Quality Characterization of Pasta Enriched with Mustard Protein Isolate

M. Alireza Sadeghi and S. Bhagya

ABSTRACT: Mustard protein isolate (MPI) prepared by steam injection heating for removal of antinutritional factors was used at different levels, including 0%, 2.5%, 5%, and 10%, for supplementation of pasta products. The effects of supplementation levels on rheological properties of pasta dough and chemical composition, and cooking, nutritional, and color characteristics of dried samples were evaluated. The results showed that as the supplementation level increased, the dough development time (DDT) increased from 3.5 min in the control to 13.8 min in 10% supplementation level. Maximum consistency (MC) increased from 351 farinograph units (FU) in the control to 371 and 386 FU in 2.5% and 5% supplementation levels, respectively, but decreased to 346 FU in 10% supplementation level. Mixing tolerance index (MTI) decreased as the supplementation increased. The most pronounced effect of enrichment on chemical composition was the increase in protein content; the increase was around 4.5% with supplementation of each 5% MPI in pasta formulation. Study of cooking characteristics of enriched pasta samples showed that cooked weight, cooking loss, protein loss, and stickiness decreased and firmness increased as the supplementation level increased. The nutritional properties of sample showed that enrichment of semolina with MPI had a pronounced effect on lysine, cysteine, arginine, and histidine contents. All computed nutritional indices were higher in enriched samples compared to the control. Color measurement of sample showed that a and b values increased and L value decreased as the supplementation level increased. The SEM of different samples shows that enrichment of pasta with MPI increases the matrix around starch granules.

Keywords: cooking characteristics, mustard protein isolate (MPI), nutritional properties, pasta, rheological properties

Introduction

Pasta products such as macaroni, spaghetti, vermicelli, and noodles are manufactured from semolina and flour produced from durum wheat. Pasta products are becoming popular in current lifestyle because they are healthy, tasty, and convenient for transportation and preparation (Cubadda 1994). In recent years, pasta has become more popular due to its nutritional properties, being regarded as a product with low glycemic index (Jenkins and others 1988; Bjork and others 2000). Nutritionists consider pasta to be highly digestible. It also provides significant quantities of complex carbohydrates, protein, B vitamins, and iron and is low in sodium and total fat (Douglass and Mathews 1982). The protein content of durum wheat is around 11% to 15% but deficient in essential amino acids, lysine, and methionine. To supplement these limiting amino acids, oilseed proteins, which are rich sources of these essential amino acids, could be blended with wheat flour to enrich the product. Protein fortification has been suggested as a convenient method of increasing the nutritional value of pasta, especially for use in developing countries (Bahnassey and Khan 1986).

The food industry is seeking less expensive protein for use in the manufacture of modern convenience foods. Proteins, as isolates or concentrates, are necessary ingredients in many food processes, where they perform specific function. Mustard (Brassica juncea) is one of the major oilseed crops of India, with an annual production of 5 million tonnes (FAOSTAT 2005). The meal is rich in protein (38%). The protein is of excellent nutritional quality, being rich in lysine with adequate amounts of sulfur-containing amino acids—limiting amino acids in most of the cereals and oilseed proteins (Tzeng and others 1988). The presence of toxic and antinutritional constituents such as glucosinolates, phytates, phenolics, and hulls limits the use of rapeseed/mustard as a source of protein in food products (Tzeng and others 1988; Thompson 1993).

Recently, we reported a new method for the production of mustard protein isolate (MPI) with reduced toxic and antinutritional constituents for food and feed purposes (Alireza Sadeghi and others 2006). The objective of the present study was to prepare supplemented pasta products using MPI at different levels in pasta formulation, and then the effects of supplementation on rheological properties of pasta dough and chemical composition and cooking, nutritional, and color characteristics of dried samples were evaluated.

Materials and Methods

Materials

Semolina was purchased from a local market in Mysore, India. All chemicals used were of analytical grade.

Preparation of MPI

The MPI was prepared according to our previous study (Alireza Sadeghi and others 2006) as follows. Defatted mustard meal in the range of 0.5 to 2.5 kg, dispersed in 0.1 mol/L NaCl in a ratio 1:15 (w/v), was incubated at 37 °C for 1 h. The pH was adjusted to 11 with the addition of 2 mol/L NaOH. The dispersion was subjected to shaking for 30 min at room temperature before centrifuging at 5000 rpm for 20 min. The pH of the supernatant was readjusted to...
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7 with 2 mol/L HCl. Activated carbon granules (2%, w/v) were added and kept for shaking for 1 h and filtered. Live steam was injected to the supernatant to raise the temperature (93 ± 2 °C), cooled and centrifuged at 1118 × g (Beckman centrifuge, Model: GS-15R, Rotor: F0850, Beckman Instruments Inc., Palo Alto, Calif., U.S.A.) to precipitate protein. The precipitate was dispersed in water in a ratio of 1:10 (w/v) and centrifuged. The process was repeated once. The wet protein isolate was dispersed in water and neutralized with HCl/NaOH. The dispersion with a solid content of 20% was spray dried (Model BLSA, Bowen Engineering Inc., Newark, N.J., U.S.A). The inlet temperature of 150 °C and outlet temperature 110 ± 5 °C were used.

Preparation of spaghetti samples

Semolina with a given amount of moisture was mixed with pre-calculated amount of distilled water (40 °C) in a Hobart mixer (Model N-50, Hobart Canada, North York, Ontario, Canada) at beater speed 1 (58 rpm) for 5 min to make 500 g dough. The premixed mixture was transferred to a laboratory pasta machine (La Montferrina, Maccherie per Pasta, Masoero Arturo & C.s.n.c., Castell’Alfero, Asti, Italy) and mixed for 5 min. The dough was extruded using the single screw laboratory pasta machine with a speed of 60 rpm. The temperature of extruded dough was around 37 to 40 °C. A 36-strand, 1.7-mm diameter die was used to shape the dough as spaghetti strands. The extruded dough shaped as long strands was hung on wooden sticks and kept in a drier. A high temperature short time (HTST) system was used at a temperature of 85 °C, and relative humidity of the chamber was reduced from 90% to 65% during a 5-h drying period. Dried spaghetti was cooled and packed in polyethylene bags to be used for different tests and experiments. There was at least a 10-day gap between drying and cooking of spaghetti samples to stabilize the dried samples under ambient temperature. Enriched spaghetti formulations were made using different levels of replacement of semolina with MPI in spaghetti formula, including 2.5%, 5%, and 10% replacements.

Chemical composition

The spaghetti samples were analyzed by standard methods 934.01, 988.05, 942.05, and 962.09 for moisture, protein (N × 6.25), ash, and crude fiber, respectively (AOAC 2000). The dietary fiber was determined according to the method described by Nils and others (1983).

Farinogram characteristics of semolina

The farinogram characteristics of semolina were determined using Brabender-E farinograph (Brabender, OHG, Duisburg, Germany) according to the method described by Irvine and others (1961). The modified software version 2.3.2, which is specific for measurement of farinogram characteristics of semolina, was supplied by the manufacturer and used in this study. Three terms were used to describe the farinograms: (1) the dough development time (DDT) is the time from zero to the point of maximum consistency of dough immediately before the 1st indication of weakening; (2) the maximum consistency (MC) is the height in farinograph units (FU) at the center of the curve at the point of maximum consistency; and (3) mixing tolerance index (MTI) is the difference in FU between the top of the curve at the peak (maximum consistency) and the top of the curve measured 4 min after the peak is reached (Irvine and others 1961).

Spaghetti cooking quality

To evaluate the cooking quality of spaghetti samples, 10 g of raw spaghetti were cooked in 150 mL of boiling distilled water for 10 min. The following parameters were used to evaluate the cooking quality of the different spaghetti samples.

Cooked weight. Cooked weight was the weight of 10 g of dry spaghetti after cooking (Manthey and Harelund 2001).

Cooking loss (total solids in gruel). Cooking loss was measured according to the BIS method (ISI 1485 1993) with some modification. Ten grams of spaghetti were broken into a length of approximately 5 cm and cooked in 200 mL of boiling distilled water. Spaghetti was cooked to its optimal cooking time with occasional stirring. After cooking, the sample was rinsed with a stream of distilled water (around 50 mL) for about 30 s in a Buchner funnel and allowed to drain for 2 min. The total volume of gruel and the rinsed water collected was measured. The gruel was stirred well for even distribution of the solid content. Twenty milliliters of gruel were pipetted out into a tarred Petri dish and evaporated to dryness on a water bath. The Petri dish was transferred to a hot air oven maintained at 105 ± 2 °C and dried to constant mass. The cooking loss was calculated using the following formula:

$$\text{Total solid in gruel (percent by mass)} = \frac{(M_2 - M_1) \times V}{2}$$

where

- $M_2$ = mass in grams of Petri dish with total solid,
- $M_1$ = mass in grams of empty Petri dish, and
- $V$ = volume of gruel in milliliters.

Protein loss. Protein loss was the amount of protein lost in cooking water as the percentage of total protein in samples.

Spaghetti firmness. A universal texture measuring system (twin screw material testing, M/C, UTM Lloyds, LR-5K, Lloyd Instruments Ltd., Fareham, U.K.) was used according to the method of Walsh and Gilles (1971).

Spaghetti stickiness. Surface stickiness of the cooked spaghetti was determined using a universal texture measuring system with a special plunger and sample holder according to the method of Dexter and others (1983).

In vitro digestibility

The method of Akeson and Stahman (1964) using pepsin pancreatin enzymes was employed to determine in vitro digestibility.

Amino acid analysis

Samples containing 5-mg protein were hydrolyzed for 24 h under vacuum at 110 °C using 5.8 M HCl. Amino acid analysis was carried out by precolumn derivatization using phenylisothiocyanate. The phenyl thiocarbomyl amino acids were analyzed using a Waters Pico-Tag amino acid analysis system (Bidlingmeyer and others 1984). Tryptophan was estimated by the acid ninhydrin method (Pinter and Molnar 1990).

Chemical score

Chemical score was calculated using the following formula (FAO 1968):

$$\frac{\text{grams essential amino acid in test protein}}{\text{grams total essential amino acid in test protein}} \times \frac{\text{grams total essential amino acid in egg} \times 100}{\text{grams essential amino acid in egg}}$$

Essential amino acid index (EAAI) and biological value (BV)

EAAI was calculated according to the method of Oser (1951) and BV was calculated using the formula of Oser (1959), namely,

$$\text{BV} = 1.09 \times \text{EAAI} - 11.7.$$
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Nutritional index (NI)
NI was calculated using the formula of Crisan and Sands (1978).
\[
\text{NI} = \frac{\text{EAAI} \times \% \text{ Protein}}{100}
\]

Computed protein efficiency ratio (C-PER)
The C-PER was calculated according to the method of Satterlee and others (1979) using the formula
\[
\text{C-PER} = -2.1074 + 7.1312 (\text{SPC}) - 2.5188 (\text{SPC})^2
\]
where SPC is the essential amino acid score ratio of sample to casein.

Protein digestibility corrected amino acid score (PDCAAS)
The PDCAAS was calculated according to the method of Sarwar and McDonough (1990) using the essential amino acid composition of the test sample and the amino acid pattern suggested by FAO/WHO (1990) for 10- to 12-y-old children and for adults.

Color measurement
The color measurement for samples was done using the Minolta CM3500D (Osaka, Japan) instrument using visible wavelength. Colors of samples were measured by the C-illuminating 2D view angle. The values of L (lightness), a (redness and greenness), and b (blue- ness and yellowness) were measured using a Hunter color system.

Scanning electron microscopy (SEM)
Scanning electron microscopy studies of different samples were carried out using a LEO surface scanning electron microscope (Model 435 VP, Leo Electronic Systems, Cambridge, U.K.). Before loading the samples into the system, the samples were coated with gold using a Polaron SEM coating system E-5000. The average coating time was 2 to 3 min. The thickness of coating was 200 to 300 nm, which was calculated using the following formula:
\[
T = 7.5 I t
\]
where \(I\) = current in mA, \(t\) = time in minutes, and \(T\) = thickness in Å. The coated samples were loaded on the system and the image was viewed under 20-kV potential using a 35-mm Ricoh camera (Tokyo, Japan).

Sensory evaluation
Sensory evaluation was carried out on the cooked spaghetti by a panel of 20 trained judges (10 male and 10 female) in the Dept. of Sensory Science, CFTRI, Mysore, India. The panelists were asked to score different quality characteristics, including color and appearance, taste and flavor, and texture, on a 10-point hedonic scale. Analysis of variance (ANOVA) was used to test the difference between the parameters.

Statistical analysis
The data collected were subjected to ANOVA by Duncan’s multiple range test (DMRT) to compare any significant difference among the mean values (Snedecor and Cochran 1967).

Results and Discussion
The rheological properties of spaghetti dough with different levels of supplementation of semolina with MPI as different terms are shown in Table 1.

The results showed that the MC of spaghetti dough increased from 351 FU for the control to 371 and 386 FU for 2.5% and 5% supplementation, respectively. However, the replacement of semolina with 10% supplementation decreased drastically the MC of dough. The increased MC with 2.5% and 5% supplementation may be due

### Table 1 — Rheological properties of spaghetti dough supplemented with different levels of MPI.

<table>
<thead>
<tr>
<th>Supplementation level (%)</th>
<th>Dough development time (DDT) (min)</th>
<th>Maximum consistency (MC) (FU)</th>
<th>Mixing tolerance index (MTI) (FU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3.5 ± 0.05c</td>
<td>351 ± 2c</td>
<td>59 ± 1c</td>
</tr>
<tr>
<td>2.5</td>
<td>5 ± 0.03c</td>
<td>371 ± 3c</td>
<td>53 ± 2c</td>
</tr>
<tr>
<td>5</td>
<td>7 ± 0.04c</td>
<td>386 ± 2c</td>
<td>38 ± 1c</td>
</tr>
<tr>
<td>10</td>
<td>13.8 ± 0.07c</td>
<td>346 ± 1c</td>
<td>23 ± 2c</td>
</tr>
</tbody>
</table>

Mean ± SD of 3 determinations. Values followed by different letters in each column are significantly different \((P < 0.05)\).

### Table 2 — Chemical composition of spaghetti prepared with different levels of supplementation with MPI.

<table>
<thead>
<tr>
<th>Constituents (%)</th>
<th>MPI</th>
<th>Control</th>
<th>2.5%</th>
<th>5%</th>
<th>10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>5.0 ± 1.0</td>
<td>13.2 ± 0.1*</td>
<td>12.0 ± 0.1b</td>
<td>11.9 ± 0.1b</td>
<td>11.9 ± 0.1b</td>
</tr>
<tr>
<td>Ash</td>
<td>Trace</td>
<td>0.82 ± 0.01*</td>
<td>0.81 ± 0.02a</td>
<td>0.80 ± 0.02a</td>
<td>0.79 ± 0.3*</td>
</tr>
<tr>
<td>Protein</td>
<td>95.0 ± 1.0</td>
<td>11.5 ± 0.1*</td>
<td>13.8 ± 0.08c</td>
<td>16.0 ± 0.1b</td>
<td>20.6 ± 0.1*</td>
</tr>
<tr>
<td>Crude fiber</td>
<td>ND</td>
<td>5.05 ± 0.03a</td>
<td>4.88 ± 0.02b</td>
<td>4.82 ± 0.03c</td>
<td>4.71 ± 0.03c</td>
</tr>
<tr>
<td>Dietary fiber</td>
<td>ND</td>
<td>8.34 ± 0.02c</td>
<td>8.28 ± 0.03b</td>
<td>8.23 ± 0.02b</td>
<td>8.20 ± 0.03b</td>
</tr>
</tbody>
</table>

Mean ± SD of 3 determinations. ND = not detectable. Values followed by different letters in each row are significantly different \((P < 0.05)\).

### Table 3 — Cooking characteristics of spaghettis supplemented with different levels of MPI.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Control</th>
<th>2.5%</th>
<th>5%</th>
<th>10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooked weight (g)</td>
<td>31.4 ± 0.15*</td>
<td>28.2 ± 0.10a</td>
<td>27.4 ± 0.2b</td>
<td>26.50 ± 0.15c</td>
</tr>
<tr>
<td>Cooking loss (%)</td>
<td>7.16 ± 0.04a</td>
<td>6.85 ± 0.05b</td>
<td>6.31 ± 0.04c</td>
<td>6.15 ± 0.05c</td>
</tr>
<tr>
<td>Protein loss (%)</td>
<td>11.3 ± 0.12a</td>
<td>9.4 ± 0.10b</td>
<td>8.1 ± 0.15c</td>
<td>7.5 ± 0.10c</td>
</tr>
<tr>
<td>Firmness (g)</td>
<td>77 ± 2c</td>
<td>90 ± 3b</td>
<td>90 ± 2c</td>
<td>90 ± 2c</td>
</tr>
<tr>
<td>Stickiness (N/m²)</td>
<td>437 ± 10a</td>
<td>409 ± 12b</td>
<td>395 ± 8c</td>
<td>378 ± 9d</td>
</tr>
</tbody>
</table>

* From 10-g raw spaghetti.
Mean ± SD of 3 determinations. Values followed by different letters for each cooking characteristic are significantly different \((P < 0.05)\).
Table 4 — Amino acid composition of spaghetti supplemented with different levels of MPI (g/100 g protein).

<table>
<thead>
<tr>
<th>Amino acids</th>
<th>MPI</th>
<th>Control</th>
<th>2.5%</th>
<th>5%</th>
<th>10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lysine</td>
<td>4.90 ± 0.10</td>
<td>1.80 ± 0.03</td>
<td>2.43 ± 0.01</td>
<td>3.10 ± 0.03</td>
<td>3.75 ± 0.04</td>
</tr>
<tr>
<td>Methionine</td>
<td>2.73 ± 0.04</td>
<td>1.38 ± 0.03</td>
<td>1.53 ± 0.03</td>
<td>1.76 ± 0.01</td>
<td>2.02 ± 0.02</td>
</tr>
<tr>
<td>Cysteine</td>
<td>2.94 ± 0.08</td>
<td>1.21 ± 0.05</td>
<td>1.41 ± 0.04</td>
<td>1.76 ± 0.04</td>
<td>2.12 ± 0.03</td>
</tr>
<tr>
<td>Tryptophan</td>
<td>1.55 ± 0.04</td>
<td>1.69 ± 0.04</td>
<td>1.66 ± 0.04</td>
<td>1.65 ± 0.05</td>
<td>1.63 ± 0.06</td>
</tr>
<tr>
<td>Histidine</td>
<td>2.86 ± 0.03</td>
<td>1.15 ± 0.05</td>
<td>1.50 ± 0.05</td>
<td>1.76 ± 0.04</td>
<td>2.39 ± 0.03</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>3.65 ± 0.06</td>
<td>2.88 ± 0.07</td>
<td>3.16 ± 0.06</td>
<td>3.25 ± 0.03</td>
<td>3.32 ± 0.04</td>
</tr>
<tr>
<td>Leucine</td>
<td>7.75 ± 0.05</td>
<td>8.56 ± 0.04</td>
<td>8.43 ± 0.05</td>
<td>8.29 ± 0.06</td>
<td>8.12 ± 0.03</td>
</tr>
<tr>
<td>Thrreonine</td>
<td>4.31 ± 0.09</td>
<td>2.00 ± 0.03</td>
<td>2.35 ± 0.05</td>
<td>2.80 ± 0.06</td>
<td>3.23 ± 0.05</td>
</tr>
<tr>
<td>Valine</td>
<td>5.17 ± 0.05</td>
<td>3.86 ± 0.04</td>
<td>4.17 ± 0.03</td>
<td>4.28 ± 0.05</td>
<td>4.38 ± 0.06</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td>4.51 ± 0.04</td>
<td>5.56 ± 0.02</td>
<td>5.38 ± 0.03</td>
<td>5.15 ± 0.05</td>
<td>4.76 ± 0.04</td>
</tr>
<tr>
<td>Tyrosine</td>
<td>2.26 ± 0.05</td>
<td>1.59 ± 0.01</td>
<td>1.70 ± 0.02</td>
<td>1.74 ± 0.02</td>
<td>1.89 ± 0.03</td>
</tr>
<tr>
<td>Aspartic acid</td>
<td>6.97 ± 0.08</td>
<td>3.02 ± 0.05</td>
<td>3.43 ± 0.07</td>
<td>3.89 ± 0.06</td>
<td>4.78 ± 0.08</td>
</tr>
<tr>
<td>Glutamic acid</td>
<td>20.83 ± 0.15</td>
<td>34.61 ± 0.25</td>
<td>31.28 ± 0.18</td>
<td>28.67 ± 0.32</td>
<td>25.30 ± 0.25</td>
</tr>
<tr>
<td>Serine</td>
<td>4.49 ± 0.05</td>
<td>4.91 ± 0.10</td>
<td>4.75 ± 0.08</td>
<td>4.69 ± 0.05</td>
<td>4.55 ± 0.05</td>
</tr>
<tr>
<td>Glycine</td>
<td>5.19 ± 0.04</td>
<td>2.91 ± 0.04</td>
<td>3.26 ± 0.04</td>
<td>3.37 ± 0.03</td>
<td>3.55 ± 0.05</td>
</tr>
<tr>
<td>Arginine</td>
<td>9.97 ± 0.05</td>
<td>4.30 ± 0.06</td>
<td>5.37 ± 0.04</td>
<td>6.15 ± 0.05</td>
<td>7.07 ± 0.08</td>
</tr>
<tr>
<td>Alanine</td>
<td>4.36 ± 0.10</td>
<td>3.35 ± 0.05</td>
<td>3.65 ± 0.05</td>
<td>3.97 ± 0.03</td>
<td>4.25 ± 0.05</td>
</tr>
<tr>
<td>Proline</td>
<td>5.56 ± 0.05</td>
<td>15.22 ± 0.15</td>
<td>14.54 ± 0.18</td>
<td>13.72 ± 0.20</td>
<td>12.89 ± 0.14</td>
</tr>
</tbody>
</table>

Mean ± SD of 4 determinations.

Table 5 — Computed nutritional indices of spaghetti prepared with different levels of supplementation with MPI.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Supplementation levels (%)</th>
<th>Control</th>
<th>2.5%</th>
<th>5%</th>
<th>10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>In vitro digestibility (%)</td>
<td></td>
<td>83 ± 0.5</td>
<td>84.7 ± 0.5</td>
<td>87.1 ± 0.4</td>
<td>88.6 ± 0.4</td>
</tr>
<tr>
<td>Limiting amino acid</td>
<td></td>
<td>Lysine</td>
<td>Lysine</td>
<td>Lysine</td>
<td>Lysine</td>
</tr>
<tr>
<td>C-PER</td>
<td></td>
<td>0.45</td>
<td>1.00</td>
<td>1.58</td>
<td>1.92</td>
</tr>
<tr>
<td>EAAI</td>
<td></td>
<td>53.8</td>
<td>62.8</td>
<td>66.5</td>
<td>75.3</td>
</tr>
<tr>
<td>P-BV</td>
<td></td>
<td>47</td>
<td>56.8</td>
<td>60.8</td>
<td>70.4</td>
</tr>
<tr>
<td>NI</td>
<td></td>
<td>6.2</td>
<td>7.9</td>
<td>9.8</td>
<td>14.6</td>
</tr>
<tr>
<td>PDCAAS</td>
<td></td>
<td>10 to 12 y old</td>
<td>34</td>
<td>46.8</td>
<td>61.4</td>
</tr>
<tr>
<td>Adults</td>
<td></td>
<td>59.7</td>
<td>79.5</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

*Mean ± SD of 4 determinations.

The MTI decreased with an increase in the replacement level of MPI in spaghetti dough (Table 1). Irvine and others (1961) have reported that as the amount of protein (gluten) increases, DDT decreases with an increase in MC and MTI. However, increasing the nongluten protein may weaken the gluten network, which increases the DDT and reduces the MTI. It has been reported that the addition of the high-protein soy or cottonseed meal products at 5% to 20% level decreased the MTI value of semolina dough (Haber and others 1978).

The chemical composition of enriched spaghetti compared to the control is presented in Table 2. The most pronounced effect of enrichment was the increase in protein content. The protein content of the control was 11.5%, and it increased to 13.8%, 16%, and 20.6% with supplementation of semolina with 2.5%, 5%, and 10% MPI, respectively. The increase of protein content was around 4.5% with replacement of each 5% MPI. Though other constituents were statistically different in some cases, there was not much variation among them. Wu and others (2001) reported that protein content increased by 2.3% to 2.4% with each 5% substitution of regular corn gluten meal for semolina and 2.8% to 3.15% with each 5% substitution of water-washed corn gluten meal for semolina.

The cooking characteristics of enriched spaghetti were compared to the control, and the results are presented in Table 3. The cooked weight of the control was 31.4 g, and it reduced to 28.2, 27.4, and 26.5 g for 2.5%, 5%, and 10% replacements, respectively. Nielsen and others (1988) have reported that the use of higher proportions of denatured protein in enriched spaghetti lowered the cooked weight of samples. Haber and others (1978) have reported...
that the cooked weight of spaghetti made from 100% semolina decreased markedly with the addition of high-protein materials from soybean or cottonseed. Similar observation was made by supplementation of spaghetti with different legumes, including navy, pinto, and lentil (Bahnassey and Khan 1986). Breen and others (1977) have also reported that the cooked weight of spaghetti made from a bean formula was lower than that of the control.

The results of cooking loss and protein loss are presented in Table 3. As the level of enrichment increased, the cooking loss and protein loss were decreased. The decrease may be due to the low solubility of MPI that resulted in lowering the cooking loss and protein loss in the enriched spaghetti compared to the control.

Table 3 shows the results of firmness of enriched spaghetti samples as compared to the control. The firmness value of the control was 77 gf, which increased to 90 gf for all the supplementation levels. There was no significant difference between the firmness values of enriched spaghetti samples. The addition of high-protein materials from soy and cottonseed to semolina resulted in an increase in the firmness of spaghetti (Haber and others 1978). Similar observations have been made by other researchers (Paulsen 1961; Matsuo and others 1972; Bahnassey and Khan 1986).

The stickiness of the control spaghetti was 437 N/m², and it reduced to 409, 395, and 378 N/m² for 2.5%, 5%, and 10% enrichment levels, respectively (Table 3). The reduction in the stickiness may be due to reduction in starch proportion in the enriched spaghetti or physical entrapment of starch in protein network with increased replacement level.

The amino acid composition of the control and enriched spaghetti samples prepared by replacement of semolina with different levels of MPI is presented in Table 4. The results showed that
the supplementation of semolina with MPI increased the amount of some amino acids like lysine, methionine, cysteine, and arginine. However, the amount of glutamic acid, proline, and phenylalanine reduced with enrichment of semolina with MPI. This may be due to the presence of higher amounts of these amino acids in semolina. Enrichment of semolina with MPI had pronounced effect on lysine, cysteine, arginine, and histidine contents. This is possibly due to higher contents of these amino acids in MPI (Table 4).

The computed nutritional indices of the control spaghetti compared to spaghetti prepared by enrichment of semolina with different levels of MPI are presented in Table 5. The chemical score indicated that lysine was the 1st limiting amino acid in all cases, including the control. The computed PER (C-PER) was increased from 0.45 for the control to 1.0, 1.58, and 1.92 for 2.5%, 5%, and 10% enrichment, respectively, indicating that mustard proteins are a good source of essential amino acids. The PDCAAS score for the control spaghetti was 59.7, which increased to 79.5, 100, and 100 for adults by enrichment of semolina with 2.5%, 5%, and 10% MPI, respectively. The results clearly indicated that MPI could be used as a good source of protein in high-protein formulations for adults.

In general, enrichment with MPI improved all the nutritional qualities of the spaghetti. These results are in close agreement with the reported data (Paulsen 1961; Breen and others 1977; Nielsen and others 1980; Rayas-Duarte and others 1996; Wu and others 2001).

The color characteristics of enriched and control spaghetti samples, semolina, and MPI are presented in Table 6. The \( L \) values (lightness) of semolina and the control spaghetti were higher than enriched spaghetti samples. The \( L \) value decreased with the increase in supplementation level. This may be due to the lower \( L \)
value of MPI compared to semolina. It may also be due to the effect of extrusion and drying on color characteristics of spaghetti.

The $a$ values (redness) of spaghetti with different enrichment levels were higher than those of the control and semolina. The redness increased with increased level of supplementation. The increased $a$ value may be due to the higher $a$ value of MPI compared to semolina. Changes in $a$ value may also be due to the effect of extrusion and drying.

The $b$ values (yellowness) of spaghetti with different levels of enrichment were higher than the control or semolina, which increased with an increase in enrichment levels. This may be due to the higher $b$ value of MPI compared to semolina. However, compared to semolina, the $b$ value was slightly increased in the control spaghetti. This could be attributed to processing (extrusion and drying) effects. Wu and others (2001) have reported that semolina color became darker (lower $L$ value) and more yellow (higher $b$ value) as water/ethanol-washed corn gluten meal was substituted for semolina or farina. The $L$ value of spaghetti was decreased and $b$ value increased when pea flour or pea protein concentrate was used at different levels in spaghetti formulation (Nielsen and others 1980).

The sensory characteristics of the cooked control and enriched spaghetti samples were evaluated for different parameters and the results are presented in Table 7. The results showed that there was no significant difference in color preference of a panelist between the control and 2.5%-enriched spaghetti. However, 5% and 10% enrichment scored higher values. This is mainly due to the higher $b$ values (yellowness) of the enriched spaghetti (Table 6) compared...
Quality characterization of pasta...

to the control. Generally, the higher yellow color in pasta products is highly accepted by the consumers. The flavor and texture of the control and 2.5%-enriched spaghetti did not show any significant difference. However, the spaghetti samples enriched with 5% and 10% MPI scored lower for taste and flavor. This may be due to lower wheaty flavor of enriched spaghetti compared to the control. The texture of enriched spaghetti samples was scored higher than the control sample. This could be due to higher firmness and lower stickiness of enriched spaghetti compared to the control (Table 3).

The SEM of surface and cross sections of spaghetti prepared at different levels of supplementation with MPI compared to the control spaghetti are shown in Figure 1 to 4. Figure 1A, 2A, 3A, and 4A show numerous starch granules of varying size visible on the surface structure of dry spaghetti. In addition, the outer layer of dry spaghetti appeared to be associated with a thin protein film as already reported in the literature (Donnelly 1982; Cunin and others 1995). Moreover, many cracks and small holes were apparent in the protein matrix at the surface. This was partly due to shrinkage during sample preparation and partly due to the surface tension in spaghetti dough during drying. Enrichment of semolina with MPI increases the matrix around the starch granules, as shown in Figure 1 to 4. The internal structure of dry spaghetti (Figure 1B, 2B, 3B, and 4B) shows a homogenous and porous structure where starch granules were deeply embedded in a protein matrix. The replacement of semolina by MPI increased the protein matrix around the starch granules. The low moisture content of pasta dough and the insufficient mixing during extrusion do not allow complete development of a gluten network, as would be the case in bread dough. The results of SEM of spaghetti samples are in close agreement with the results reported by other researchers (Resmini and Pagani 1983; Pagani and others 1986).
Conclusions

Supplementation of spaghetti with MPI resulted in a product with higher protein content and better nutritional properties. All calculated nutritional indices were increased as the supplementation level increased. Rheological properties of spaghetti with different levels of supplementation showed that addition of MPI in higher level increased DDT and decreased MTl. However, MC was increased in 2.5% and 5% supplementation levels but decreased in 10% supplementation level. Cooking characteristics of supplemented spaghetti products showed that as the level of supplementation increased, the cooked weight, cooking loss, protein loss, and stickiness decreased and the firmness increased. The color measurement of the sample showed that the a (redness) and b ( yellowness) values increased and the L value (lightness) decreased as the supplementation level increased. The SEM of different samples shows that enrichment of pasta with MPI increases the matrix around starch granules.

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References