Wet Fractionation of Garbanzo Bean and Pea Flours

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ABSTRACT

Garbanzo bean and pea flours originating from the central part of the cotyledons were higher in starch but lower in protein and fiber than those from the outer layer of the cotyledon. These flours were fractionated by the wet process into prime starch, tailing starch, and solubles. The patented wet-fractionation method was successfully modified to reduce the total amount of water during the process. The modified process produced comparable yield and purity of separated fractions. Under the recycling water method, the yields of prime starch were 46.7, 33.6, and 41.1%, respectively, in garbanzo bean and two smooth pea cultivars (Latah and SS Alaska). Isolated prime starches were <0.4% in protein and <0.19% in ash, indicating high purity.

Legume starches have been identified as a new food ingredient. Pea starch, for example, has been used widely in the processed meat industry as a substitute for traditional starches in canned meats, cooked sausages, and patés (Comer and Fry 1978, Beck and Kevin 1995). Legume starches have also shown great potential as functional ingredients in high-temperature extrusion processes (Gujska et al 1994). Interest in the starches of various legumes is based on inherent properties that are mainly attributed to relatively high amylose content (Schoch and Maywald 1968). For instance, smooth pea starch has 30–45% amylose (Schoch and Maywald 1968, Vose 1977, Colonna et al 1980, Chavan and Kadam 1989), while wrinkled pea starch has 60–90% amylose (Schoch and Maywald 1968, Vose 1977, Colonna et al 1980, Stute 1990).

A difficult fractionation process has been a problem in the utilization of legume starches. Dry methods of fractionation using pin milling and air classification for separation of starch and protein have been developed, yet these processes typically result in high starch damage and low purity of the final starch product (Sosulski and Youngs 1979, Colonna et al 1980). Compared to dry methods, most wet methods of legume starch isolation are lengthy, laborious, and costly. Techniques for the isolation of legume starches by wet fractionation have been reported by Kawamura et al (1955), Kawamura and Tada (1958), and Deshpande and Damodaran (1990). The procedures most widely used today for starch isolation from legumes were developed by Schoch and Maywald (1968).

Difficulties in the separation of pure starch from legumes include a highly hydratable fine fiber (cotyledon cell wall material) and the strong adherence of large amounts of insoluble proteins to starch granules (Schoch and Maywald 1968). All of the accepted methods generally require steeping in toluene or alkali solutions to prevent fermentation and to aid the separation of starch from the protein matrix. The steeping step is typically followed by wet grinding and repeated screening using extensive amounts of water.

Czuchajowska and Pomeranz (1994) developed a method of legume fractionation superior to existing methods. This technique for isolation of pure starches and protein concentrates combines elements of both dry and wet-fractionation procedures. The method involves an initial selection of milled legume flours, followed by a simple and fast wet-fractionation procedure that does not require presoaking or chemicals, and that needs much less water than the commonly used method by Schoch and Maywald (1968). This method was applied to garbanzo beans, with some limited consideration given to other legumes.

The objectives of the present study were: 1) to separate legume flour into fractions and to select the most suitable portion for the wet-fractionation process, based on physical and chemical characteristics; 2) to extend the patented wet-fractionation process of Czuchajowska and Pomeranz to smooth and wrinkled peas; and 3) to modify the patented fractionation method to reduce the amount of water used in the process, without affecting yield and purity of isolated fractions.

MATERIALS AND METHODS

Materials

Garbanzo bean flour, stone milled from chips, which are seeds split or broken during harvesting and handling, was provided by Blue Mountain Seeds, Inc. (Walla Walla, WA). One smooth pea cultivar, Latah, was obtained from F. Muehlbauer, ARS-USDA (Pullman, WA). A second smooth pea cultivar, SS Alaska, and a wrinkled pea cultivar, Scout, were purchased from Crites, Co. (Moscow, ID). Pea seeds were ground to flour for chemical analysis using a cyclone mill (Udy Corp., Fort Collins, CO) fitted with a sieve with 0.5-mm round openings.

Garbanzo bean flour was further fractionated by dry sieving. Flour (300 g) was sieved through three screens with 330, 230, and 86-μm openings. Coarse fraction, with particles >330 μm during the milling process, came from the outer layer of cotyledon. Fine fraction, with particles <86 μm, originated from the center part of garbanzo bean seeds (Czuchajowska and Pomeranz 1994).

Pea seeds were milled using a Bühler experimental roller mill (Uzwil, Switzerland) and separated into eight fractions. The corrugated and smooth rolls of the mill gave three break flours (1B, 2B, and 3B) and three reduction flours (1R, 2R, and 3R), as well as shorts and bran. Most of the cotyledon parts of peas were separated into break and reduction flours and seed coats (hull) into bran. Both break and reduction flours were passed through a screen with 120-μm openings during milling.

Wet Fractionation

Garbanzo bean flour, with particle size <86 μm, and pea flours, a blend of three breaks and first reduction, were fractionated into prime starch, tailing starch, and water solubles according to the method of Czuchajowska and Pomeranz (1994). The method for fractionation is shown in Figure 1. Samples (200 g) were blended with 500 mL of water for 3 min using a blender (Osterizer, J. Oster Mfg., Milwaukee, WI). The slurry was then centrifuged at 1,500 × *g* for 15 min. The supernatant was decanted, and remaining solid layers were blended in 500 mL of water and centrifuged

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again. The same procedure was repeated once more. The supernatant was decanted, and tailing starch was carefully separated from the bottom prime starch using a spatula. The prime starch was further purified using 200 mL of water. Both tailing starch and water solubles were lyophilized, while prime starch was air dried at 22ºC.

The patented method for fractionation was modified to reduce the amount of waste water without losing the efficiency of the methodology. The first modification was to reduce the amount of water used for each washing process from 500 mL to 400 mL, lowering the total amount of water used from 1,500 mL to 1,200 mL. In addition to reducing the amount of water in each washing step, the second modification also recycled the supernatant from the third washing and used it for the first washing step of the following samples.

The fractionation method was further modified when applied to the wrinkled pea cultivar Scout, which showed poor separation of its main components. First, the amount of water for the first blending step was increased to 500 mL. After centrifugation of the slurry, the supernatant was decanted and the tailing starch was separated from prime starch. Both tailing and prime starch were blended separately with 300 mL of water and purified twice. Water solubles were collected from the washing of both prime and tailing starches.

The second modification was to soak samples (200 g) in 500 mL of water for 8 hr at 4ºC before fractionation, as previously described. Both tailing and solubles were lyophilized, and prime starch was air dried at 22ºC.

Chemical Analyses

Protein contents (N × 6.25) of whole pea flours, commercial garbanzo bean flour, and all fractions separated by dry and wet processes were determined by a Leco instrument (Leco Corp., St. Joseph, MI) equipped with a thermoconductivity detector. Moisture content was determined by oven drying for 1 hr at 130ºC (Method 44-15A, AACC 1995), ash by dry combustion for 16 hr at 580ºC (Method 08-01), and free lipid by petroleum ether extraction, followed by evaporation to constant weight under vacuum (Method 30-25). Insoluble and soluble dietary fiber content was determined by the procedure of Prosky et al (1988). Starch content was determined after enzymatic conversion to glucose by successive treatment with α-amylase, protease, and amyloglucosidase (Prosky et al 1988). The released glucose was measured with glucose oxidase-perioxodase reagent (Lloyd and Whelan 1969).

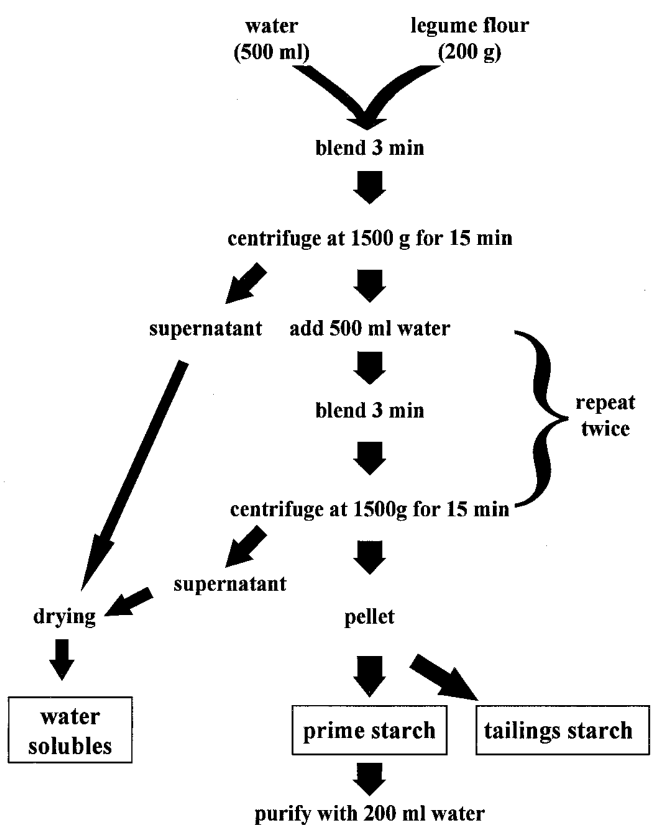

Fig. 1. Patented wet-fractionation process.

Physical Measurement

Particle size distribution was determined with 2.0-g samples of pea and garbanzo bean flour fractions previously defatted and air dried by the method of Czuchajowska and Pomeranz (1993). Samples were sifted and pulsed at amplitude 2 for 8 min on stainless steel sieves of 63, 74, 88, and 105-µm openings using a model L3 sonic sifter (ATM Corp., Milwaukee, WI).

Water-holding capacity of samples selected for the wet-fractionation process was measured using standard methods (Method 88-04, AACC 1995).

Statistical Analyses

At least two replicates were made for fractionation, chemical, and physical measurements. Data were analyzed with a computer software package (SAS 1986), using analysis of variance and Fisher's least significant difference (LSD) procedure.

RESULTS AND DISCUSSION

Chemical Compositions of Legumes

The chemical compositions of commercially milled garbanzo bean flour and Udy ground whole seeds of two smooth and one wrinkled pea cultivars are summarized in Table I. The smooth pea (SS Alaska and Latah) and the wrinkled pea (Scout) had protein contents of 21.9, 26.9, and 26.1%, respectively, which were comparable with values reported by Kosson et al (1994). The protein content of commercial garbanzo bean flour used in this study was slightly lower than that reported previously by Czuchajowska and Pomeranz (1994). This could be due to the variation in the blends of cracked and broken seeds (chips) from which the flour was milled. Ash content of the four samples investigated showed comparable levels of 3.1–3.5%. Large differences were found in the free lipids content range of 0.7–6.3%. The commercial garbanzo bean flour had the highest lipid content, while the lowest was presented in Latah. SS Alaska had a lipid content of 1.4%, while Scout had 1.8%. The lipids content for smooth and wrinkled peas is in agreement with values reported by Kosson et al (1994). Starch and total fiber contents also showed large variation in the investigated materials. The highest starch content of 47.1%, but the lowest total fiber content of 23.5% were found in commercially milled garbanzo bean flour, while the lowest starch content of 32.7% and the highest total fiber content of 32.5% were found

TABLE I
Chemical Composition (%) of Legume Samples[a]

Sample	Protein[b]	Free Lipid	Ash	Starch	Total Fiber
Garbanzo bean					
Commercial flour	21.4d[c]	6.3a	3.2c	47.1a	23.5d
Smooth pea cultivars					
Latah	26.9a	0.7d	3.1c	40.9c	27.6b
SS Alaska	21.9c	1.3c	3.3b	45.2b	26.6c
Wrinkled pea cultivar					
Scout	26.1b	1.8b	3.5a	32.7d	32.5a

[a] Results expressed on a dry weight basis.
[b] N × 6.25.
[c] Mean values in the same column with different letters are significantly different ($P < 0.05$).

in Scout. Both smooth pea cultivars had comparable levels of total fiber, while starch content was 4% higher in SS Alaska than in Latah.

Fractionation by Milling and Sieving

The yield and changes in chemical composition of commercially milled garbanzo bean flour after fractionation by dry sieving are shown in Table II. Protein, free lipids, and ash contents were significantly lower in fine garbanzo bean fractions (<86 μm) than in coarse fractions (>86 μm). The sieving process decreased protein content by 5% in the fine fraction, but increased starch by as much as 10%. Comparable changes in chemical composition between the coarse and fine fractions as the result of sieving were also reported for garbanzo bean flour by Czuchajowska and Pomeranz (1994), who proposed that the differences were due to the fact that the coarse material originated from the outer part and the fine fractions were from the inner part of the cotyledon. Similar patterns have also been reported for smooth and wrinkled peas by Kosson et al (1994).

It should be pointed out that the yield of fine garbanzo bean fractions in this study is 10% lower than that previously reported by Czuchajowska and Pomeranz (1994), possibly due to the already mentioned large variation in chips, which are seeds that have broken and cracked during harvesting and handling, and are considered as by-products of marketable whole seeds. Therefore, the yield of fractions obtained by sieving commercially milled flour will differ.

The yield and chemical compositions of eight fractions obtained from roller-milling of two smooth and one wrinkled pea cultivars are summarized in Table III. Significantly higher levels of protein, ash, and lipids were found in shorts than in break or reduction flours in all three pea samples. The results indicate that the germ and outer layer of cotyledon, rich in protein and lipids, were included in shorts. The yield of shorts was lowest in Latah, representing 4.5% of total flour, followed by SS Alaska at 5.6%, and highest in Scout at 14.6%. Yield ranges of 12.7–14.3% for bran were similar in the three pea samples. Bran, which contains mostly hull, was low in protein (11.9%) and free lipids (0.74%).

In general, moving from first break to third reduction flour yields a higher protein content, while the starch content decreases. The largest changes in these two components took place in the second reduction stream, indicating that the three breaks and the first reduction flours originated from the softer part of cotyledon, having lower protein content and higher starch content than the second and third reduction flours, which came from the harder

TABLE II
Yield and Chemical Compositions (%) of Garbanzo Bean Flour Fractions Separated by Sieving[a]

Fraction (μm)	Yield	Protein[b]	Free Lipid	Ash	Starch
Garbanzo bean					
>330	52.10	22.04	6.49	3.71	45.5
230 ~ 330	6.89	22.28	6.79	3.61	46.8
86 ~ 230	10.20	23.37	7.11	3.71	51.1
<86	30.10	17.97	5.49	3.03	55.8
LSD[c]	0.39	0.44	0.18	0.03	0.02

[a] Results expressed on a dry weight basis.
[b] N × 6.25.
[c] Least significant difference ($P < 0.05$). Differences between two means exceeding this value are significant.

TABLE III
Yield and Chemical Compositions (%) of Milling Fractions of Pea Seeds[a]

Fraction[b]	Yield	Protein[c]	Free Lipid	Ash	Starch
Smooth pea cultivars					
Latah					
1B	4.32	27.99	0.66	3.06	52.3
2B	6.46	28.87	0.65	3.16	54.3
3B	1.37	27.48	0.65	3.09	54.3
1R	53.85	29.33	0.65	3.25	53.6
2R	12.60	31.13	0.74	3.39	51.1
3R	4.19	31.31	0.82	3.41	50.7
Shorts	4.51	31.66	1.08	3.76	nd[d]
Bran	12.70	9.38	0.31	3.57	nd
LSD[e]	6.38	0.24	0.04	0.02	0.24
SS Alaska					
1B	5.11	20.17	1.25	2.53	60.2
2B	6.73	21.54	1.14	2.77	57.9
3B	1.19	20.68	1.15	2.63	58.3
1R	44.66	23.92	1.19	2.97	56.2
2R	16.41	26.43	1.46	3.23	50.4
3R	6.04	27.55	1.65	3.38	46.1
Shorts	5.56	30.54	2.38	3.76	nd
Bran	14.32	11.93	0.62	3.11	nd
LSD	3.18	0.51	0.03	0.01	0.10
Wrinkled pea cultivar					
Scout					
1B	5.54	26.49	2.06	3.29	51.1
2B	4.99	28.06	2.08	3.29	50.8
3B	0.86	27.38	1.99	3.35	51.8
1R	41.16	28.76	2.02	3.32	46.3
2R	12.09	29.54	2.24	3.39	45.9
3R	6.36	29.69	2.31	3.43	45.9
Shorts	14.61	30.68	2.81	3.58	nd
Bran	14.21	10.02	0.74	3.23	nd
LSD	1.06	0.26	0.09	0.01	0.07

[a] Results expressed on a dry weight basis.
[b] 1B, 2,B, 3B = 1st, 2nd, and 3rd break flours, respectively. 1R, 2R, 3R = 1st, 2nd, and 3rd reduction flours, respectively.
[c] N × 6.25.
[d] Not determined.
[e] Least significant difference ($P < 0.05$). Differences between two means exceeding this value are significant.

TABLE IV
Chemical Compositions (%) and Water Holding Capacity (WHC, g/g) of Materials Selected for Wet-Fractionation Process[a]

Sample	Protein[b]	Free Lipid	Ash	Starch	Fiber	WHC
Garbanzo bean						
< 86 μm	17.97d[c]	5.50a	3.03c	55.80b	13.6b	0.77d
Smooth pea[d]						
Latah	29.16a	0.65d	3.22b	53.61c	10.4d	0.84b
SS Alaska	23.24c	1.18c	2.89d	56.78a	13.1c	0.80c
Wrinkled pea[d]						
Scout	28.39b	2.03b	3.31a	47.25d	19.3a	1.16a

[a] Results expressed on a dry weight basis.
[b] N × 6.25.
[c] Mean values in the same column with different letters are significantly different ($P < 0.05$).
[d] Blend of three break flours and first reduction flour.

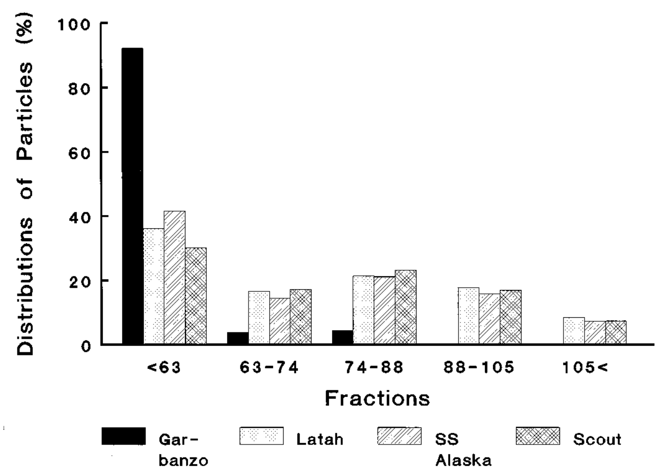

Fig. 2. Particle size distributions of garbanzo bean and pea flours selected for wet-fractionation process.

part of cotyledon and required sequential reduction. The distribution of free lipids content follows the pattern of protein content and was significantly higher in the second and third reduction than in the three breaks and first reduction.

Distribution of chemical components within the cotyledon of smooth peas as presented by Kosson et al (1994), based on the abrading technique, is in agreement with the results of the milling process from the present study. Garbanzo bean and pea flours coming from the outer layer of the cotyledon have larger particle size, higher protein, lower starch, and higher fiber contents than those from the inner layer of the cotyledon (Tables II and III), making the former materials unsuitable for wet-fractionation process. Both the chemical composition and physical properties of materials are important for wet fractionation. Therefore, flour fractions, which are more desirable for wet fractionation were selected based on their chemical composition and physical properties. Materials selected for the wet-fractionation process were garbanzo bean flour with fraction <86 μm, representing over 30% of the cotyledon from the inner part of the seeds; and smooth and wrinkled peas, blends of three breaks and the first reduction flour streams, representing 52–66% of the cotyledon.

Chemical composition of the material selected for the wet-fractionation process is summarized in Table IV. Starch contents ranged from 47.3 to 56.8%, the lowest being from Scout, with the highest from SS Alaska. Protein content was lowest in garbanzo bean (17.9%) and higher in SS Alaska (23.2%), Latah (29.2%), and Scout (28.4%). The selected materials had significantly ($P < 0.05$) lower fiber content (13.6% in garbanzo bean, 10.4% in Latah, 13.1% in SS Alaska, and 19.3% in Scout) than the unselected fractions (19.9, 16.4, 19.4, and 22.9%). Therefore, the material originating from the central part of the cotyledon had preferable chemical composition for the wet-fractionation process. The change in chemical composition was achieved by simple processes such as sieving of garbanzo bean commercially stone-milled flour, or milling of the smooth and wrinkled peas on a Bühler mill.

The low water-holding capacity and small particle size are crucial features for the selection for wet fractionation. Water acts as a medium to wash out solubles and should not be highly absorbed; low water-holding capacity is desirable. In this study, the water-holding capacity of the fraction from Scout was significantly higher than for the fractions from the two smooth peas and the garbanzo bean. The particle size distribution of the selected material is presented in Figure 2. Clearly, particles <63 μm represented the major fraction of the garbanzo bean and pea flours.

Wet Fractionation Process

Reduction of water use and its recycling during the wet process of legume fractionation is of great concern. The concentration of water solubles in subsequent washing steps was considered as an indicator of washing efficiency. The comparison of yield of water solubles of garbanzo bean flours fractionated by the patented and reduced methods is presented in Figure 3. The amount of water solubles in the first washing was significantly lower in the reduced water method than in the patented process used for garbanzo beans. However, the amount of solubles was significantly higher in the second and third washing in the reduced water method, resulting in comparable total yields of water solubles in both patented and reduced water methods. In general, >90% of total water solubles in both patented and reduced water fractionation processes were washed out in the first and second washing steps, while <10% came out in the third washing (Fig. 3). Based

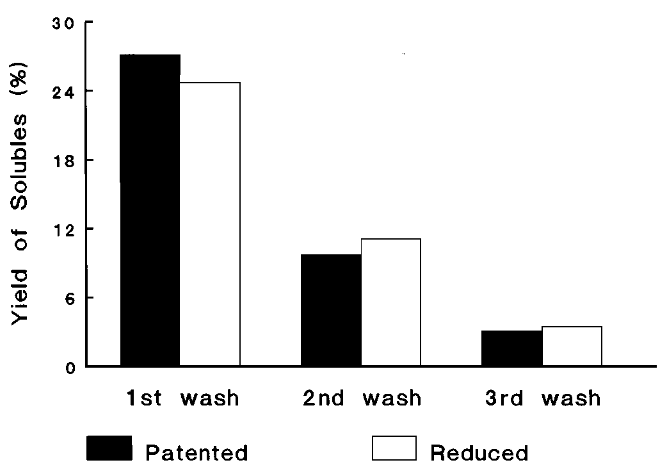

Fig. 3. Yield of water solubles in garbanzo beans during wet-fractionation process.

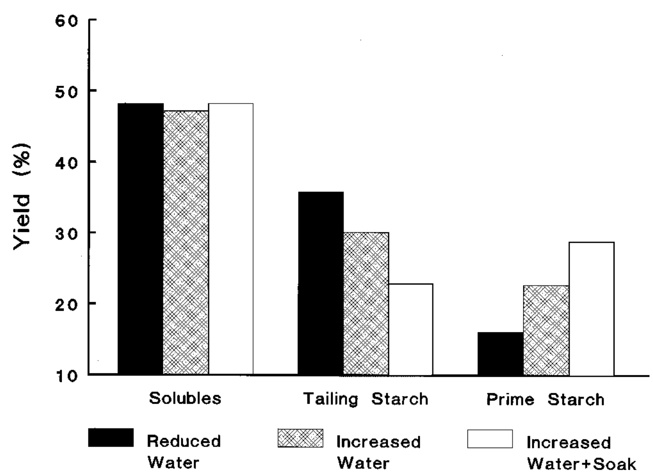

Fig. 4. Changes in yields of solubles, tailing, and prime starch in Scout, a wrinkled pea cultivar, by increasing the total amount of water in the fractionation process or by soaking sample before fractionation.

TABLE V
Yield, Protein, and Ash Contents (%) of Garbanzo Bean Fractions from the Patented, Reduced Water and Recycled Water Methods of Wet Fractionation[a]

	Yield			Protein[b]			Ash		
Fraction	Patent[c]	Reduced[d]	Recycled[e]	Patent	Reduced	Recycled	Patent	Reduced	Recycled
Total water solubles	39.9a[f]	39.3a	38.9b	41.81a	41.79a	42.81a	6.11a	6.19a	6.41a
Tailing starch	15.0a	14.3a	14.4a	7.81a	7.22a	7.05a	1.93a	2.08a	2.11a
Prime starch	45.0b	46.4a	46.7a	0.35a	0.41a	0.42a	0.16a	0.17a	0.17a

[a] Results expressed on a dry weight basis.
[b] N × 6.25.
[c] Original patented method with water-to-flour ratio 2.5:1.
[d] Water-to-flour ratio 2:1.
[e] Water-to-flour ratio 2:1, water from 3rd wash of previous batch was recycled for 1st wash.
[f] Mean values in the same row with different letters are significantly different ($P < 0.05$).

on these results, the water used in the third washing was reused for the first washing in the next batch of the reduced water method of the fractionation processes.

Yield, protein, and ash content of water solubles, tailing starch, and prime starch of garbanzo bean in three fractionation methods (patented, reduced water, and recycled water) are summarized in Table V. Yield of water solubles was comparable in patented and reduced water methods, but slightly lower in the recycled water method. No significant differences were observed in the yield of tailing starch from the three methods. Interestingly, there were slight increases in prime starch yield with reduced water or recycled water methods. Protein and ash contents of fractions, water solubles, tailing starch, and prime starch from the three fractionation methods were not statistically different ($P < 0.05$). As indicated by low protein (0.35 ~ 0.42%) and ash (0.16 ~ 0.17%) contents, high purity of prime starch was obtained from all three fractionation methods applied.

Both reduced water and recycled water methods were applied for the fractionation of selected pea flours. Yields of water solubles, tailing, and prime starches and their protein and ash contents are shown in Table VI. In Latah and SS Alaska, there were no significant differences in the yields of water solubles, nor in tailing and prime starches between reduced and recycled water methods, except for a small increase in tailing starch yield in Latah, when water was recycled. High purity of prime starches was obtained by both fractionation methods from Latah and SS Alaska, as indicated by low protein (0.33% ~ 0.45%) and ash (0.01% ~ 0.08%) content. Prime starch yields varied widely among cultivars with the highest in SS Alaska, less in Latah, and least in Scout.

The reduced water and recycled water methods produced higher or comparable yield and comparable or slightly higher protein and ash contents of prime starch in both garbanzo bean and smooth pea cultivars when compared to the method reported by Schoch and Maywald (1968). The fractionation methods (patent, reduced water, and recycled water) eliminate typical problems inherent in current methods (Schoch and Maywald 1968) without affecting yield and purity of prime starch: the need of multiple steeping, using chemicals such as toluene and sodium hydroxide, wet grinding, repeated screening and especially use of a large amount of water.

Contrary to smooth peas, wrinkled pea Scout showed a low yield of prime starch and a high yield of tailing starch in the reduced water method (Table VI). Protein and ash content of prime starch were also higher than for smooth pea starches. For this reason, the recycled water method was not applied to Scout. Lower yield and lower purity of prime starch in Scout than in smooth peas are mainly due to its high protein and fiber content, and also to its high water-holding capacity (Table IV). Wrinkled peas are known to be difficult to fractionate, possibly due to their highly hydratable fiber component (Schoch and Maywald 1968) and the deep fissures and indentations of the starch granules, which cause a greater adherence between starch granules and the protein matrix (Colonna et al 1980). Therefore, to improve the separation of the main components in Scout, two other modifications were made to the method of Czuchajowska and Pomeranz (1994). By increasing the total amount of water, separating tailing and prime starch from the first washing, and further washing both prime and tailing starch separately, yield of prime starch was significantly improved with a decrease in tailing starch yield (Fig. 4). Further modification of this methodology included soaking samples for 8 hr at 4ºC before wet fractionation. Soaking samples before fractionation, further increased yield of prime starch from 16 to 30% and, correspondingly, tailing starch yield decreased (Fig. 4).

SUMMARY

By milling and sieving, fine granular flours of garbanzo beans and peas, which mainly come from the central part of the cotyledon, were separated from coarse granular flour, which comes from the outer layer of the cotyledon. The fine, granular flours were lower in protein and fiber, and higher in starch content. Selected legume flours for wet fractionation had desirable characteristics, such as high starch, low protein, and fiber content, small particles of flour and low water-holding capacity. Therefore, presoaking or use of chemicals was not needed during the wet-fractionation process. The wet-fractionation method of Czuchajowska and Pomeranz (1994) was successfully extended to pea flours and modified to reduce the total amount of water used during fractionation processes. The modified method did not adversely affect fractionation processes, and produced comparable yield and purity of separated fractions. Flour from Scout, having the lowest starch content, but higher fiber and water-holding capacity than other legumes, required a larger amount of water and presoaking for fractionation processes. The results indicate that special care should be taken in selecting wrinkled pea cultivars for wet processes.

TABLE VI
Yield, Protein, and Ash Contents (%) of Pea Fractions for the Reduced Water and Recycled Water Methods of Wet Fractionation[a]

Fraction	Yield		Protein[b]		Ash	
	Reduced[c]	Recycled[d]	Reduced	Recycled	Reduced	Recycled
Latah						
Total water solubles	42.8a[e]	41.9a	65.29a	68.79a	6.21a	6.11a
Tailing starch	20.1b	24.5a	7.61a	4.91b	1.29a	0.99b
Prime starch	37.1a	33.6a	0.33a	0.41a	0.01b	0.06a
SS Alaska						
Total water solubles	37.1a	36.9a	56.81a	60.41a	7.21b	7.31a
Tailing starch	20.8a	22.1a	4.55a	5.01a	1.37a	1.19b
Prime starch	42.2a	41.1a	0.35a	0.45a	0.08a	0.04b
Scout						
Total water solubles	48.2	nd[f]	56.89	nd	4.51	nd
Tailing starch	35.8	nd	5.24	nd	0.92	nd
Prime starch	16.1	nd	1.11	nd	0.36	nd

[a] Results expressed on a dry weight basis.
[b] N × 6.25.
[c] Water-to-flour ratio 2:1.
[d] Water-to-flour ratio 2:1, water from 3rd wash of previous batch was recycled for 1st batch.
[e] Mean values in the same row with different letters are significantly different ($P < 0.05$).
[f] Not determined.

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