen and Rasper (1982) studied protein properties that determine bread loaf volume and found two test proteins with very similar hydration capacity and solubility giving the best and worst effect. Therefore, good protein dispersibility should not be used as the basis for selecting a protein additive for wheat products if the objective is improvement of dough properties, probably because gluten itself is not water soluble.

There is some concern on the possible effects of soy products on dough properties. Enzyme-active soy flours contain lipoxygenase which may improve the rheological properties of bread dough through an oxidoreduction process (Drapron and Godon 1989). However, lipoxygenase is not precipitated at pH 4.5 (Snyder and Kwon 1987) and is therefore not present in soy protein isolates, which are prepared by isoelectric precipitation process. Hence, the soy proteins used in this study and those used in Yasumatsu et al (1972) and Chen and Rasper (1982) should not have significant lipoxygenase activity. Although we did not find any information on *Amaranthus* and buckwheat lipoxygenase, we presume that since the protein concentrates used in this study were prepared by isoelectric precipitation, this enzyme was therefore absent. Another enzyme that could influence the physical properties of wheat dough is peroxidase, but it is also likely to be absent in materials that underwent isoelectric precipitation. Also, among cereal grains, wheat peroxidase is the most active (Reed and Thorn 1978) and is therefore uniquely implicated in increasing dough strength. Moreover, enzymes such as lipoxygenase and peroxidase are soluble proteins and if present would be in the soluble fraction. Our results (and those of previous studies cited) implicate the insoluble protein fraction in the apparent dough strengthening effect.

Oscillatory Rheological Testing

The dough produced at peak in the mixograph was tested with a dynamic oscillatory rheometer. The effect of added proteins on wheat dough resulted in considerable increase in elastic modulus (G') (Table I, Fig. 2). Phase degree (δ) is a measure of the liquid-like vs. solid-like behavior of a material (Loh 1986), and addition of IPC generally decreased δ (Fig. 3). It is evident (Table I) that the difference between the G' of the control dough and those with protein additive became more apparent as the level of IPC added increased.

The results from both mixograph and dynamic oscillatory measurements agree in showing that IPCs strengthen dough structure. The correlation coefficient between the insoluble protein fraction and G' was 0.72 ($P < 0.05$) and for δ it was –0.59 (P = 0.05). The correlation of the glutelin fraction with G' was 0.73 (P

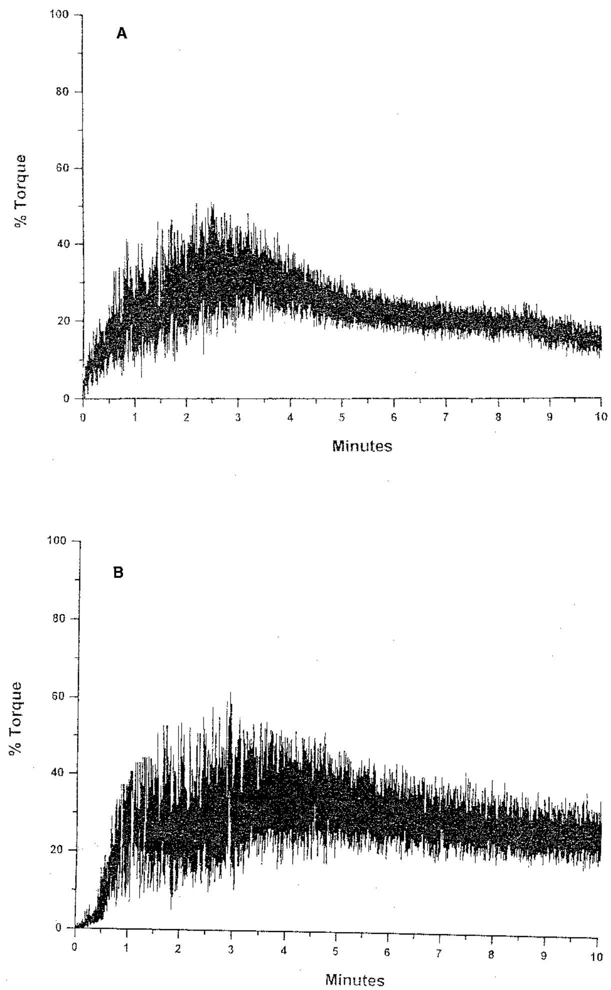

Fig. 1. Mixogram of "D" flour **(A)** and "D" flour plus 4% K112 protein concentrate **(B)**.

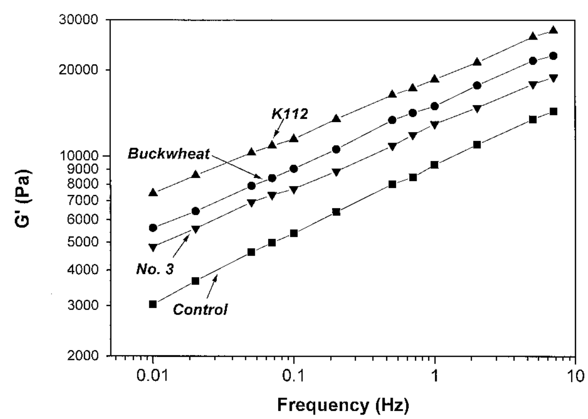

Fig. 2. Effect of protein concentrates (4% flour weight basis) on the elastic modulus (G') of wheat flour dough.

TABLE II
Effect of 2% *Amaranthus* and Buckwheat (BW) Protein Concentrates and Soy Protein Isolate (SPI) on the Cooking Properties of Noodles

Treatment	Cooking Loss (%)	Weight Increase (%)	Volume Increase (%)
Control	4.82a–c[a]	112b	84
Protein additive			
SPI	5.28cd	120ab	107
BW	4.94bc	120ab	100
K112	5.76de	144ab	90
K350	5.78de	127ab	99
K459	4.20a	114b	86
R104	6.39e	159a	89
No. 3	4.56ab	124ab	76
LSD[b]	0.69	43	ns[c]

[a] Means in the same column with different letter are significantly different; (n = 3).
[b] Least significant difference ($P < 0.05$).
[c] Not significant.

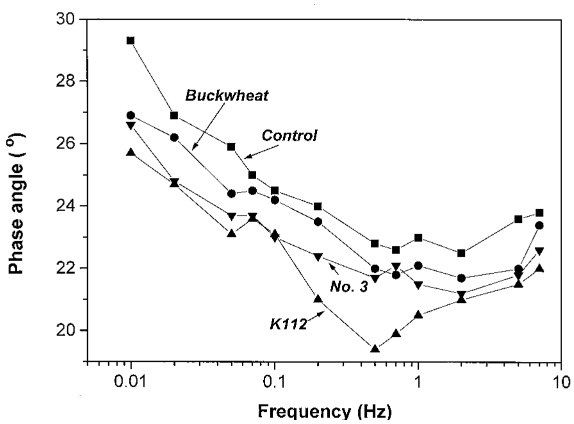

Fig. 3. Effect of protein concentrates (4% flour weight basis) on the phase degree (δ) of wheat flour dough.

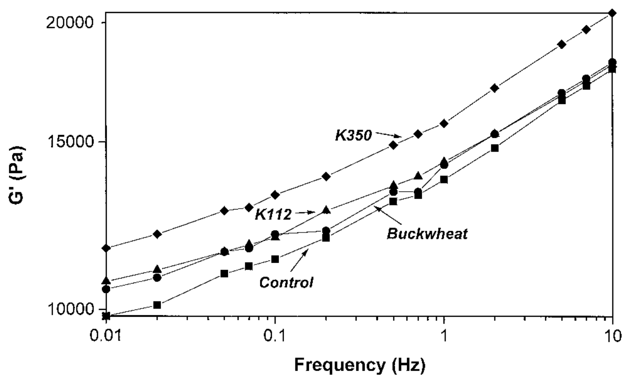

Fig. 4. Effect of protein concentrates (2% flour weight basis) on the elastic modulus (G') of cooked Chinese dry noodles.

= 0.05) and with δ was –0.63 (P = 0.05). Hence, IPCs increase dough rigidity and decrease its liquid-like property. All the mixograph attributes, especially peak width (WP), were highly correlated with G' and δ. The correlation of WP with G' was 0.85 (P < 0.001) and with δ was –0.65 (P < 0.01). Both experimental techniques are therefore useful in characterizing the physical properties of wheat dough as affected by protein additives.

Effect of Proteins on Dough Properties

In a previous study (Bejosano 1997), we found that most of the water-soluble proteins (≈48%) of the protein concentrates were low molecular weight albumins, while the insoluble fractions (≈52%) were mostly glutelins consisting of high and low molecular weight subunits. Comparable results were obtained by Segura-Nieto et al (1992) on *A. hypochondriacus* proteins. Using SDS-PAGE, they found the albumin fraction contained mostly low molecular weight components (4–9 kDa), while the glutelin fraction had at least six main sets of polypeptides with molecular weights ranging from 20 to 93 kDa.

The dough tests showed that the insoluble-glutelin fraction but not the water-soluble protein fraction was responsible for the apparent strengthening effect on wheat dough. Protein hydrophobicity (Bigelow's principle) was estimated from the amino acid composition of the IPCs (data not shown), and the proportion of hydrophobic amino acids (excluding tryptophan, which was not determined) was significantly correlated to the quantity of insoluble protein fraction (r = 0.75, P < 0.05). Segura-Nieto et al (1992) showed that *A., hypochondriacus* seed total proteins contained 22.8% hydrophobic amino acids (tryptophan not determined), while the albumin fraction had 18.7% and glutelin had 25.8%. Although there are more accurate means of quantifying protein hydrophobicity, using this method gave us an indication that hydrophobic amino acids are more associated with the water-insoluble fraction of the protein additives used.

Attributes of wheat glutenin (polymeric high molecular weight, hydrophobicity, and insolubility) that are associated with enhanced dough properties also describe the glutelin fraction of the IPCs in this study. MacRitchie (1984, 1986, 1992) described in detail the mechanisms involved during dough mixing on how gluten proteins act in building dough physical properties. Entanglement networks are produced by polypeptide molecules during mixing (hence the importance of molecular size), and the time required to mix a dough to peak is proportional to the size of the largest molecule present. The mixograph peak time is therefore claimed to be a sensitive measure of the molecular weight distribution of the glutenin in a flour (MacRitchie 1992). Although the effect of exogenous added proteins has not been comprehensively examined, our present study suggests the role of polymeric proteins in the IPCs in dough formation.

Noodle Properties

We chose to make dry noodles for this study because of their popularity in China, and because the market for this type of noodle seems more open to modifications in formulation than many others. Various types of additives can be used in their manufacture, such as eggs, milk, mung beans, and soybeans (Huang 1996).

The addition of IPCs gave no clear trend of benefits to cooking properties of noodles, but neither was there any adverse effect observed (Table II). Cooking loss slightly increased with the addition of some proteins. R104 protein concentrate caused the highest cooking loss as well as the most weight gain after cooking. Volume expansion after cooking was not significantly affected by the addition of the IPCs. There was no correlation between increase in weight and increase in volume, or between cooking loss and increase in volume. The correlation between cooking loss and increase in weight was significant (r = 0.84, P < 0.01). We have no explanation for this, but the same trend was observed on the cooking properties of pasta (Edwards et al 1993).

Noodle color was measured before and after cooking because the IPCs all had distinct colors that could adversely affect product quality. For raw noodles, there was significant reduction in the L (brightness) value with the addition of most of the IPCs (except K112 and soy protein), with buckwheat proteins causing a particularly marked darkening (Table III). Nevertheless, even comparing different wheat samples, Oh et al (1985b) found that noodle brightness was inversely proportional to protein content. All the IPCs increased b (yellowness) values of raw noodles. Also, increases in a (redness) values were observed with the addition of IPCs, with buckwheat protein causing the highest change and the effect of K112 IPC not being significant when compared to the control.

The IPCs significantly affected the color of cooked noodles especially the brightness (L). The effect of K112 proteins was substantial and comparable to that of buckwheat proteins (Table III). Significant increases were also found for b values with IPCs; the No. 3 proteins caused the greatest increase. The effect of the IPCs on a values was also significant but was greatest with the addition of buckwheat proteins. Buckwheat IPC strongly affected color of both raw and cooked noodles, as expected due to the dark purplish-brown color of the dry protein powder. Hence, buckwheat IPC might not be suitable for use unless this problem is resolved.

The observed results support the assumption on the absence of lipoxygenase and peroxidase in the protein additives used, as these two enzymes are known to cause bleaching effects on wheat dough. There is no evidence for the presence of polyphenol oxidase in the protein samples used. However, Matsuo (1987) noted that noodle formulations have much lower water contents than bread dough, making them less sensitive to enzyme action.

TABLE III
Effect of 2% *Amaranthus* and Buckwheat (BW) Protein Concentrates and Soy Protein Isolate (SPI) on the Color Values[a] of Raw and Cooked Noodles

Treatment	Raw Noodles			Cooked Noodles		
	L	*a*	*b*	*L*	*a*	*b*
Control	84.0a[b]	0.83d	9.18b	78.6a	0.28d	10.86f
Protein additive						
SPI	85.0a	1.14bc	11.92a	76.5b	0.27cd	11.72ef
BW	78.7d	2.64a	12.45a	71.1f	2.19a	11.16ef
K112	84.8a	0.95cd	11.39a	71.7ef	0.19cd	12.23de
K350	80.6c	1.29b	12.88a	73.4de	0.13c	13.01cd
K459	82.3b	1.34b	13.06a	75.3bc	0.54b	14.19ab
R104	81.2bc	1.16bc	12.63a	74.3cd	0.16cd	13.44bc
No. 3	81.6bc	1.23bc	12.41a	75.5bc	0.85b	15.12a
LSD[c]	1.45	0.30	2.17	1.67	0.40	1.17

[a] *L* (brightness), *a* (redness), *b* (yellowness).
[b] Means in the same column with different letters are significantly different; ($n = 3$).
[c] Least significant difference ($P < 0.05$).

Table IV and Fig. 4 show how the IPCs affected the G' of the cooked noodles. Significant increase in G' resulted from addition of K350 and soy protein. The control noodles gave the highest mean δ, although individual IPC changes relative to the control were not significant. It thus appears the previously observed effects of the IPCs on dough physical properties were not effectively translated into the same effect on the cooked noodle properties. The amount of insoluble protein fraction added to the noodle formulation was significantly correlated to the phase degree results δ ($r = -0.71$, $P < 0.05$) but not to G' of the cooked noodles. The results therefore indicate that while it had relatively lesser role on dough formation (where the role of proteins predominates), the starch component assumed greater influence on noodles during the cooking process.

As noted previously, addition of K112, K350, and R104 IPCs increased cooking loss. These proteins were also effective in enhancing the physical properties of wheat dough due to their relatively high proportion of insoluble proteins. Addition of these particular IPCs might have strengthened wheat dough, but could have also resulted in increased erosion of surface starch of noodles during cooking, causing higher cooking loss (Oh et al 1985a, Rho et al 1988).

The method used for assessing the physical properties of cooked noodles did not distinguish between the surface and the core. Hence, the possible firming effect of the IPCs on the core was somewhat counterbalanced by surface softening due to loss of surface starch. This would explain why K112 and R104 proteins gave the same effect on G' measurements (Table IV) as those of the other IPCs, as a consequence of the surface softening resulting from increased water absorption at the noodle surface layer. Nevertheless, addition of protein concentrates does not impair the physical properties noodles, while some improvement was attributed to the use of soy and K350 proteins.

This study shows that it is probably more feasible to add protein concentrates to a noodle formulation rather than supplementing with flours from nonwheat sources, especially when the main purpose is for nutritional improvement, and it is much easier to control product quality in doing so. Rayas-Duarte et al (1996) showed an improvement in the lysine content of spaghetti when buckwheat and *Amaranthus* flours were added to wheat flour. However, they noted some reduction in product quality because significant improvement in the lysine content was only attained at a 15% substitution level. Such enhancement of lysine level can also be obtained by adding protein concentrates instead of flour. Based on lysine content of the five *Amaranthus* IPCs (Bejosano and Corke 1998), adding them to a noodle formulation at 2.5% (substitution of flour weight) would give the same lysine content as substitution of 15% *Amaranthus* flour for wheat flour. Compared to *Amaranthus* flours the IPCs had significantly higher in vitro protein digestibility (Bejosano and Corke 1998), providing another nutritional benefit.

TABLE IV
Effect of 2% *Amaranthus* and Buckwheat (BW) Protein Concentrates and Soy Protein Isolate (SPI) on Dynamic Oscillatory Rheological Properties[a] of Cooked Noodles (measured at 1 Hz frequency)

Treatment	G'	δ
Control	13.75c[b]	11.00
Protein additive		
SPI	16.45a	9.79
BW	14.20bc	10.35
K112	14.35a–c	9.62
K350	15.70ab	9.75
K459	15.22a–c	10.18
R104	14.40a–c	9.78
No. 3	15.00a–c	10.11
LSD[c]	2.15	ns[d]

[a] G' = elastic modulus (kPa); δ = phase degree.
[b] Means in the same column with different letter are significantly different; ($n = 3$).
[c] Least significant difference ($P < 0.05$).
[d] Not significant.

CONCLUSIONS

Mixograph analysis showed that addition of *Amaranthus* and buckwheat IPCs resulted in significant changes in the physical properties of wheat flour dough. Dynamic oscillatory rheological measurements indicated that the effect was due to the amount of insoluble fraction of the protein additive and not to the water-soluble fraction. Using the same IPCs to make Chinese dry noodles, the positive effects of IPCs on dough properties were not translated into enhancement of noodle quality, and improvement of the physical properties of cooked noodles by addition of IPCs was only slight. Noodles represent a complex system, and it should not be expected that strengthening of dough following addition of IPCs should necessarily result in improved cooked noodle properties. This is due to the difference in cooking properties within the noodle layers, where a strong dough may be advantageous to the noodle core but may not be favorable to the surface layer.

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[Received April 30, 1997. Accepted November 10, 1997.]