Air Classification of Legumes. I. Separation Efficiency, Yield, and Composition of the Starch and Protein Fractions[1]

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Cereal Chem. 58(2):144–148

ABSTRACT

Two samples of each of eight grain legumes (mung beans, green lentils, Great Northern beans, faba beans, field peas, navy beans, baby lima beans, and cowpeas) were mechanically dehulled, pin milled, and air classified into starch and protein concentrates. The starch fractions contained 58.0–76.1% starch and 7.7–20.1% protein, whereas the protein fractions contained 49.3–75.1% protein and 0.0–4.6% starch. The starch fractions from the first classification were remilled and air classified, yielding starch fractions, containing 71.0–85.9% starch and 4.0–10.4% protein, and a second series of protein concentrates, containing 38.0–68.2% protein and 0.4–16.6% starch. Values for starch separation efficiency and protein separation efficiency (PSE) were calculated for each legume. Differences in PSE among legumes were significant ($P < 0.05$), but differences in starch separation efficiency were not. Mung beans exhibited the highest PSE (88.9%) and cowpeas the lowest (78.2%). The fat, ash, and crude fiber contents were similar in the corresponding fractions of the various legumes, with fat and ash showing a marked concentration in the protein fractions. On the basis of PSE and the protein contents of the two protein fractions, mung beans and lentils were the most suitable legumes for air classification, and lima beans and cowpeas were the least suitable.

Air classification of impact-milled flours has proven to be an effective technique for producing starch-rich and protein-rich fractions from a number of starchy grain legumes (Kon et al 1977, Patel et al 1980, Sosulski and Youngs 1979, Vose et al 1976, Youngs 1975). Little emphasis, however, has been placed on comparing the efficiency of protein-starch separation in different legumes or on determining the reproducibility of separation data.

[1]Paper 18654 from the National Research Council of Canada.

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009-0352/81/0214405/$03.00/0

The primary objective of this study was to determine whether significant differences existed in the efficiency of separating protein from starch in eight grain legumes fractionated by pin milling and air classification with the double-pass procedure employed by Youngs (1975) and Vose et al (1976). In addition, the suitability of air classification as a method of producing starch and protein concentrates was assessed for each legume by comparing the yields and compositions of their air-classified fractions.

MATERIALS AND METHODS

Legume Samples

Two series of eight grain legumes were studied: mung beans (*Vigna radiata*), green lentils (*Lens culinaris*), Great Northern beans (*Phaseolus vulgaris*), faba beans (*Vicia faba minor* cv. Diana and Ackerperle), smooth field peas (*Pisum sativum* cv. Trapper), navy beans (*Phaseolus vulgaris*), baby lima beans (*Phaseolus lunatus*), and cowpeas (*Vigna unguiculata*). Eleven of the samples were commercial varieties obtained at Early Seed and Feed Co., Saskatoon, Saskatchewan. Of the other five, one sample of field peas and one of faba beans were obtained from test plots at the University of Saskatchewan, and one Great Northern bean sample was obtained from the University of Idaho; one cowpea sample was a Senagalese variety, and the other was purchased from the Ring Around East Texas Seed Co., Tyler, TX. When both samples of a legume were obtained in the same locality, each was selected from a different growing season to ensure that identical samples were not used.

Processing

All samples were equilibrated to a moisture content of 8% before processing. Field peas, faba beans, green lentils, and navy beans were dehulled in a Currier type of plate mill followed by air aspiration. Mung beans, baby lima beans, Great Northern beans, and cowpeas were dehulled in a modified Hill grain thresher (Reichert and Youngs 1976). After dehulling, the moisture content of the seeds was readjusted to 8% if necessary.

The pin-milling and air-classification process is presented schematically in Fig. 1. Each dehulled sample (10–15 kg) was pin milled in an Alpine pin mill model 250 CW (with counter-rotating pins operating at 6,000 and 11,500 rpm) at a feed rate of approximately 2.5 kg/min. The flours were then fractionated into starch (SI) and protein (PI) concentrates, using an Alpine air classifier type 132 MP at a feed rate of approximately 0.5 kg/min and a vane setting of 12. The SI fraction was remilled at a feed rate of approximately 1.5 kg/min and then fractionated at the same cut point and a feed rate of approximately 1.0 kg/min, resulting in starch (SII) and protein (PII) concentrates. Because of unavoidable losses of portions of the PI and PII fractions in the fines collection system, protein fraction yields were calculated as the difference between the dry weight of the flour (or remilled SI) that was classified and the dry weight of the recovered starch fraction. Dry weights were used to negate the effect on fraction yields of moisture changes during air classification.

TABLE I
Yields[a] of Air-Classified Fractions[b] of Pin-Milled Legume Flours Expressed as a Percentage of Flour Weight

Legume	Series 1 SII	Series 1 PI	Series 1 PII	Series 2 SII	Series 2 PI	Series 2 PII
Mung bean	61.2	27.1	11.7	59.2	29.8	11.0
Lentil	62.9	21.9	15.2	62.2	27.9	9.9
Northern bean	57.8	29.3	12.9	56.3	28.5	15.2
Faba bean	62.8	21.1	16.1	62.8	23.2	14.0
Field pea	65.9	22.3	11.8	65.8	23.0	11.2
Navy bean	62.6	22.2	15.2	61.7	23.4	14.9
Lima bean	60.6	23.8	15.6	61.5	26.4	12.1
Cowpea	62.5	25.0	12.5	58.5	26.1	15.4

[a]Calculated on a dry weight basis.
[b]PI = First protein fraction; SII and PII = starch and protein fractions, respectively, from remilling of first starch fraction.

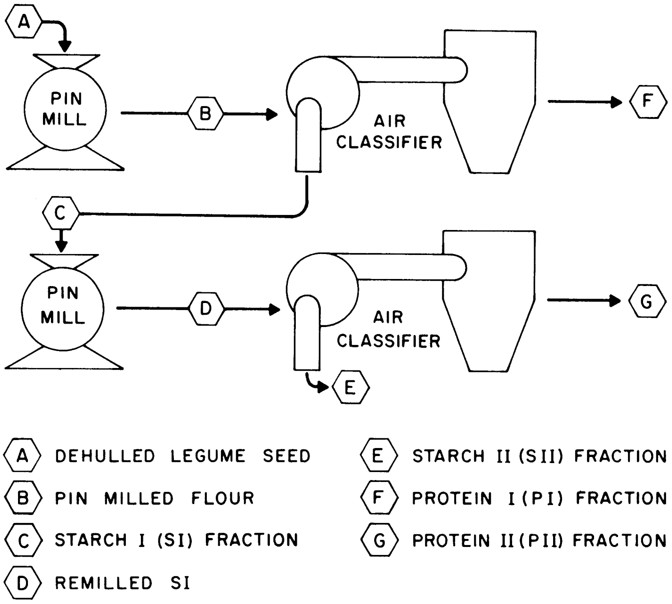

Fig. 1. The double-pass pin milling and air classification process.

TABLE II
Protein and Starch Contents[a] of Pin-Milled Legume Flours and Air-Classified Fractions[b]

Legume	Series	Protein[c] (%) in Flour	SI	SII	PI	PII	Starch (%) in Flour	SI	SII	PI	PII
Mung bean	1	25.8	11.7	4.6	61.4	52.5	52.2	74.0	82.5	2.4	11.2
	2	27.5	12.4	5.3	63.2	57.1	52.8	75.9	85.6	2.4	8.7
Lentil	1	26.3	16.5	5.4	64.6	54.3	53.6	65.8	85.6	0.2	5.8
	2	19.5	7.7	4.0	49.3	38.0	56.2	76.1	84.9	4.6	16.6
Northern bean	1	22.6	11.4	4.8	50.7	38.8	47.2	68.6	80.6	0.7	3.0
	2	26.5	14.6	6.4	57.5	47.6	45.5	61.3	79.1	0.4	1.6
Faba bean	1	30.4	19.6	7.2	71.3	63.8	51.3	63.8	81.7	0.7	4.0
	2	31.6	20.1	8.6	75.1	68.2	51.9	65.9	80.6	1.7	4.1
Field pea	1	23.0	12.4	6.2	59.2	51.8	54.2	72.4	81.5	1.6	3.7
	2	21.5	12.1	5.4	56.3	45.5	56.6	73.4	85.9	2.9	6.9
Navy bean	1	26.5	17.2	9.0	58.6	50.7	44.9	58.0	71.0	1.0	2.6
	2	26.1	16.2	7.8	61.3	48.9	47.0	59.0	75.2	0.7	2.7
Lima bean	1	22.8	14.7	7.1	49.6	43.4	48.8	61.9	79.6	0.0	0.4
	2	24.0	14.7	8.2	49.5	46.0	50.5	67.3	80.7	1.3	2.9
Cowpea	1	23.6	14.2	8.0	51.6	45.8	52.0	68.8	80.7	3.2	9.2
	2	27.2	16.2	10.4	51.0	45.5	44.2	61.3	73.4	0.4	1.6

[a]Values are the average of two determinations expressed on a moisture-free basis.
[b]PI = First protein fraction; SII and PII = starch and protein fractions, respectively, from remilling of first starch fraction (SI).
[c]%N × 6.25.

TABLE III
Starch Separation Efficiency (SSE) and Protein Separation Efficiency (PSE) Achieved in Pin Milling and Air Classification of Eight Legumes

Legume	SSE (%) Series 1	SSE (%) Series 2	SSE (%) Mean[a]	PSE (%) Series 1	PSE (%) Series 2	PSE (%) Mean[a]
Mung bean	96.7	96.0	96.4 a	89.1	88.7	88.9 a
Lentil	100.0	94.0	97.0 a	87.1	87.2	87.2 a
Northern bean	98.7	97.8	98.3 a	87.6	86.4	87.0 a
Faba bean	100.0	97.5	98.8 a	85.2	82.9	84.1 b
Field pea	99.1	99.8	99.5 a	82.2	83.3	82.8 bc
Navy bean	97.6	98.7	98.2 a	78.9	81.6	80.3 cd
Lima bean	100.0	98.2	99.1 a	81.1	79.2	80.2 cd
Cowpea	96.9	97.1	97.0 a	78.8	77.6	78.2 d

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

TABLE IV
Fat Contents[a] (%) of Pin-Milled Legume Flours and Air-Classified Fractions[b]

Legume[c]	Flour	SI	SII	PI	PII
Mung bean	0.95	0.32	0.18	1.70	1.74
Lentil	0.91	0.49	0.08	2.01	2.20
Northern bean	1.32	0.51	0.41	3.00	2.09
Faba bean	1.65	0.92	0.47	3.43	2.76
Field pea	1.13	0.78	0.51	3.21	2.65
Navy bean	1.74	0.98	0.64	3.49	3.26
Lima bean	1.10	0.47	0.25	2.00	1.69
Cowpea	1.31	0.64	0.22	3.08	2.96

[a] Values are the average of two determinations expressed on a moisture-free basis (diethyl ether extract).
[b] PI = First protein fraction; SII and PII = starch and protein fractions, respectively, from remilling of first starch fraction (SI).
[c] Data from Series 1 only are shown.

Analytical Methods

Moisture, fat, ash, crude fiber, and protein were determined by AACC procedures (1969). Starch was determined by the dual enzyme method of Banks et al (1970).

Calculation of Starch and Protein Separation Efficiency

The percentage of the total starch in the pin-milled flour that was recovered in the SII fraction was used as a measure of starch separation efficiency (SSE). Similarly, the percentage of the total flour protein recovered in the PI and PII fractions was used as a measure of protein separation efficiency (PSE). In practice, PSE was determined by calculating the percentage of the total flour protein recovered in the SII fraction and subtracting this value from 100%.

Statistical Analysis

Starch and protein separation data were subjected to analysis of variance and Duncan's multiple range test (Duncan 1955).

RESULTS AND DISCUSSION

Yields of the air-classified fractions from each grain legume are shown in Table I. The ratios of separated starch and protein concentrate, SII/(PI + PII), were different among legumes; with the exception of cowpeas and mung beans, however, the fraction yields were similar for samples of a particular legume.

Table II shows the protein and starch contents of the flours and air-classified fractions. The first air classification yielded PI fractions with protein contents from 1.9 to 2.6 times those of the corresponding flours, ranging from 49.3% in a lentil to 75.1% in a faba bean. Some starch was found in the PI fractions, presumably from the presence of small and damaged starch granules in the pin-milled flours (Youngs 1975, Vose 1977). The starch contents of the PI fractions varied from 0.0% in a lima bean to 4.6% in a lentil. The SI fractions were substantially enriched in starch as compared to the original flours. Starch contents were from 1.2 to 1.7 times those of the corresponding flours, ranging from 58.0% in a navy bean to 76.1% in a lentil SI. Considerable protein remained in the SI fractions, with protein contents ranging from 7.7% in a lentil to 20.1% in a faba bean. Protein bodies attached to starch granules, agglomerates of starch and other cotyledon components, chloroplast membrane remnants, and dehydrated stromal material have been shown to contribute to this residual protein in air-classified field pea starch (Reichert and Youngs 1978).

Remilling of the SI fraction from field peas has proven effective in reducing the number of agglomerates and in removing most of the protein bodies from the starch granules (Reichert and Youngs 1978, Vose et al 1976). Air classification of a remilled SI yielded an SII fraction with a considerably lower protein content and higher starch content than the SI. In our study, SII fractions with protein contents approximately one-half those of the corresponding SI fractions were produced, ranging from 4.0% in a lentil to 10.4% in a cowpea. The starch contents of the SII fractions ranged from 71.0% in a navy bean to 85.6% in a lentil. The PII fractions exhibited the expected decrease in protein content and increase in starch content as compared to the PI fractions, with protein contents ranging from 38.0% in a lentil to 68.2% in a faba bean. A navy bean sample showed the largest decrease in protein content, declining from 61.3% in the PI to 48.9% in the PII, and a lima bean sample showed the smallest, dropping from 49.5 to 46.0%. The starch contents of the PII fractions ranged from 0.4% in a lima bean to 16.6% in a lentil, as compared to 0.0 and 4.6% in the respective PI fractions. The increased starch damage incurred by remilling the SI fraction, as observed by Vose (1977) with field pea starch, is presumably responsible for the increased starch contents of the PII fractions.

Values for the efficiency of the separation of starch and protein are presented in Table III. Significant differences were detected among legumes for PSE but not for SSE. The values obtained for SSE were similar to those reported by Sosulski and Youngs (1979), but the PSE values from this study were much higher, a reflection of the greater proportion of the protein milled free of the starch granules and classified into the protein fractions with the double-pass procedure.

Differences in PSE 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. 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 PSE by reducing the yield of the protein fractions. Studies on the air classification of wheat flours have shown that hard wheats do produce lower yields of the fine (high protein) fraction than do soft wheats (Ziegler and Greer 1971). Chloroplast membrane remnants and dehydrated stromal material are not readily separated from starch granules even after several pin millings and are concentrated in the starch fraction (Reichert and Youngs 1978). Differences among legumes in the levels of these components (which contain protein) would contribute to differences in PSE.

Because significant differences in SSE were not detected, differences among legumes with respect to the proportion of the starch granules having diameters below the cut-point of the air classifier or with respect to the susceptibility of the starch granules to damage during pin milling were apparently not great enough to affect the proportion of the total starch that was classified into the SII fractions.

The fat, ash, and crude fiber contents of the Series 1 pin-milled flours and air-classified fractions are presented in Tables IV–VI. Because only small differences existed in the levels of these components in the corresponding fractions of Series 1 and 2, data from only one series are shown. The concentrations of fat, ash, and crude fiber in the corresponding fractions of the eight legumes were similar, with fat and ash, and to a lesser extent crude fiber, showing a marked concentration in the protein fractions. Crude fiber was unique in that the levels in the PII fractions were higher than those in the PI fractions.

Linear correlation coefficients between the levels of protein,

TABLE V
Ash Contents[a] (%) of Pin-Milled Legume Flours and Air-Classified Fractions[b]

Legume[c]	Fraction				
	Flour	SI	SII	PI	PII
Mung bean	3.22	1.90	0.90	7.16	6.25
Lentil	2.33	1.80	1.18	5.40	4.79
Northern bean	4.26	2.34	1.18	9.41	6.22
Faba bean	2.61	1.98	1.16	5.01	4.82
Field pea	2.56	1.68	1.06	5.64	5.21
Navy bean	3.73	2.62	1.59	7.91	6.58
Lima bean	4.75	3.09	1.59	8.24	7.50
Cowpea	3.46	2.69	1.77	7.61	6.99

[a] Values are the average of two determinations expressed on a moisture-free basis.
[b] PI = First protein fraction; SII and PII = starch and protein fractions, respectively, from remilling of first starch fraction (SI).
[c] Data from Series 1 only are shown.

TABLE VI
Crude Fiber Contents[a] (%) of Pin-Milled Legume Flours and Air-Classified Fractions[b]

Legume[c]	Fraction				
	Flour	SI	SII	PI	PII
Mung bean	1.31	1.17	0.97	2.00	1.95
Lentil	1.22	1.14	0.66	1.48	2.68
Northern bean	1.70	1.60	0.85	1.91	3.41
Faba bean	1.30	1.18	0.72	1.88	2.62
Field pea	1.48	1.38	1.00	1.85	2.81
Navy bean	1.95	2.26	2.01	1.21	2.91
Lima bean	1.83	1.86	1.37	1.79	2.80
Cowpea	1.28	0.93	0.60	2.41	2.69

[a] Values are the average of two determinations expressed on a moisture-free basis.
[b] PI = First protein fraction; SII and PII = starch and protein fractions, respectively, from remilling of first starch fraction (SI).
[c] Data from Series 1 only are shown.

starch, fat, ash, and crude fiber in the pin-milled flours and their levels in the air-classified fractions are shown in Table VII. With the exception of the protein and ash contents of the SII fractions and the crude fiber content of the PI fraction, the concentrations of the five components in the fractions were dependent on their concentrations in the original flours. Therefore, selection of the starting material on the basis of proximate composition and starch content is indicated if the production of air-classified fractions of consistent composition is to be achieved. In practice, the starch and protein contents of the fractions are of primary importance, so selection would probably be based on the levels of these two components only.

The suitability of pin milling and air classification as a method of producing starch and protein concentrates from the various legumes can be assessed by comparing the PSE values (Table III) and the starch and protein contents of the air-classified fractions (Table II) of each legume. The relative importance of these characteristics would depend upon the anticipated uses of the air-classified fractions. Because significant differences in SSE were not detected and because the corresponding fractions of the eight legumes were similar in fat, ash, and crude fiber content, these values need not be considered when comparisons are made. The cut point 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 point for all samples facilitated comparison.

Mung beans and lentils were best suited to fractionation by pin milling and air classification; they exhibited high PSE values, high starch and low protein levels in the SII fractions, and—with the exception of the Series-2 lentil sample (produced from a low-protein flour)—high protein levels in the PI and PII fractions. However, these two legumes did produce protein fractions with high starch levels, which could be a drawback in some applications. Northern beans also gave a high PSE value and acceptable starch and protein levels in the SII fractions but produced PII fractions lower in protein.

Faba beans, field peas, and navy beans demonstrated intermediate PSE values. Faba beans produced PI and PII fractions very high in protein and low in starch and SII fractions high in starch. However, the protein levels in the SII fractions were high. The protein contents of the PI and PII fractions of field peas were lower than those of faba beans and the starch contents slightly higher. The SII fractions had starch contents similar to those of faba beans but protein contents somewhat lower. Navy beans yielded PI and PII fractions with high protein contents and low starch contents. However, the SII fractions were high in protein and low in starch.

Lima beans and cowpeas had the lowest PSE values of the eight grain legumes studied, and both yielded protein fractions with relatively low protein contents. Lima bean protein fractions were low in starch, whereas one sample of cowpeas was high in this respect. The SII fractions of these legumes were relatively high in protein, and—with the exception of one cowpea SII (produced from a low-starch flour)—the starch contents were acceptable.

TABLE VII
Linear Correlation Coefficients Between the Levels of Protein, Starch, Fat, Ash, and Crude Fiber in Pin-Milled Legume Flours and Their Levels in the Air-Classified Fractions[a]

Fraction	Component				
	Protein	Starch	Fat	Ash	Crude Fiber
SI	0.836[b]	0.813[b]	0.817[b]	0.817[b]	0.928[b]
SII	0.479	0.867[b]	0.739[b]	0.477	0.876[b]
PI	0.807[b]	0.687[b]	0.883[b]	0.887[b]	0.206
PII	0.870[b]	0.691[b]	0.832[b]	0.829[b]	0.562[c]

[a] PI = First protein fraction; SII and PII = starch and protein fractions, respectively, from remilling of first starch fraction (SI).
[b] $P = 0.01$.
[c] $P = 0.05$.

In summary, six of the eight legumes gave very good separation and concentration of protein-rich and starch-rich fractions when pin-mill ground and air classified. On the basis of this study, only lima beans and cowpeas would be considered poor choices for this method because they exhibit both poor PSE values and lower protein contents in the protein fractions. The use of a higher cut point during air classification to improve the PSE would probably not be feasible with these two legumes. The already lower protein levels of the PI and PII fractions would be further reduced by the additional starch and other nonprotein material classified into these fractions at higher cut points. The PSE values of the remaining six legumes, which ranged from intermediate to high in this study, could be improved by the use of a higher cut point. The relatively high protein concentrations in the protein fractions obtained from these legumes (providing the protein content of the original flour was suitably high) would allow some dilution by additional nonprotein components at higher cut points and still yield a product of acceptable protein content. However, high starch levels in the protein fractions (particularly the PII fraction of mung beans and lentils) may prohibit a large increase in the cut point.

ACKNOWLEDGMENTS

We thank D. Knapp and D. Dymond for technical assistance.

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[Received June 6, 1980. Accepted September 30, 1980]