Physicochemical Studies of Pin-Milled and Air-Classified Dry Edible Bean Fractions[1]

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ABSTRACT

Pin-milling and air classification techniques were used to obtain various fractions from dry edible beans for potential use in food product development. Fine fractions (protein-rich), called FI and FII, and one coarse fraction (starch-rich), called CII, were separated from roasted and nonroasted navy bean, pinto bean, and chick-pea. The yields of FI varied from 5 to 13% (dry basis), whereas FII varied from 4 to 10% (dry basis), with the roasted beans showing higher values. Also, FI and FII fractions were about 2.5 times higher in protein content (47–55%) than the original flour. The protein content of CII fractions ranged from 15.5 to 26.0% (dry basis), with the roasted beans showing higher values. Also, the coarse fraction showed almost no starch damage during pin-milling. These values indicated a high efficiency of separation by air classification. An evaluation of the yield and composition of the air-classified fractions of the samples revealed that the air classification of flours from dehulled legumes was essentially a process of separating starch from other seed constituents in that most nonstarch components examined were concentrated in the fine fractions.

With respect to legume utilization, milling of legume products has received increased interest in recent years. Milled products such as whole flour and air-classified high-protein and high-starch fractions from beans will provide increased versatility and improved utilization of beans.

Although there have been many studies on dry edible beans, there are few studies on the flours and air-classified fractions of navy and pinto beans (*Phaseolus vulgaris* L.) and chick-pea (garbanzo bean, *Cicer arietinum* L.). Several studies on milling of legume flours and incorporation of flour into food products have been reported (Ensminger et al 1986), and yield and compositional data of high-protein and high-starch concentrates for dry edible beans obtained through air classification are reported (Vose et al 1976, Patel et al 1980, Tyler et al 1981, Sahasrabudhe et al 1981). However, in contrast to roller-milling characteristics of wheat, very little is known regarding the impact-milling characteristics of starchy grain legumes. A few researchers, such as Vose et al (1976), Sosulski and Youngs (1979), and Tyler et al (1981), report that the differences among legumes in the degree of separation of protein and starch are partly due to differences in their impact-milling characteristics.

Air classification of impact-milled flours is an effective technique for producing starch-rich and protein-rich fractions from several starchy grain legumes (Youngs 1975, Vose et al 1976,

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Kon et al 1977, Reichert and Youngs 1978, Sosulski and Youngs 1979, Colonna et al 1980, Patel et al 1980, Tyler et al 1981).

The purpose of this study was to determine the efficiency of separation of protein from starch in three grain legumes fractionated by pin-milling and air classification according to the double-pass procedure (Tyler et al 1981). In addition, the physical properties and chemical compositions of roasted and nonroasted bean flours and their fractions were evaluated for the potential suitability of these fractions for use in food systems.

MATERIALS AND METHODS

Sample Preparation

Three commercial dry legume samples were used: navy bean (*Phaseolus vulgaris* L.), Min-Dak brand, obtained from Agri Sales Inc., Olivia, MN; pinto bean (*Phaseolus vulgaris* L.), obtained from Frijoles Pintos, ANV Export Corp., St. Johns, MI; and chick-pea (*Cicer arietinum*), obtained from Harvest Gold Inc., Richardton, ND.

The schematic diagram for sample preparation, pin-milling, and air classification procedures of cleaned legume seeds is shown in Figure 1. All legume samples were dried in a convection-type air dryer at 90–95° C to lower the moisture contents of the legumes to under 10%, which is required for optimum milling conditions. Legume samples were roasted by a particle-to-particle heat transfer type roaster at the Food Protein Research and Development Center, Texas A&M University, College Station, TX, according to the procedure of Aguilera et al (1982).

The dehulling process consisted of three steps—breaking, sieving, and aspirating. For the first steps of the dehulling process, an Allis-Chalmers experimental mill (Allis-Chalmers Inc., Milwaukee, WI) was used to break the beans into chunks, which were generally about half the size of wheat kernels. The settings for proper breaking were as follows: setting nos. 1-6 (double pass) for navy bean, setting nos. 1-4-6 (triple pass) for pinto bean, and setting nos. 0-4-6 (triple pass) for chick-pea samples with 1 kg per 1.25-min feed rate. Then nos. 18, 46, and 84 sieves were used to collect the flour generated by the breaking process before air aspirating. The feed rate for sieving was 1.5 kg per 3 min. After sieving, a Kice air aspirator (Kice Metal Products Inc., Wichita, KS) was used for separating the hull and bean chunks. The conditions for aspirating were as follows: the navy and pinto beans were feeder set 30–60, air-flow set 450, three passes, and chick-pea was feeder set 60, air-flow set 450, four passes.

Pin-Milling and Air Classification

After removing the hull from the samples, a double pass of pin-milling and air classification steps was used as shown in Figure 1. Each dehulled sample was pin-milled in an Alpine Kolloplex laboratory pin mill model 160 Z (Alpine American Corp., Natick, MA) with one set of stationary pins and another set of pins rotating at 14,000 rpm. The feed rate was approximately 1 kg/3.5–4 min. At this stage, pin-milled flour was obtained. The pin-milled flours were fractionated into coarse (CI) and fine (FI) fractions using an Alpine-Augsburg Mikroplex air classifier, type 132 MP (Alpine American Corp., Natick, MA) at a feed rate of approximately 0.25 kg/min and a vane setting of 12.

The coarse fraction (CI) from air classification was remilled at the same feed rate of the first pin-milling and air classified at the same cut-point and feed rate as before, resulting in a second coarse (CII) and a 2nd fine (FII) fraction. At the end of the air classification process, three fractions, FI, FII, and CII, were obtained. Because of unavoidable losses of fine particles of the FI and FII fractions in the fines collection system of the air classifier, fine fraction yields were calculated as the difference between the dry weight of the starting coarse fraction and the recovered coarse fraction. Dry weight was used to negate the effect of moisture changes during air classification.

Physical Property Analyses

Impact milling efficiency. To determine the impact milling efficiency, duplicate samples of the three legumes were dehulled, pin-milled and air-classified into coarse (starch-rich) and fine (protein-rich) fractions as described by Tyler et al (1981) and Tyler (1984). The percentage of the total flour protein recovered in the FI and FII fractions were used as a measure of protein separation efficiency. Also, the weight ratio between fine and coarse fractions, the ratio between each fraction, such as hull, FI, FII, and CII fractions, were determined for evaluating milling and air-classification efficiency.

Particle size index. The particle size index of each fraction was determined with a Northrop Microtrac 7991-01 particle size analyzer (Leeds and Northrup Co., Largo, FL). The mean particle size diameter and particle size distribution of each fraction were measured in triplicate by optimum amount of sample with xylene as inert solvent.

Color determination. Color measurements on pin-milled and air-classified fractions were performed with a Gardner XL-800 series colorimeter (Gardner/Nortec Instrument Div., Pacific Scientific Corp., Silver Spring, MD). The procedure was that of Sathe and Salunkhe (1981) with a reference standard black tile no. 45-161 (X, Y, Z = 0.00) and white tile no. 45-161 (X = 89.24, Y = 91.56, Z = 106.79) and were expressed in terms of L, a, and b values, where L = lightness; a = red when positive, grey when zero, and green when negative; and b = yellow when positive, grey when zero, and blue when negative.

Chemical Composition Analyses

Proximate analysis. The moisture (method 44-15A), protein (46-11A), lipid (30-10), and ash contents (08-01) of all fractions were determined in duplicate according to AACC approved methods (1983). The conversion factor of 6.25 was used for con-

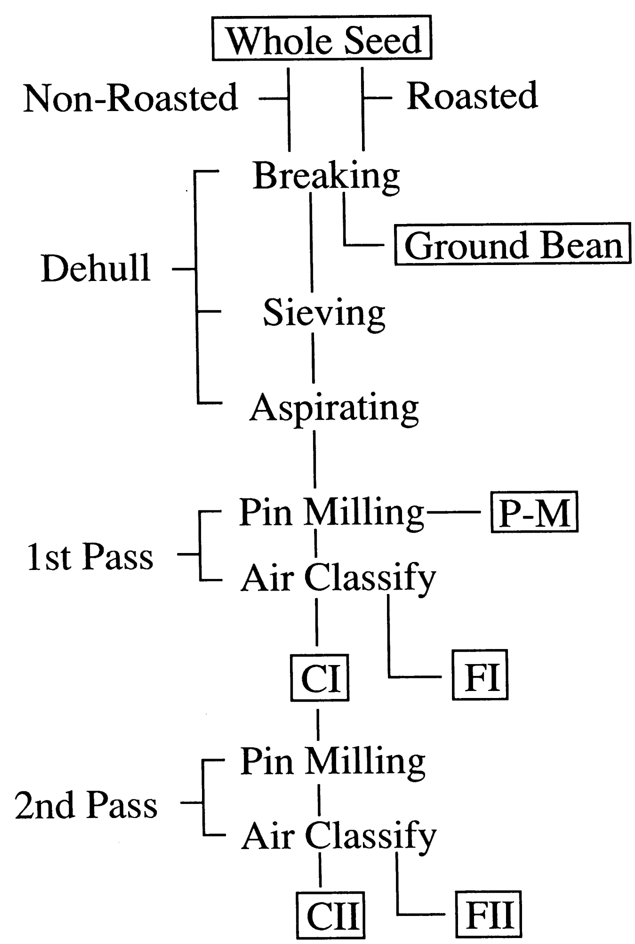

Fig. 1. Schematic diagram of double-pass sample preparation process of legume seeds. P-M = pin-milled flour, CI and CII = first and second coarse fractions, FI and FII = first and second fine fractions.

version of nitrogen to protein content, and all results were reported as a percentage on a dry weight basis.

Starch damage. Starch damage was determined enzymatically in duplicate on all legume fractions. The method of Farrand (1964) was used with a modification. Instead of the malt flour containing α-amylase activity, a commercial bacterial α-amylase preparation from *Bacillus subtillis* (United States Biochemical Corporation, Cleveland, OH) was used that was adjusted to give the same level of activity as in the malt of the original procedure. (This modification was suggested by David R. Shelton, Department of Cereal Science and Food Technology, NDSU, Fargo, ND). The results of this procedure were expressed in percent starch damaged and were reported on a dry weight basis.

Total dietary fiber. The total dietary fiber content was determined enzymatically in duplicate on all fractions. The method of Prosky et al (1984, 1985) was used with slight modifications as proposed by Sigma Chemical Company (1985). Before analysis, the chick-pea fractions, which contained more than 5% fat content, were defatted three times by Soxhlet with 350 ml of petroleum ether. The defatted legume sample (1 g) was placed in a 600-ml tall-form beaker and 50 ml of pH 5.0 phosphate buffer was added. The results were reported as percent total dietary fiber, based on dry weight.

Amino acid analysis. Amino acid analysis of the legume samples were carried out according to the procedure of Schuster (1984) using a Hewlett-Packard HP 1090 Liquid Chromatograph system.

Statistical Analysis

Data were analyzed by Duncan's multiple range test using the Statistical Analysis System (SAS) as described by SAS Institute (1985).

RESULTS AND DISCUSSION

Physical Property Analysis

Milling efficiency. Efficient air classification requires efficient milling, since only when the structural units of the endosperm, primarily protein and starch, are milled free of each other can they be separated. In other words, factors that affect the breakdown of the endosperm (the degree of reduction) also affect the yield and protein content of the air-classified fractions (Tyler et al 1981).

The yields of the coarse (CII) and fine (FI and FII) fractions from each legume are shown in Table I. Generally, pinto bean (nonroasted and roasted) had the highest fine fraction yields, which include the FI and FII fractions, followed by navy bean, then chick-pea. Also, roasted samples gave slightly higher first fine fraction (FI) yields than nonroasted samples, except in navy beans. Nonroasted navy bean showed a higher first fine fraction (FI) yield (10.84%) than the FI of roasted navy bean (9.54%). Our results agree with those of Sosulski and Youngs (1979) and Tyler (1982), who also pin-milled and air classified nonroasted beans. Generally, however, better separation of the hull from the endosperm is obtained with roasted samples as shown in the present study. The ratios of separated coarse and fine fractions, CII/(FI + FII), were different among legumes; however, the fraction yields were similar for samples of a particular legume.

Potential effects on yield of variations in process parameters such as seed moisture content, feed rates to the impact mill and air classifier, and air classifier cut-size were minimized by processing all samples under constant conditions. However, the fine fraction (FI and FII) separation efficiency of chick-pea was considerably lower than that of the other legume samples. The significantly higher quantity of lipid in chick-pea flour may have interfered with the air classification of the pin-milled flour because of the tendency for the flour to agglomerate. From comparison of the ratio of fine to the coarse fraction, the navy bean showed a lower ratio which probably indicated harder characteristics than pinto bean. Statistically, these differences are not significant. Also, in this case, chick-pea is not comparable with the other legumes due to its high lipid content.

Particle size determination. The mean particle diameter of the fine (FI and FII) and coarse (CII) fractions from each legume are shown in Table I. The mean particle diameter of samples showed quite similar values for all samples of a particular fraction except chick-pea, especially the nonroasted FII fractions, most likely due to their high lipid contents, as mentioned before. Roasted and nonroasted navy and pinto bean showed 13 μm as the point of separation (cut-size) of fine from coarse fractions. Chick-pea showed 13-μm cut-size at first air classification and 75 (nonroasted) and 53 (roasted) μm at second air classification, perhaps due to high lipid content. Those size distribution data indicate that roasting did not affect the particle size during the pin-milling process. Statistical analyses also showed no significant effect due to roasting. These results indicate the uniformity of the air classification procedure used in this study. The cut-size used for air classification in this study was not necessarily optimal for any or all of the legumes studied. However, the use of the same cut-size for all samples facilitated comparisons.

Color of fractions. The color of fractions was evaluated in three dimensions: lightness (*L* value), redness (*a* value), and yellowness (*b* value) (Table II). The *L* value shows that the fine fractions are whiter than the coarse fractions due to the concentration of hull in the coarse fractions and also to their larger particle size. Statistical analysis showed that the navy bean is significantly whiter in color than the other bean samples. Roasting, however, did not affect the brightness of sample (*L* value).

TABLE I
Duncan's Multiple Range Test for Yields and Particle Size Diameter of Different Legume Flours and Their Fractions

Variables	n	Yield Mean[a] (%)	Particle Size Mean[a] (μm)
Legume effect			
Navy	8	25.0 a	14.1 a
Pinto	8	25.0 a	14.4 a
Chick-pea	8	25.0 a	14.9 a
Treatment effect			
Nonroasted	12	25.0 a	14.2 a
Roasted	12	25.0 a	14.8 a
Fraction effect[b]			
Hull	6	10.8 b	...
Pin-milled	6	...	26.8 a
FI	6	9.5 b	5.8 c
FII	6	7.1 b	7.6 c
CII	6	72.6 a	17.8 a

[a] Means in the same column followed by the same letter are not significantly different ($P = 0.05$).
[b] FI = First fine fraction; CII and FII = coarse and fine fractions, respectively, from remilling of first coarse fraction.

TABLE II
Duncan's Multiple Range Test for Color Values[a] of Air-Classified Legume Flours and Their Fractions

Variables	N	Mean[b] L	Mean[b] a	Mean[b] b
Legume effect				
Navy	10	88.4 a	0.2 b	7.4 b
Pinto	10	87.1 b	0.6 a	7.8 b
Chick-pea	10	87.5 b	−0.6 c	18.0 a
Treatment effect				
Nonroasted	15	87.7 a	0.1 a	11.0 b
Roasted	15	87.6 a	0.1 a	11.4 a
Fraction effect				
Whole	6	76.4 c	1.5 a	14.4 a
Pin-milled	6	89.4 b	−0.2 b	11.5 b
FI	6	91.9 a	−0.5 b	8.5 c
FII	6	91.6 a	−0.5 b	9.1 c
CII	6	88.8 b	−0.1 b	11.6 b

[a] *L* = Lightness (100 white, 0 black), *a* = redness (+ red, − green), *b* = yellowness (+ yellow, − blue).
[b] Means in the same column followed by the same letter are not significantly different ($P = 0.05$).

The *a* value (redness) of pinto bean was significantly higher than the other samples. Chick-pea, however, showed a negative value, which indicated a greener color. But, after air classification, no significant differences were detected between fine and coarse fractions (Table II). Also roasting did not affect the *a* value.

The *b* value (yellow color) of chick-pea was higher in both roasted and nonroasted samples of all fractions. Also, the roasted sample showed significantly higher values than the nonroasted samples. The legume flours were creamy yellow, especially chick-pea flour (Table II). The air-classified fractions of navy and pinto beans were slightly less yellow than the original pin-milled flour fraction, perhaps due to their particle size and composition.

Chemical Composition Analyses

These analyses included moisture, protein, starch damage, total ash, and total dietary fiber. Generally, the dry seeds of legumes have a similar chemical composition with the exception of the class peanuts (*Archis* sp.) and soybeans (*Glycine* sp.) which have a high fat and relatively low carbohydrate content (FAO 1958).

Moisture content. The moisture contents of each bean type and its fractions were determined as shown in Table III. The moisture content varied greatly depending on the sample. During the first air classification, the moisture content showed a larger decrease than the fractions obtained from the second air classification step (FII and CII). Such a result would be expected because of greater moisture loss where a large number of particles and their surfaces are involved.

Note that the moisture content is lower in the fine fractions (FI and FII). Coarse fraction yield and the protein contents of the coarse fractions declined as seed moisture content was reduced, whereas fine fraction yield and the starch contents of the coarse and the fine fractions showed increases (Tables I, III, and IV). These results agree with those of Tyler and Panchuk (1982). In contrast, protein fraction yield, starch contents of the starch and protein fractions, protein separation efficiency, and neutral detergent fiber content of the protein fraction were greater at lower seed moistures (Tyler and Panchuk 1982).

Protein content. The air-classified fine fractions showed very high protein contents (Table IV). Most of the starch was concentrated in the coarse fraction. Generally, the values in this study are somewhat lower than those of Vose et al (1976) and Sosulski and Youngs (1979) most likely due to variety differences. But, the trend of these results is very similar to those of other researchers mentioned above. The pin-milled flour protein content, 22–27%, increased approximately two and one-half times as a result of removing the starch component through air classification.

The first air-classified fractions (FI) contained protein contents ranging from 54.1% in navy to 58.7% in chick-pea, which is 2.0 to 2.5 times higher than those of the corresponding flours. In each case, crude fat, cell wall material (fiber materials), and ash also passed into the fine protein fraction from the air-classifier, as discussed later. These results are similar to those of Sosulski and McCurdy (1987).

The FII fractions exhibited the expected decrease in protein content compared with the FI fractions, with protein contents ranging from 38.7% in chick-pea to 53.4% in roasted navy bean. The chick-pea samples showed the largest decrease in protein content, declining from 58.7% in the FI to 38.7% in the FII, whereas the roasted navy bean samples showed the smallest decrease, dropping from 54.1 to 53.4%. Differences in protein content among legumes may be caused by differences in seed hardness or in the amount of residual protein that cannot be separated from the starch granule by pin-milling (Ziegler and Greer 1971). A harder cotyledon would presumably be more difficult to pin-mill, resulting in a flour with more agglomerates of starch and proteinaceous material. Higher levels of these agglomerates would reduce the protein content by reducing the yield of the fine fractions. Ziegler and Greer (1971) found similar results from studies of hard wheat flour. Statistical analysis did not show the treatment effect (roasting and nonroasting) to have a significant difference.

Lipid content. All three legumes showed significant differences in lipid content (Table IV). Chick-pea showed the highest lipid content, followed by navy, then pinto bean. After air classification, most of the fat was concentrated in the fine fractions (FI and FII) and significant differences were observed among the fractions. The higher lipid content of chick-pea could have affected most other determinations such as particle size distribution, mean particle diameter, and yield. The significant quantity of lipid in chick-pea flour appeared to interfere with the air classification of the pin-milled flour, apparently because of the tendency for the flour particles to agglomerate. Roasting, however, had no significant effect on the lipid content.

Ash content. The ash content of legume seeds is usually in the range of 3–4% (Eden 1968), which is considerably higher than for cereals. The navy and pinto bean showed significantly higher

TABLE III
Moisture Content (%) of Pin-Milled Legume Flours and Air-Classified Fractions[a]

Flour	Whole[b]	P-M[c]	FI[c]	FII[c]	CII[c]
Navy	9.13	8.36	6.83	6.27	7.37
R-Navy[d]	8.54	8.36	6.38	6.15	7.21
Pinto	9.50	8.48	6.07	6.20	7.73
R-Pinto	8.00	7.67	5.94	5.87	7.02
Chick-pea	8.42	7.79	5.55	5.75	6.70
R-Chick-pea	7.62	7.22	5.39	5.68	6.58

[a] Values reported are an average of two determinations.
[b] Whole ground bean flour which includes hull.
[c] P-M = Pin-milled; FI = first fine fraction; CII and FII = coarse and fine fractions, respectively, from remilling of first coarse fraction.
[d] R = Roasted dry edible beans.

TABLE IV
Duncan's Multiple Range Test for Protein, Lipid, and Ash Contents of Air-Classified Legume Flours and Their Fractions

Variables	*n*	Mean[a] (%) Protein	Lipid	Ash
Legume effect				
Navy	10	33.9 a	2.6 b	5.8 a
Pinto	10	33.0 a	2.0 c	5.4 a
Chick-pea	10	35.0 a	7.1 a	3.3 b
Treatment effect				
Nonroasted	15	33.8 a	3.7 a	5.0 a
Roasted	15	341. a	4.1 a	4.6 a
Fraction effect				
Hull	6	23.6 c	2.4 c	3.5 b
Pin-milled	6	24.3 c	3.2 c	3.4 b
FI	6	55.4 a	6.0 a	7.6 a
FII	6	47.7 b	5.2 b	6.8 a
CII	6	18.9 d	2.7 c	2.7 b

[a] Means in the same column followed by the same letter are not significantly different ($P = 0.05$).

TABLE V
Duncan's Multiple Range Test for Starch Damage of Air-Classified Legume Flours and Their Fractions

Variables	*n*	Mean[a] (%)
Legume effect		
Navy	8	40.5 a
Pinto	8	28.5 b
Chick-pea	8	22.4 b
Treatment effect		
Nonroasted	12	32.3 a
Roasted	12	28.6 a
Fraction effect		
Pin-milled	6	0.5 c
FI	6	70.3 a
FII	6	50.9 b
CII	6	0.2 c

[a] Means with the same letter are not significantly different ($P = 0.05$).

ash content in their fractions than chick-pea fractions (Table IV). The reason for this is the differences in their hull characteristics. The navy and pinto beans seem to have a stronger attachment between hull and endosperm, whereas the chick-pea has weaker hull attachment. There was more hull remaining in the navy and pinto beans than chick-pea after aspiration on the Kice aspirator. Also, most of the ash is concentrated in the fine fraction, similar to the lipid content. Chick-pea showed significantly lower values than the other legumes.

Also, roasting did not significantly affect the ash content of the legumes, although nonroasted beans showed a slightly higher ash content at all stages of sample fractionation than roasted. However, ash content of legume flours has not been investigated as an indicator of milling efficiency as in wheat milling (Watson et al 1975).

Starch damage. In Table V, the starch damage of each fraction is expressed as a percentage (Farrand 1964). It should be noted that this method measures starch damage in arbitrary units, expressed on a percentage scale, and gives an estimated proportion of the total starch that is damaged. The range for the commercial milling of all types of flours on this arbitrary scale is approximately 0–45%. Most bread flours fall into a range of 15–30%. Because of the arbitrary nature of the zero, it is conceivable that the method could give a negative starch damage percentage. This would not preclude comparison of levels of damage, but it would indicate abnormally low water absorption characteristics (Farrand 1964).

TABLE VI
Duncan's Multiple Range Test for Total Dietary Fiber Content of Air-Classified Legume Flours and Their Fractions

Variables	*n*	Mean[a] (%)
Legume effect		
Navy	5	23.0 a
Pinto	5	24.3 a
Chick-pea	5	15.4 a
Fraction effect		
Whole	3	33.7 a
Pin-milled	3	15.5 b
FI	3	19.2 b
FII	3	21.4 b
CII	3	14.8 b

[a] Means with the same letter are not significantly different ($P = 0.05$).

TABLE VII
Amino Acid Composition[a] of Air-Classified Roasted and Nonroasted Legume Flours

Flour/	Roasted[b]				Nonroasted[b]			
Amino Acid	P-M	FI	FII	CII	P-M	FI	FII	CII
Navy bean								
Aspartic acid	11.61	8.44	8.01	11.77	10.44	7.58	7.44	11.70
Glutamic acid	14.53	12.05	11.23	14.42	13.41	10.25	9.90	14.93
Serine	5.05	4.11	3.86	4.67	4.27	3.56	3.49	4.87
Histidine	2.70	2.33	2.40	2.89	2.66	2.33	4.21	3.39
Glycine	4.22	3.71	3.57	4.09	3.80	3.34	3.26	3.96
Threonine	5.01	3.82	3.71	5.05	4.56	3.45	3.40	5.03
Arginine	6.41	6.15	6.05	6.31	7.13	5.56	5.53	8.20
Alanine	4.39	3.62	3.49	4.32	4.00	3.27	3.21	4.22
Tyrosine	3.08	2.98	2.62	2.98	2.95	3.56	2.51	3.10
Methionine	0.87	0.91	0.84	0.82	0.84	0.85	0.81	0.82
Valine	5.39	4.36	4.31	6.50	5.03	4.17	4.08	5.24
Phenylalanine	5.77	5.51	5.25	5.60	5.45	5.04	4.92	5.58
Isoleucine	4.64	4.22	4.13	4.41	4.39	4.03	3.93	4.35
Leucine	7.78	7.37	7.05	7.31	7.35	7.00	6.80	7.33
Lysine	7.11	6.26	6.15	7.07	6.70	5.76	5.68	6.97
Pinto bean								
Aspartic acid	10.54	6.60	6.60	9.94	10.65	7.62	7.43	11.27
Glutamic acid	14.49	9.45	9.25	12.10	15.24	11.28	10.49	15.74
Serine	4.09	3.22	3.20	4.22	4.55	3.82	3.56	4.22
Histidine	3.02	2.07	2.12	3.00	3.02	2.61	2.54	3.19
Glycine	3.70	2.83	2.79	3.46	3.84	3.34	3.20	3.80
Threonine	4.03	2.76	2.82	4.04	4.34	3.28	3.14	4.38
Arginine	7.90	5.18	5.14	6.92	7.46	5.89	5.81	8.46
Alanine	3.84	2.73	2.76	3.60	3.97	3.21	3.09	4.01
Tyrosine	3.05	2.37	2.29	2.84	3.30	2.81	2.60	3.19
Methionine	0.89	0.42	0.35	0.41	0.36	0.47	0.37	0.53
Valine	5.06	3.12	3.09	4.07	4.55	3.58	3.64	4.92
Phenylalanine	5.47	4.39	4.23	4.90	5.68	5.21	4.99	5.47
Isoleucine	4.47	3.08	3.00	3.61	4.09	3.58	3.59	4.25
Leucine	7.36	5.73	5.54	6.38	7.38	6.73	6.49	7.34
Lysine	6.97	4.62	5.34	6.30	7.06	6.29	6.04	7.00
Chick-pea								
Aspartic acid	10.80	7.23	9.08	9.81	9.68	7.15	6.26	8.65
Glutamic acid	16.72	10.74	14.08	10.46	14.70	10.99	9.27	12.82
Serine	4.04	3.20	3.02	3.76	3.71	3.00	2.65	3.26
Histidine	2.58	2.22	2.50	2.46	2.48	2.02	1.77	2.25
Glycine	3.99	3.18	3.50	3.65	3.65	2.92	2.59	3.13
Threonine	3.63	2.58	3.21	3.47	3.38	2.46	2.22	3.03
Arginine	13.16	9.76	11.19	11.96	12.31	9.69	8.79	10.92
Alanine	4.06	3.07	3.59	3.76	3.71	2.92	2.59	3.26
Tyrosine	2.66	2.15	2.48	2.49	2.40	1.93	1.68	2.13
Methionine	0.41	0.54	0.58	0.34	0.23	0.33	0.25	0.34
Valine	4.09	3.31	3.81	3.75	3.66	2.92	2.59	3.27
Phenylalanine	5.90	3.37	5.40	5.42	5.48	4.69	4.16	4.77
Isoleucine	3.99	3.53	3.77	3.60	3.58	3.06	2.71	3.16
Leucine	6.82	6.17	6.43	6.23	6.26	5.49	4.82	5.43
Lysine	6.65	5.79	6.19	6.20	6.58	5.28	4.68	5.46

[a] In grams of amino acid per 100 g of protein.
[b] P-M = pin-milled, FI = first fine; CII and FII = coarse and fine fractions, respectively, from remilling of first coarse fraction.

In the case of legume flour, starch is damaged during pin-milling. Also, the majority of damaged starch was concentrated mostly in the fine fractions with significant differences between FI and FII. These results also show that there is significantly more starch damage in navy bean fractions (legume effect). Roasting did not significantly affect the starch damage. These results also show that the undamaged starch granules are concentrated in the coarse (CII) fraction after air classification.

Dietary fiber content. Most of the fiber data on legumes have been reported on the whole seed and using the crude fiber method. However, the total dietary fiber contents of legumes have not been widely investigated. Total dietary fiber values for some plant material were investigated by Prosky et al (1984). But, in 1985 Prosky indicated that those values were very broad ranges for the same type of samples. Also, a commercial standard sample was not available.

The results in Table VI show slightly higher values than that from the USDA, NMD laboratory (Hyattsville, MD); however, in Table VI, the trend of results seem to be uniform. Because of sample limitations, the treatment effect (roasting and nonroasting) was eliminated from these analyses. Chick-pea showed the lowest value among the analyzed legume samples. The presence or absence of the hulls in these legumes had little effect on fiber content of the high-protein, low-density fraction. Milled hulls were air classified along with the denser starch fraction. This was particularly true for navy beans. However, the total dietary fiber content in each air-classified fraction was not statistically significant.

Amino acid composition. Since protein quality is a function of essential amino acid composition, study of amino acid patterns for legume flours and their protein concentrates was of interest. The hydrolysates of the protein in the flour, protein (fine) fractions, and starch (coarse) fraction of each legume species gave a similar amino acid distribution as shown in Table VII. Whereas the nonessential amino acids, aspartic acid and glutamic acids, constituted over 30% of the total, the concentrations of nine essential amino acids in each of the legume fractions were similar to the requirements for humans recently elaborated by the NAS (1980). The amino acid composition of bean fractions showed that, except for leucine, lysine was the most abundant of the essential amino acids; lysine was higher than in soybeans and about four times that in wheat. These data are in agreement with the data reported by Kakade and Evans (1965), Yadav and Liener (1977), Patel et al (1980), Bahanssey et al (1986), and Sosulski et al (1987).

Although samples were higher in lysine and leucine contents than NAS standards (1980), Patel and Johnson (1974) and Sosulski and McCurdy (1987) reported that methionine, one of the two sulfur-containing amino acids, was the first limiting amino acid in bean and pea flour and their fractions. The variation in amino acid content between air-classified fractions of bean samples could be ascribed to changes in distribution occurring during pin-milling and air classification (Patel 1974). Roasting did not seem to affect the amino acid composition of the different samples. A slight decrease in amino acids was noted in the amino acid composition of protein concentrates compared with the legume flour samples. This difference is perhaps due to the difference in ratio of amino acid composition between interstitial (fine fractions) and adherent proteins (coarse fractions), the latter having a higher amino acid composition than any of the other fractions. It should also be pointed out that the coarse (CII) fraction is very similar in composition to the pin-milled (PM) fraction. Similar trends were found for interstitial and adherent proteins for hard wheats (Kent and Evers 1969). Comparing the three classes of beans, chick-pea showed much higher arginine content than navy and pinto beans.

CONCLUSIONS

Two of the three legumes, navy and pinto beans gave very good separation and concentration of protein-rich fractions when pin-milled and air classified. On the basis of this study, only chick-pea would be considered a poor choice for this method because it exhibited poor separation values in the fine fractions, most likely due to its high lipid content. However, manipulation of chick-pea sample preparation and milling and air classification conditions may result in better separations. In addition, the individual protein and starch fractions, even in the crude form, obtained by air classification exhibited a wide range in physicochemical characteristics. These air-classified products, possibly with future refining of the protein and starch fractions, could serve to expand the range of functional raw materials available to the food and related industries.

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