Quality of Spaghetti Containing Buckwheat, Amaranth, and Lupin Flours

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ABSTRACT

Light and dark buckwheat, amaranth, and lupin flours were substituted for extra fancy and fancy durum wheat flours at 5, 15, 25, and 30% to produce multigrain pastas. The samples were analyzed for color, cooked weight, firmness, cooking loss (total solids) and total carbohydrate loss in the cooking water, in vitro protein digestibility, lysine content, and sensory attributes. Color scores of spaghetti containing light buckwheat and amaranth decreased as the substitution level increased. Color scores of dry spaghetti containing lupin remained constant at all substitution levels (10.3 average). The optimum cooking time of spaghetti was similar in all samples, about 11.3 min. The majority of the samples exhibited acceptable cooked weights of about three times the dry weight. The cooking loss ranged from 7.2 to 8.0%, significantly higher than that of the controls but still at acceptable levels. Samples containing dark buckwheat and amaranth showed significantly lower firmness values than the control durum-flour spaghettis. Total carbohydrate in the cooking water was independent of substitution level within a flour. Samples in which amaranth was substituted for durum showed the highest total carbohydrate in the water (2.7%), and those with lupin showed the lowest (1.2%). Lupin-containing spaghetti showed higher in vitro protein digestibility content (86.4%) than did the controls and the other composite samples (averages 85.5 and 84.3%, respectively). The lysine content increased as the substitution level increased, and lupin-containing spaghetti showed the highest lysine values (average 3.2 g/100 g of protein). Sensory evaluation showed that changes in texture and flavor were detected at 30% light buckwheat, 15% dark buckwheat, 25% amaranth, and 15% lupin. The results showed that multigrain pasta can be produced with higher levels of lysine than commercial pasta made of 100% durum wheat flour and also with acceptable cooking quality and sensory attributes.

Annual pasta consumption in the United States increased from 11 lb per person in 1975 to 19 lb in 1991 (Duxbury 1992) and is projected to reach 30 lb per person by the year 2000 (Hamblin 1991). In comparison, annual consumption in Italy is 60 lb per capita (Anonymous 1992).

One reason for the increase in pasta consumption within the last 20 years is the consumer's changing perception of pasta. Americans find pasta inexpensive, versatile, easy to store, and quick and simple to prepare (Hamblin 1991).

Pasta is recognized as low in sodium and fat, with no cholesterol, and as a rich source of complex carbohydrates (Giese 1992). A 2-oz serving of dry pasta provides 10% of the protein suggested by the U.S. Recommended Daily Allowances for adults. But like most food proteins, pasta proteins must be complemented with other food sources. Pasta is limiting in two of the eight essential amino acids: lysine and threonine (Stephenson 1983).

Ingredients other than the basic durum semolina and water have been incorporated into pasta formulations, including tomatoes and spinach for color, basil and garlic for flavor, and flours or protein isolates from other grains and legumes for nutritional improvement. When bean concentrates or isolates were added to pasta products at up to 20%, the flavor and firmness of the product were acceptable (Morad et al 1980, Seyam et al 1983, Duxbury 1992).

The objective of this study was to determine the in vitro protein digestibility, lysine content, cooking quality, and sensory attributes of multigrain pasta made with durum flours partially replaced by amaranth, buckwheat, and lupin flours.

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MATERIALS AND METHODS

Samples

Dark and light buckwheat flours were obtained from Minn-Dak Growers Ltd. (Grand Forks, ND). Amaranth seeds (*Amaranthus cruentus* K-283) were obtained from NU-World Amaranth, Inc. (Naperville, IL). Lupin (*Lupinus albus*) seeds were obtained from the Carrington Research/Extension Center of North Dakota State University (Carrington, ND). The lupin seeds, from experimental plots grown in 1990, were pooled and a composite sample was used. Commercial durum wheat fancy and extra fancy patent flours and semolina were obtained from the North Dakota Mill and Elevator (Grand Forks, ND).

Whole-meal flours of amaranth and lupin were obtained by milling cleaned grains. Lupin seeds were first cracked using an experimental roller mill (Allis-Chalmers, Milwaukee, WI) and pulverized in a laboratory-scale ball mill (Northern Process Products Div., Akron, OH). Amaranth seeds were milled using the latter mill. Milling was adjusted until 70% of the flour passed through a U.S. No. 70 sieve (212 μm).

Extrusion

Mixed flours were processed and spaghetti noodles were produced on a DeMaco semicommercial laboratory extruder (De Francisci Machini Corp., Brooklyn, NY), as described by Walsh et al (1971). The following conditions were used: extrusion temperature, 49.5°C; mixing chamber vacuum, 46 cm (18 in.) of Hg; and screw extrusion speed, 20 rpm. Spaghetti samples were prepared in two replicate batches of 1 kg each and processed on different days. They were dried in a laboratory dryer (Standard Industries, Inc., Fargo, ND) using an 18-hr drying cycle, programmed with relative humidity in a straight-line gradient from 95 to 61% and temperature from 40 to 30°C.

Commercial light and dark buckwheat flours and whole amaranth and lupin flours were substituted for extra fancy and fancy durum wheat flours. The levels of substitution for each flour were 0, 5, 15, 25, and 30%. Control samples were made with extra fancy and fancy durum flours; the semolina sample was used as a reference.

Absorption

Absorption, as defined by Seyam et al (1974), was the amount of water, expressed as percent of flour, required to bring the dough to proper consistency for extruding. The consistency was tested subjectively by an experienced operator, until a dough of granular consistency was formed when pressed.

Proximate Analysis

Moisture, crude fat, ash, and protein contents were determined in raw flours and in cooked and freeze-dried spaghetti samples after cooking at optimum cooking times, according to AACC methods 44-15A, 30-25, 08-01, and 46-11A, respectively (AACC 1983). Minor modifications were made to the crude fat and ash methods. Crude fat analysis was done using a 16-hr extraction time with hexane. Ash analysis used 350°C for 1 hr with the muffle furnace door opened, 450°C for 1 hr with the door half opened, and 590°C for 16 hr with the door closed.

Color Analysis

A Hunterlab Tristimulus Colorimeter model D25L-9 (Hunter Associates Laboratory, Inc., Reston, VA) was used to record L and b color values on both raw and cooked spaghetti samples. The values were used to determine a single color score from the color map described by Walsh (1970) and AACC method 14-22 (AACC 1983). The color map designed for dry spaghetti was used to estimate the relative change in color of cooked spaghetti. Thus, the cooked color values should be considered tentative.

Spaghetti Cooking Quality Evaluation

Cooked weight (g), as a measure of the degree of spaghetti hydration, of a 10-g dry spaghetti sample was recorded as described by AACC method 16-50 (AACC 1983).

The optimum cooking time (min) for each sample was determined using AACC method 16-50 (AACC 1983). The spaghetti was considered cooked when the observed white core had disappeared after the spaghetti was pressed between two Plexiglas plates.

Cooking loss, weight of total solids expressed as percent, was measured by evaporating the spaghetti cooking water to dryness in a 100°C oven, as described by AACC method 16-50 (AACC 1983).

Firmness score of cooked spaghetti samples was measured with a universal testing machine (UTM) (Instron, Canton, MA), equipped with a special shearing tooth, based on the method of Walsh et al (1971) and AACC method 16-50. The amount of work (g·cm) required to shear two cooked spaghetti strands was measured.

The total weight and carbohydrate in the cooking water were determined using the procedure described by Dubois et al (1951, 1956).

TABLE I
Proximate Analysis of Light and Dark Buckwheat, Amaranth, Lupin, and Durum Flours

Flour	Moisture (%)	Protein[a] (%)	Ash[a] (%)	Oil[a] (%)
Light buckwheat	13.8	9.6	1.30	1.44
Dark buckwheat	9.6	9.1	2.26	2.06
Amaranth[b]	8.3	14.2	3.02	6.31
Lupin[b]	7.0	30.7	3.37	8.12
Durum wheat flours				
Extra fancy	13.9	14.0	0.77	0.92
Fancy	13.7	14.1	1.02	1.11

[a] 14% moisture basis, $n = 6$.
[b] Whole flour.

In vitro Protein Digestibility

The percent in vitro protein digestibility of the spaghetti samples was determined using the technique described by Hsu et al (1977).

Lysine

The lysine content was determined with AOAC method 982.30 (AOAC 1990).

Sensory Evaluation

The Spectrum method of descriptive analysis described by Meilgaard et al (1987) was used for sensory evaluation by nine trained panelists. The spaghetti noodle samples made with extra fancy durum wheat were chosen for sensory evaluation.

The texture attributes firmness, pastiness, adhesiveness, and nature of particles were evaluated by methods adapted from Larmond and Voisey (1973) and Anonymous (1992). Nature of particles was defined as the degree to which the particles retained their individuality while being chewed. The flavor attributes earthy, raw bean, and musty, as well as the texture attribute grittiness, were identified by the panelists as important pasta characteristics to evaluate. An unstructured scale (12 cm), anchored with the lower intensity in the left-hand side, was used to score each attribute.

Statistical Analysis

Analysis of variance and Duncan's multiple range test were done using the Statistical Analysis System (SAS Institute 1986).

RESULTS AND DISCUSSION

Raw Material

The proximate analysis of the raw flours is shown in Table I. Buckwheat flours showed lower protein content and higher ash and oil than the fancy and extra fancy durum flours. Whole lupin flour had the highest proximate values, while whole amaranth flour showed a protein content similar to that of the durum flours but higher ash and oil contents. These values were within the ranges reported by Bressani (1990), Duranti and Cerletti (1983), and Mohamed and Rayas-Duarte (1995).

Absorption of Flours

The average absorption values for the flour mixes before extrusion were 35.5% for dark and 34.5% for light buckwheat, 33.0% for amaranth, and 31.2% for lupin. The value for the 100% durum flour (control) was 32.9%. Differences in absorption might be attributed to the type of proteins present in the flours, starch damage, and relative composition of the fiber. The fiber content of the raw material was 3.0 and 1.8% in dark and light buckwheat, respectively (Minn-Dak Growers, Inc., Grand Forks, ND), compared to 2.8% in amaranth and 4.0% in lupin (Uriyapongson and Rayas-Duarte 1994, Mohamed and Rayas-Duarte 1995).

Spaghetti Samples

The proximate analyses of cooked and freeze-dried spaghetti samples are reported in Tables II and III. The protein content of samples containing light and dark buckwheat significantly decreased at substitutions higher than 15%. The addition of lupin flour significantly increased the protein content, but no significant effect was observed with the addition of amaranth flour (Table III).

Ash contents of spaghetti samples containing light buckwheat were similar at all substitution levels (Table II), while dark buckwheat significantly increased the ash content at 25 and 30% substitution levels. As the percent of substitution increased, the oil content of amaranth- and lupin-containing spaghetti samples also increased (Tables II and III). This may be important in the stability or shelf life of the products. The sample with 30% lupin had about 1.94% oil (on average). The fatty acid composition of this oil, and particularly the amount of linolenic acid present, would be important in determining the stability of the product. The fatty acid composition of the whole-seed lupin sample is oleic (C18:1) 45.5%, linoleic (C18:2) 18.4%, and linolenic (C18:3) 9.0% (P. Rayas-Duarte, *unpublished data*).

Color

Color scores of dry and cooked spaghetti samples are shown in Table IV. Color of dry spaghetti is an important quality factor for U.S. consumers. In pasta products made with semolina, the higher the value, the more desirable the product. Compared to the durum flour controls, dry light buckwheat and amaranth spaghetti samples showed a significant reduction in color score as the sub-

TABLE II
Proximate Composition of Cooked and Freeze-Dried Spaghetti Samples Containing Light or Dark Buckwheat[a]

Substitution, %	Durum Flour[b]	Moisture, %	Protein,[c] %	Ash,[c] %	Oil,[c] %
Light buckwheat					
5	EF	4.62 ± 0.95 a	13.62 ± 0.19 ab	0.43 ± 0.01 a	0.35 ± 0.01 a
15	EF	4.67 ± 0.99 a	13.19 ± 0.13 ab	0.42 ± 0.01 a	0.29 ± 0.01 ab
25	EF	4.54 ± 0.96 a	12.69 ± 0.13 c	0.47 ± 0.02 a	0.24 ± 0.02 b
30	EF	5.22 ± 0.79 a	12.51 ± 0.12 c	0.47 ± 0.01 a	0.29 ± 0.02 b
5	F	5.22 ± 0.84 a	14.14 ± 0.09 a	0.59 ± 0.03 a	0.53 ± 0.02 a
15	F	5.24 ± 0.77 a	13.72 ± 0.13 ab	0.55 ± 0.01 a	0.39 ± 0.01 ab
25	F	5.25 ± 0.83 a	13.11 ± 0.13 c	0.57 ± 0.01 a	0.28 ± 0.03 b
30	F	4.96 ± 0.82 a	12.95 ± 0.11 c	0.56 ± 0.01 a	0.27 ± 0.04 b
Dark buckwheat					
5	EF	5.62 ± 0.51 a	13.54 ± 0.11 a	0.42 ± 0.01 a	0.37 ± 0.02 a
15	EF	4.93 ± 0.86 a	13.12 ± 0.11 ab	0.46 ± 0.01 ab	0.31 ± 0.15 a
25	EF	4.90 ± 0.89 a	12.80 ± 0.12 b	0.52 ± 0.01 bc	0.29 ± 0.02 a
30	EF	5.71 ± 0.72 a	12.53 ± 0.08 b	0.56 ± 0.01 c	0.28 ± 0.01 a
5	F	5.38 ± 0.78 a	14.17 ± 0.09 a	0.58 ± 0.02 a	0.43 ± 0.04 a
15	F	5.29 ± 0.81 a	13.80 ± 0.07 a	0.58 ± 0.01 ab	0.36 ± 0.03 a
25	F	5.09 ± 0.93 a	13.18 ± 0.11 b	0.64 ± 0.02 bc	0.36 ± 0.01 a
30	F	5.23 ± 0.89 a	13.04 ± 0.05 b	0.66 ± 0.01 c	0.35 ± 0.02 a
Control	EF	6.44 ± 0.65	13.87 ± 0.09	0.45 ± 0.01	0.48 ± 0.03
	F	6.61 ± 0.67	14.36 ± 0.05	0.58 ± 0.01	0.58 ± 0.05
Reference	S	6.37 ± 0.69	14.15 ± 0.20	0.44 ± 0.01	0.44 ± 0.02

[a] Duncan's multiple range test. Means (± standard error) within a column and durum flour type with same letter are not significantly different ($\alpha = 0.05$), $n = 8$ and 16 for samples and controls/reference, respectively.
[b] EF = extra fancy and F = fancy durum wheat flours, S = semolina.
[c] 14% moisture basis.

TABLE III
Proximate Composition of Cooked and Freeze-Dried Spaghetti Samples Containing Amaranth or Lupin[a]

Substitution, %	Durum Flour[b]	Moisture, %	Protein,[c] %	Ash,[c] %	Oil,[c] %
Amaranth[d]					
5	EF	6.17 ± 0.57 a	13.89 ± 0.20 a	0.49 ± 0.01 c	0.50 ± 0.03 c
15	EF	6.43 ± 0.46 a	13.93 ± 0.10 a	0.67 ± 0.01 b	0.76 ± 0.06 b
25	EF	6.08 ± 0.84 a	14.14 ± 0.14 a	0.89 ± 0.03 a	1.11 ± 0.06 a
30	EF	6.23 ± 0.53 a	14.12 ± 0.11 a	0.95 ± 0.03 a	1.19 ± 0.07 a
5	F	6.05 ± 0.76 a	14.45 ± 0.15 a	0.63 ± 0.01 c	0.63 ± 0.03 c
15	F	5.99 ± 0.68 a	14.48 ± 0.08 a	0.80 ± 0.02 b	0.95 ± 0.03 b
25	F	5.89 ± 0.75 a	14.65 ± 0.07 a	0.98 ± 0.07 a	1.23 ± 0.03 a
30	F	6.25 ± 0.95 a	14.62 ± 0.05 a	1.08 ± 0.03 a	1.33 ± 0.11 a
Lupin[d]					
5	EF	5.56 ± 0.99 a	14.58 ± 0.14 d	0.43 ± 0.01 b	0.62 ± 0.04 d
15	EF	5.47 ± 0.92 a	16.01 ± 0.21 c	0.56 ± 0.01 a	1.18 ± 0.07 c
25	EF	5.01 ± 0.98 a	17.80 ± 0.24 b	0.68 ± 0.01 a	1.67 ± 0.09 b
30	EF	4.62 ± 0.99 a	18.99 ± 0.14 ab	0.72 ± 0.02 a	1.88 ± 0.08 a
5	F	4.80 ± 1.05 a	15.18 ± 0.14 d	0.62 ± 0.02 b	0.86 ± 0.03 d
15	F	4.69 ± 1.00 a	16.93 ± 0.13 c	0.65 ± 0.01 b	1.31 ± 0.06 c
25	F	4.71 ± 0.99 a	19.07 ± 0.16 b	0.77 ± 0.04 ab	1.87 ± 0.06 b
30	F	5.24 ± 0.78 a	19.84 ± 0.19 a	0.85 ± 0.01 ab	2.00 ± 0.07 a
Control	EF	6.44 ± 0.65	13.87 ± 0.09	0.45 ± 0.01	0.48 ± 0.03
	F	6.61 ± 0.67	14.36 ± 0.05	0.58 ± 0.01	0.58 ± 0.05
Reference	S	6.37 ± 0.69	14.15 ± 0.20	0.44 ± 0.01	0.44 ± 0.02

[a] Duncan's multiple range test. Means (± standard error) with same letter within column and durum flour type are not significantly different ($\alpha = 0.05$), $n = 8$ and 16 for samples and controls, respectively.
[b] EF = extra fancy and F = fancy durum wheat flours.
[c] 14% moisture basis.
[d] Whole flour.

stitution level increased. Dry spaghetti samples with lupin maintained their color score of 10 at all substitution levels. These results were considered acceptable when compared to the 9.5 and 9.3 average color scores reported on spaghetti made from semolina from 1) the durum wheat survey data five-year average (1989–1994 crop years), and 2) the durum wheat produced in the U.S. 1993–1994 crops years, respectively (Moore et al 1994, U.S. Wheat Associates 1994). Morad et al (1980) reported that a desirable amber color resulted when lupin flour was added to pasta. Color scores of 8.5 and 8.0 were reported by Seyam et al (1983) in spaghetti samples made of semolina, 20% navy bean protein isolates, and 3% gluten. The dark buckwheat samples had low *L* (darker) and negative *b* color values (blue hue), and were out of range in the color map.

The tentative color scores of cooked spaghetti samples obtained from the dry spaghetti color map showed an overall trend similar to that of the dry scores but with reduced values. Few exceptions were observed, i.e., where the actual color score value increased (Table IV).

Multigrain breads are darker and coarser than white breads, yet the market for these bread loaves has grown and expanded. Multigrain pastas may have the advantage of being perceived by a section of the population as a pasta variety related to wellness.

Optimum Cooking Time

Optimum cooking times of the composite-flour spaghetti samples were independent of the substitution level and flour type used and were within the range of the control and reference samples (11.2 ± 0.3 min).

Cooked Weight

Overall, the cooked weight of each composite-flour sample was not significantly different, suggesting that the water absorption of the samples was not altered. Samples with light and dark buckwheat gained about three times their weight in water when cooked, while amaranth- and lupin-containing samples gained about 2.9 times their weight. This compares with the ideal expected cooked weight of semolina spaghetti of about three times the dry weight (Dick and Youngs 1988).

Cooking Loss

Cooking loss (%), analyzed as weight of the total solids lost in the cooking water, is reported in Table V. Samples containing light buckwheat did not show significant differences in cooking loss. However, the cooking loss significantly increased in samples containing dark buckwheat, amaranth, and lupin at 15–30, 25–30, and 30% substitution levels, respectively. Overall average values

TABLE IV
Color Scores of Raw and Cooked Spaghetti Containing Light or Dark Buckwheat, Amaranth, or Lupin Flour[a,b]

Substitution, %	Durum Flour[c]	Light Buckwheat	Dark[d] Buckwheat	Amaranth[e]	Lupin[e]
Raw					
5	EF	9.3 ± 0.3 a	NM	10.0 ± 0.3 a	10.5 ± 0.3 a
15	EF	6.0 ± 0.3 b	NM	6.8 ± 0.3 b	10.3 ± 0.3 a
25	EF	4.8 ± 0.3 c	NM	5.0 ± 0.3 c	10.0 ± 0.3 a
30	EF	4.3 ± 0.3 c	NM	4.5 ± 0.3 c	10.0 ± 0.3 a
5	F	9.3 ± 0.3 a	NM	9.5 ± 0.3 a	10.0 ± 0.3 a
15	F	6.3 ± 0.3 b	NM	6.3 ± 0.3 b	10.0 ± 0.3 a
25	F	4.8 ± 0.3 c	NM	4.5 ± 0.3 c	10.0 ± 0.3 a
30	F	4.3 ± 0.3 c	NM	4.3 ± 0.3 c	10.0 ± 0.3 a
Cooked					
5	EF	6.8 ± 1.8 a	NM	9.3 ± 0.3 a	8.5 ± 0.0 a
15	EF	4.5 ± 0.5 b	NM	8.0 ± 0.0 a	10.3 ± 0.3 b
25	EF	3.8 ± 0.3 b	NM	6.0 ± 0.0 b	11.0 ± 0.0 b
30	EF	3.8 ± 0.3 b	NM	5.0 ± 0.0 c	11.0 ± 0.0 b
5	F	7.8 ± 0.8 a	NM	9.0 ± 0.0 a	8.8 ± 0.3 a
15	F	4.3 ± 0.3 b	NM	7.8 ± 0.8 a	9.8 ± 0.3 b
25	F	4.0 ± 0.0 b	NM	6.0 ± 0.0 b	10.8 ± 0.3 b
30	F	3.8 ± 0.3 b	NM	5.0 ± 0.0 c	10.3 ± 0.3 b

[a] Duncan's multiple range test. Means (± standard error) with same letter within column and durum flour type are not significantly different ($\alpha = 0.05$), $n = 8$ and 16 for samples and controls/reference, respectively.
[b] Raw controls EF = 10.0 ± 0.3, F = 10.1 ± 0.3, reference S = 10.0 ± 0.3; cooked controls EF = 8.8 ± 0.5, F = 8.6 ± 0.1, reference S = 9.4 ± 0.2
[c] EF = extra fancy and F = fancy durum wheat flours, S = semolina.
[d] NM = not measured, values out of range in the color map.
[e] Whole flour.

TABLE V
Cooking Loss (%) of Spaghetti Samples Containing Light or Dark Buckwheat, Amaranth, or Lupin Flour[a,b]

Substitution, %	Durum Flour[c]	Light Buckwheat	Dark Buckwheat	Amaranth[d]	Lupin[d]
5	EF	6.8 ± 0.3 a	6.9 ± 0.3 b	7.0 ± 0.3 b	6.8 ± 0.4 b
15	EF	6.9 ± 0.3 a	7.7 ± 0.3 a	7.8 ± 0.3 a	7.5 ± 0.4 b
25	EF	7.6 ± 0.3 a	8.3 ± 0.3 a	8.6 ± 0.3 a	8.1 ± 0.4 b
30	EF	7.2 ± 0.3 a	9.0 ± 0.3 a	9.3 ± 0.3 a	8.6 ± 0.4 a
5	F	6.5 ± 0.3 a	7.2 ± 0.3 b	6.9 ± 0.5 b	6.7 ± 0.5 b
15	F	7.6 ± 0.5 a	7.5 ± 0.3 a	7.6 ± 0.5 b	7.6 ± 0.5 b
25	F	8.2 ± 0.5 a	8.6 ± 0.3 a	8.5 ± 0.5 a	7.8 ± 0.5 b
30	F	6.9 ± 0.5 a	8.6 ± 0.3 a	8.9 ± 0.5 a	9.4 ± 0.5 a

[a] Duncan's multiple range test. Means (± standard error) with same letter within column and durum flour type are not significantly different ($\alpha = 0.05$), $n = 8$ and 16 for samples and controls/reference, respectively.
[b] Controls EF = 6.3 ± 0.3, F = 6.5 ± 0.3, reference S = 6.5 ± 0.3.
[c] EF = extra fancy and F = fancy durum wheat flour, S = semolina.
[d] Whole four.

of the two durum flours and all substitution levels yielded cooking loss values of 8.1, 8.0 and 7.8, and 7.2% for amaranth, dark buckwheat, lupin, and light buckwheat, respectively. All composite-flour spaghetti samples showed higher values (7.2–8.1%) than the control and reference samples (6.4% average). In spaghetti made with semolina, cooking loss values not higher than 7–8% are expected (Dick and Youngs 1988). The composite-flour samples still were within the expected range and could be considered to have acceptable cooking loss levels. Cooking loss values of 7% were reported in semolina spaghetti containing 20% protein dry bean isolate (Seyam et al 1983).

The ability to form a gluten matrix is unique to wheat flour and semolina and is believed to be the main factor in forming the internal spaghetti network that holds the pasta together (Irvine 1971). The addition of nongluten flours diluted the gluten strength and interrupted and weakened the overall structure of the spaghetti. This may allow leaching of more solids from the spaghetti into the cooking water. Starch was the main component (63.1% dry basis) of the cooking liquor when 100% semolina was used in spaghetti and vermicelli samples (Colonna et al 1990).

TABLE VI
Firmness Scores (g.cm) of Cooked Spaghetti Containing Light or Dark Buckwheat, Amaranth, or Lupin Flour[a,b]

Substitution (%)	Durum Flour[c]	Light Buckwheat	Dark Buckwheat	Amaranth[d]	Lupin[d]
5	EF	4.6 a	4.5 a	4.2 a	4.6 a
15	EF	4.4 ab	3.8 bc	3.5 b	5.6 a
25	EF	3.6 b	3.3 b	2.9 bc	5.9 a
30	EF	4.1 ab	3.1 b	2.4 c	5.9 a
5	F	4.8 a	4.7 a	4.2 a	6.0 a
15	F	3.8 ab	3.5 b	3.7 a	5.7 a
25	F	3.4 ab	2.9 bc	2.9 b	5.9 a
30	F	4.1 ab	2.7 c	2.9 b	5.4 a

[a] Duncan's multiple range test. Means (± standard error) with same letter within column and durum flour type are not statistically different (α = 0.05), n = 8 and 16 for samples and controls/reference, respectively.
[b] Control EF = 4.8, F = 5.1, reference S = 5.3.
[c] EF = extra fancy and E = fancy durum wheat flours, S = semolina.
[d] Whole flour.

Firmness

Firmness values (g·cm) of cooked composite-flour spaghetti samples as a function of the substitution level and flour type are shown in Table VI. Significant decreases in the firmness values of the spaghetti samples containing dark buckwheat and amaranth were observed. In contrast, lupin samples showed firmness values similar to those of the control. However, sensory evaluation showed a significant increase in adhesiveness, grittiness, and nature of particles of the spaghetti with 15% lupin (Table VII). Overall average spaghetti firmness values (g·cm) within a composite flour were lupin (5.6), reference semolina (5.3), durum flour controls (4.9), light buckwheat (4.1), dark buckwheat (3.5), and amaranth (3.3). These results were comparable to the values reported by Seyam et al (1983) for semolina spaghetti containing navy and pinto protein isolates.

Total Carbohydrate

Increasing the level of substitution of all four flours did not significantly affect the amount of total carbohydrate leached into the cooking water. The total carbohydrate loss remained constant within a composite flour. Overall means within a flour were amaranth (2.7 ± 0.6%), durum flour and semolina controls (2.6 ± 0.5%), dark (2.3 ± 0.6%) and light (2.1 ± 0.6%) buckwheat, and lupin (1.2 ± 0.6%). The low starch content (<5%) in lupin seed partially explained these results (Mohamed and Rayas-Duarte 1995). The increased cooking loss (%) observed in 15% dark buckwheat, 25% amaranth, and 30% lupin (Table V) was not apparent in the total carbohydrate data. Other components, i.e., soluble sugars, ash, and protein leached out during cooking. The results of the general phenol-sulfuric acid method were affected by the presence of protein, cysteine, and other noncarbohydrate reducing agents (Chaplin 1994). Cooking water samples contained protein that may have affected the results.

In vitro Protein Digestibility

A significant decrease in the percent in vitro protein digestibility was observed as the level of substitution of light/dark buckwheat and amaranth flours increased (Table VIII). Lupin-containing samples appeared to retain their overall protein digestibility, around 86.3%, compared to 85.5% for the controls. These results may be explained by the lack of antinutrients

TABLE VII
Sensory Evaluation of Spaghetti Samples Containing Light or Dark Buckwheat, Amaranth, or Lupin Flour[ab]

Substitution (%)	Firmness	Pastiness	Adhesiveness	Grittiness	Nature of Particles	Flavor: Earthy	Flavor: Raw Bean	Flavor: Musty
Control[b]	3.5 ± 0.4	0.9 ± 0.2	1.1 ± 0.3	0.3 ± 0.1	3.4 ± 0.3	0.2 ± 0.1	0.2 ± 0.1	0.1 ± 0.1
Light buckwheat								
5	3.7 ± 1.4 a	0.7 ± 1.0 a	1.0 ± 0.8 a	0.2 ± 0.2 a	4.0 ± 0.4 a	0.1 ± 0.1 a	0.1 ± 0.1 a	0.1 ± 0.2 a
15	4.1 ± 1.4 a	1.0 ± 1.0 a	1.1 ± 0.8 a	0.4 ± 0.2 ab	4.1 ± 0.4 a	0.3 ± 0.1 a	0.1 ± 0.1 a	0.3 ± 0.2 a
25	4.0 ± 1.4 a	1.1 ± 1.0 a	1.9 ± 0.8 a	0.7 ± 0.2 bc	3.8 ± 0.5 a	0.3 ± 0.1 a	0.3 ± 0.1 a	0.3 ± 0.2 a
30	3.7 ± 1.4 a	1.2 ± 1.0 a	1.6 ± 0.8 a	1.1 ± 0.2 c	2.9 ± 0.4 b	0.5 ± 0.1 a	0.2 ± 0.1 a	0.3 ± 0.2 a
Dark buckwheat								
5	3.8 ± 0.9 a	1.3 ± 1.5 a	1.8 ± 1.1 a	2.1 ± 0.7 b	3.2 ± 0.4 ab	0.4 ± 0.2 a	0.0 ± 0.0 a	0.6 ± 0.4 ab
15	2.6 ± 0.9 b	1.3 ± 1.5 a	2.3 ± 1.1 a	3.5 ± 0.7 c	3.0 ± 0.4 bc	0.3 ± 0.2 a	0.1 ± 0.0 a	0.8 ± 0.4 b
25	2.9 ± 0.9 b	2.3 ± 1.5 a	2.5 ± 1.1 a	4.0 ± 0.7 d	2.4 ± 0.4 cd	0.4 ± 0.2 a	0.0 ± 0.0 a	1.4 ± 0.4 c
30	2.5 ± 0.9 b	2.6 ± 1.5 a	2.3 ± 1.1 a	4.4 ± 0.7 d	2.3 ± 0.4 d	0.6 ± 0.2 a	0.1 ± 0.0 a	0.9 ± 0.4 bc
Amaranth								
5	3.5 ± 0.9 a	1.0 ± 1.6 a	1.4 ± 1.3 a	0.6 ± 0.5 a	3.6 ± 0.3 a	0.6 ± 0.7 a	0.2 ± 0.1 a	0.3 ± 0.3 a
15	2.5 ± 0.9 ab	2.3 ± 1.6 b	2.0 ± 1.3 a	0.7 ± 0.5 a	2.2 ± 0.3 b	1.2 ± 0.7 b	0.1 ± 0.1 a	0.2 ± 0.3 a
25	1.3 ± 0.9 b	4.0 ± 1.6 c	2.4 ± 1.3 a	0.8 ± 0.5 a	1.6 ± 0.3 b	1.0 ± 0.7 ab	0.2 ± 0.1 a	1.1 ± 0.3 b
30	1.1 ± 0.9 b	6.0 ± 1.6 d	2.2 ± 1.3 a	0.6 ± 0.5 a	0.9 ± 0.3 c	1.2 ± 0.7 b	0.1 ± 0.1 a	1.1 ± 0.3 b
Lupin								
5	5.0 ± 0.7 a	0.7 ± 1.6 a	1.8 ± 1.6 a	0.4 ± 0.3 a	4.5 ± 1.0 a	0.1 ± 0.1 a	0.3 ± 0.1 a	0.1 ± 0.2 a
15	4.8 ± 0.7 a	1.9 ± 1.6 a	2.3 ± 1.6 b	0.9 ± 0.3 b	3.8 ± 1.0 b	0.2 ± 0.1 a	0.3 ± 0.1 a	0.2 ± 0.2 a
25	4.7 ± 0.7 a	1.3 ± 1.6 a	2.2 ± 1.6 b	0.9 ± 0.3 b	3.5 ± 1.0 b	0.3 ± 0.1 a	0.4 ± 0.1 a	0.1 ± 0.2 a
30	5.2 ± 0.7 a	1.9 ± 1.6 a	3.7 ± 1.6 c	1.8 ± 0.3 c	3.1 ± 1.0 c	0.3 ± 0.1 a	0.4 ± 0.1 a	0.4 ± 0.4 a

[a] Duncan's multiple range test. Means (± standard error) with same letter within column and flour type are not significantly different (α = 0.05), n = 4.
[b] Made with extra fancy durum flour.

(enzyme inhibitors) in the lupin flour compared to the buckwheat and amaranth flours (Ikeda et al 1983, Schoeneberger et al 1983, Matthews 1989).

Lysine Content

Total lysine content in the composite-flour spaghetti samples is shown in Table IX.

The levels of lysine in the composite-flour samples increased significantly as the substitution levels increased, except in samples with 5% light buckwheat. Samples containing light or dark buckwheat or amaranth yielded similar lysine values, while higher values were obtained in lupin-containing samples. Lysine contents of durum, buckwheat, amaranth, and lupin flours were 1.9, 5.1, 5.2, and 5.7 g/100 g of protein, respectively. These values are in agreement with literature reports of 2.0, 5.4, 5.3, and 5.9 g/100 g of protein for the same types of samples (Shoup et al 1966, Pomeranz and Robbins 1972, Hove 1974, Betschart et al 1981). Lysine contents of 2.1 and 3.5 g/100 g of protein have been reported for conventional pasta and enriched pasta containing 10% faba bean protein concentrate (Carnovale and Lombardi 1979, Carnovale and Miuccio 1983). USDA (1989) reported 1.75 g of lysine per 100 g of protein in dry spaghetti.

Sensory Analysis

Table VII shows the intensity of the attributes firmness, pastiness, adhesiveness, grittiness, nature of particles, and three tastes (earthy, raw bean, and musty) in the composite-flour spaghetti samples made with extra fancy durum flour.

No differences in the texture attributes of firmness, pastiness, and adhesiveness or the flavor characteristics earthy, raw bean, and musty were observed as the substitution levels of light buckwheat increased. An increased score for grittiness and nature of particles was observed in spaghetti containing light buckwheat at the 25 and 30% levels, respectively. Firmness of dark buckwheat samples decreased significantly while grittiness increased at the 15% level of substitution. A significant increase in the intensity of mustiness was also noted with 25% dark buckwheat substitution.

A significantly decreased score for firmness and nature of particles of the amaranth samples was noted at 25–30% substitution in extra fancy flour. The decrease in firmness detected by the sensory panel was related to the decrease in firmness values determined with the UTM (Table VI). As the amaranth substitution increased, the samples increased significantly in pastiness score, as rated by the sensory panel, but the adhesiveness attribute was not significantly changed. The flavor attributes earthy and musty increased significantly at the 30 and 25–30% amaranth substitution levels, respectively.

The sensory evaluation of lupin samples did not reveal a significant difference in firmness and pastiness. These results agreed with the firmness values measured with the UTM (Table VI). However, the adhesiveness and grittiness characteristics increased significantly, while the intensity of nature of particles decreased significantly. The flavor characteristics tested did not reveal any significant change.

CONCLUSIONS

Acceptable cooking quality parameters were obtained in the spaghetti samples containing amaranth, buckwheat, and lupin, as measured by cooked weight, cooking loss, firmness, and total carbohydrate loss during cooking. The composite-flour spaghetti had a higher lysine content than the control durum wheat flours. Significant decreases in in vitro protein digestibility of spaghetti containing light or dark buckwheat and amaranth flours were observed. The color, in vitro protein digestibility, and lysine content of lupin-containing spaghetti samples were higher than in the other samples and the control.

TABLE VIII
Percent In Vitro Protein Digestibility of Spaghetti Samples Containing Light or Dark Buckwheat, Amaranth, or Lupin Flour[a,b]

Substitution, %	Durum Flour[c]	Light Buckwheat	Dark Buckwheat	Amaranth[d]	Lupin[d]
5	EF	85.7 + 0.1 a	85.0 + 0.1 a	86.2 ± 0.3 a	86.9 ± 0.1 b
15	EF	84.5 ± 0.7 a	84.3 ± 0.6 b	84.4 ± 0.4 ab	85.9 ± 0.5 a
25	EF	83.3 ± 0.5 b	83.5 ± 0.0 c	84.6 ± 0.5 bc	86.1 ± 0.5 a
30	EF	83.2 ± 0.4 b	83.3 ± 0.1 c	84.2 ± 0.6 c	86.4 ± 0.6 ab
5	F	85.1 ± 0.6 a	85.5 ± 0.2 a	85.6 ± 0.5 a	86.3 ± 0.2 ab
15	F	84.1 ± 0.2 a	84.4 ± 0.2 b	84.9 ± 0.1 ab	86.1 ± 0.2 a
25	F	83.4 ± 0.5 b	83.2 ± 0.4 c	84.4 ± 0.3 bc	86.4 ± 0.3 ab
30	F	83.3 ± 0.2 b	82.2 ± 0.1 c	84.3 ± 1.1 c	86.7 ± 0.6 b

[a] Duncan's multiple range test. Means (± standard error) with same letter within column and durum flour type are not significantly different ($\alpha = 0.05$), $n = 4$.
[b] Controls: EF = 85.8 ± 0.2, F = 85.3 ± 0.1, reference S = 85.7 ± 0.2.
[c] EF = extra fancy and F = fancy durum wheat flour, S = semolina.
[d] Whole flour.

TABLE IX
Lysine Content (g/100 g protein) of Spaghetti Samples Containing Light or Dark Buckwheat, Amaranth, or Lupin Flour[a,b]

Substitution, %	Durum Flour[c]	Light Buckwheat	Dark Buckwheat	Amaranth[d]	Lupin[d]
5	EF	1.4 ± 0.1 c	2.3 ± 0.5 b	2.2 ± 0.5 b	2.3 ± 0.1 b
15	EF	2.2 ± 0.1 bc	2.2 ± 0.0 ab	2.7 ± 0.1 a	3.5 ± 0.5 a
25	EF	2.5 ± 0.2 b	2.4 ± 0.1 ab	2.5 ± 0.1 a	3.5 ± 0.8 a
30	EF	2.8 ± 0.1 a	2.7 ± 0.2 a	3.2 ± 0.1 a	4.3 ± 0.2 a
5	F	2.3 ± 0.1 c	2.0 ± 0.1 b	1.9 ± 0.0 b	2.1 ± 0.3 b
15	F	2.6 ± 0.1 bc	2.5 ± 0.2 ab	3.1 ± 0.6 b	2.4 ± 0.2 b
25	F	2.7 ± 0.0 b	2.5 ± 0.0 ab	3.0 ± 0.2 a	3.9 ± 0.9 a
30	F	3.0 ± 0.1 a	2.9 ± 0.5 a	3.1 ± 0.1 a	3.8 ± 0.8 a

[a] Duncan's multiple range test. Means (± standard error) with same letter within column and flour type are not significantly different ($\alpha = 0.05$), $n = 4$.
[b] Controls: EF = 1.9 ± 0.2, F = 1.9 ± 0.1, reference S = 2.5 ± 0.5.
[c] EF = extra fancy and F = fancy durum wheat flour, S = semolina.
[d] Whole flour

A multigrain pasta having a higher lysine content than that of 100% durum wheat flour pasta, acceptable cooking quality, and sensory attributes comparable to those of durum wheat pasta can be produced, using buckwheat, amaranth, or lupin flour. An ideal level of substituted grain would optimize nutritional quality without destroying functionality properties. The levels of substitution at which negative changes in texture or flavor attributes were evident were 30% for light buckwheat, 15% for dark buckwheat, 25% for amaranth, and 15% for lupin.

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