Composition, Thermal Behavior, and Gel Texture of Prime and Tailings Starches from Garbanzo Beans and Peas

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ABSTRACT

Prime and tailings starches of garbanzo beans and peas were separated and the chemical composition, physical properties, thermal behavior, and gel properties were determined. Starch granules <35 µm were 85% in garbanzo beans, 66.8% in a smooth pea cv. Latah, and only 18.4% in a smooth pea cv. SS Alaska. Amylose content of prime starch was 35.9% in garbanzo beans, 44.5–48.8% in smooth peas, and 86.0% in wrinkled pea cv. Scout. Tailings starch amylose content was at least 8% higher than the corresponding prime starch. The endothermic enthalpy value of garbanzo bean and two smooth pea prime starches ranged from 12.1 to 14.2 J/g, while prime starch from wrinkled peas gave a distinctly lower enthalpy value of 1.1 J/g. Differential scanning calorimetry endothermic enthalpy and amylograph pasting properties of prime starch were significantly related to its amylose content ($P < 0.05$). Prime starches of garbanzo beans and smooth peas produced highly cohesive elastic gels. Wrinkled pea prime starch formed the strongest (though brittle) gel, as indicated by high hardness (21.8 N), low cohesiveness (0.29), and low springiness (0.82). Hardness of gel stored at 22°C and at 4°C was positively correlated with amylose content of starch.

Legumes have been consumed traditionally as whole seeds or as a ground flour after dehulling. The rapidly growing food industry constantly demands new ingredients, which has drawn the attention of researchers to legume components obtained by the wet-fractionation process (Schoch and Maywald 1968, Czuchajowska and Pomeranz 1994). At present, there is a strongly visible public interest in natural, unmodified sources of food ingredients. For example, unmodified starch is gaining attention because labeling a food product as "natural" is attractive to consumers. Fractionation of legumes into main components of starch, protein, and fiber increases the value of legumes by broadening their application. These legume fractions could be used to supplement nonlegume food products to improve textural and nutritional value.

Legumes in general are high in protein (15–40%) and, consequently, they have been subjected to protein extraction studies (Chavan and Kadam 1980, Colonna et al 1980, Hoover and Sosulski 1986, Deshpande and Damodoran 1990, Swanson 1990). Legume starch, which constitutes 35–60% of seed dry weight, has been recognized as a potential food ingredient (Kooistra 1962, Comer and Fry 1978, Chavan and Kadam 1980, Czuchajowska and Pomeranz 1994). Legume starches, which contain a greater percentage of amylose than do cereal starches, are characterized by high gelatinization temperature, resistance to shear thinning, fast retrogradation, and high elasticity of gel (Schoch and Maywald 1968, Lineback and Ke 1975, Vose 1977, Comer and Fry 1978, Gujska et al 1994). Fast retrogradation and high elasticity of gel is necessary for food products like sausage, paté-type meat products, and gluten-free oriental noodles. Resistance of starch paste to shear thinning at high temperature is important for canned foods and extruded snacks (Orford et al 1987, Leloup et al 1991, Czuchajowska and Pomeranz 1994, Beck and Kevin 1995).

Starch is an excellent raw material used to modify food texture and consistency. Therefore, information on starch properties in the starch-water system, such as thermal behavior, rheological properties of paste, and thickening and gelling properties are important to improve the texture of food products containing starch. Improper texture of food products not only creates problems during handling, but also lowers consumer acceptance. Textural characteristics of food products vary with the type of starch. Once the characteristics of starch are defined, it is easy to find a suitable application for the starch in food products. Comprehensive studies on legume starches, which are less frequently used in food industries than cereal and tuber starches, are needed.

In our previous study (Otto et al 1997a), legume flour coming from the central part of the cotyledon was fractionated into prime starch, tailings starch, and solubles using the patented method of Czuchajowska and Pomeranz (1994), with a reduced amount of water used in the process without affecting yield and purity of isolated fractions. Scanning electron microscope (SEM) studies of garbanzo beans and peas by Otto et al (1997b) revealed large structural differences between the inner and the outer layer of the cotyledon, which has direct influence on particle size of the milled flour. Starch granules of garbanzo beans were smaller and had smoother surface than those of peas. Wrinkled peas contained a unique shape of starch granules with deep fissures and grooves.

The formation of tailings starch is an indispensable part of the wet-fractionation process of wheat, barley, or legumes. In complex purification steps, the small, intact starch granules trapped in tailings starch can be recovered by applying a specific enzyme (Szczodrak and Pomeranz 1991). However, this expensive process used in research is not practical for application on a commercial scale. On the other hand, tailings starch, for food processing purposes, represents nutritionally interesting materials because of its complexity. Therefore, information concerning the thermal behavior and textural properties of tailings starch reported in this study could be helpful in finding ways of utilizing tailings starch without modification.

The purposes of this study were to: evaluate the chemical composition and thermal behavior of prime and tailings starches obtained from garbanzo beans and smooth and wrinkled peas; determine size distribution of prime starch granules by image analysis; examine the physical properties of prime and tailings starch gels during storage at different temperatures; and relate chemical composition of starches to textural properties of gels.

MATERIALS AND METHODS

Materials

Garbanzo bean flour, stone-milled from split or broken seeds, was provided by Blue Mountain Seeds, Inc. (Walla Walla, WA). Smooth pea cv. Latah was obtained from F. Muehlbaur, ARS-USDA, Pullman, WA. A second smooth pea, cv. SS Alaska, and a wrinkled pea, cv. Scout, were purchased from Crites Co. (Moscow, ID).

The garbanzo bean flour was further fractionated by dry sieving. Flour (300 g) was sieved through a screen with 86-µm openings. Pea seeds were milled using a Bühler roller mill (Uzwil, Switzerland) and separated into eight fractions, which included three break

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flours (1B, 2B, and 3B) coming from the corrugated rolls and three reduction flours (1R, 2R, and 3R) coming from the smooth rolls of the mill, as well as shorts and bran.

Preparation of Starch

Garbanzo bean flour with particle size <86 μm, and pea flours, a blend of three breaks and first reduction, were further fractionated into prime starch, tailings starch, and water solubles according to the method of Otto et al (1997a). Samples (200 g) were blended with 400 mL of water for 3 min using a Waring blender. The slurry was centrifuged at 1,500 × *g* for 15 min. The supernatant was decanted and the procedure was repeated a second and third time using the remaining solid layers. The top layer of the remaining solid containing the tailings starch was carefully separated from the bottom layer containing the prime starch. The prime starch was further purified with 200 mL of water. Both tailings starch and water solubles from the decanted supernatant were lyophilized, while the prime starch was air-dried at 22°C. The overall fractionation process was repeated at least 10 times and each fraction was combined.

The wet-fractionation method was modified for application to wrinkled pea cv. Scout, which showed poor separation of its main components. 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 tailings starch was separated from prime starch. Both tailings and prime starches were each blended with 300 mL of water, centrifuged, and separated. The procedure was repeated a second and third time. Prime and tailings starches from each fractionation process were combined and dried as described previously. Water solubles were collected from the washing of both prime and tailings starches.

Chemical Characteristics of Isolated Legume Starches

Protein content (N × 6.25) of both prime and tailings starches was 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 130°C (AACC 1995), ash was determined by dry combustion for 16 hr at 580°C (AACC 1995), and free lipids were determined by petroleum ether extraction, followed by evaporation to constant weight under vacuum (AACC 1995). Insoluble and soluble dietary fiber were 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). Released glucose was measured with the glucose oxidase-peroxidase reagent (Lloyd and Whelan 1969). Amylose content of starch was determined by the procedure of Knutson and Grove (1994).

Physical Properties of Starch

Starch damage was determined using an enzymatic starch damage assay kit from Megazyme Pty., Ltd. (Wicklow, Ireland) according to Approved Method 76-31 (AACC 1995). The swelling power of starches was determined by heating 1 g of starch in 30 mL of distilled water at 92.5°C and calculated based on the dry weight of starch according to the procedure of Crosbie (1991).

The size-distribution of the garbanzo bean and smooth pea starches was determined by image analysis. Starch granules were dispersed in immersion lens oil on a microscope slide and covered with a cover slip. The granule image was transferred from an Olympus BH-2 photo microscope to a Quadra 950 Macintosh computer via a Pulnix BW CCD camera (Pulnix, Sunnyvale, CA). Each image was analyzed by NIH Image Analysis version 1.52 (Bethesda, MD) and converted to micrometers. Microscopic images were calibrated with standard latex spheres of 20-μm diameter (Polysciences, Inc., Warrington, PA). Granules of starch (500 each) were measured by free-hand circling on the computer screen. Measured area values (μm^2) were converted to equivalent diameter (μm) with the formula: Equivalent diameter = $(area/\pi)^{0.5} \times 2$.

Scanning Electron Microscopy

Starch slurry (8%) was heated to 93.5°C in a Brabender amylograph and held for 10 min. A drop of starch paste was spread on the stubs, frozen at −26°C, and lyophilized. The specimen was coated with gold using a Hummer sputter-coater (Technics, Inc., San Jose, CA) and viewed under a Hitachi S-570 scanning electron microscope operated at 20 kV.

Differential Scanning Calorimetry

Differential scanning calorimetry (DSC) characteristics of starches were determined with a DSC-4 instrument (Perkins-Elmer Corp., Norwalk, CT). An indium standard was used for temperature and enthalpy calibration. A 10-mg sample and 20 μL of distilled water were placed in a stainless steel capsule, sealed, and allowed to equilibrate for 30 min at room temperature. The sample was then heated from 20 to 180°C at a rate of 10°C/min. A capsule with inert material (Al_2O_3) and water served as the reference sample. For each endothermic curve, temperature of transition onset, peak, and completion were determined by data processing software. The transition enthalpy was calculated from the peak area by software and expressed as joules per gram (J/g) of dry matter.

Amylograph

Pasting properties of starch were determined with a Brabender amylograph by a modification of the method of Shuey and Tipples (1980). Starch (36 g, dry basis) was suspended in 450 mL of distilled water. The starch slurry was heated at a rate of 1.5°C/min from 30 to 93.5°C and maintained for 30 min. The starch paste was cooled at a rate of 1.5°C/min to 50°C and held at that temperature for 30 min.

Starch Gel Texture

Starch slurry in distilled water (8%) was prepared and heated at a rate of 1.5°C/min to 93.5°C using the Brabender viscoamylograph and held at that temperature for 10 min. The paste was then poured into eight individual cylindrical stainless steel molds (3.5 cm height and 3.5 cm i.d.). Gels for wrinkled pea starch were prepared by autoclaving starch slurry (8%) at 126°C for 1 hr. Duplicate gels were stored for 24 and 72 hr at 22 and 4°C. The gels to be stored for 72 hr at 22°C were vacuum-packaged in gas impermeable plastic bags to minimize microbial growth.

The gels were removed from the molds and any excess water was removed by gentle blotting of the gel with tissue before weighing. Water loss of gel was determined by differences in weight before and after storage. The gel texture was then evaluated at least in duplicate by texture profile analysis (TPA) using the TA-XT2 texture analyzer (Stable Micro Systems, Haslemeres, England). Each cylindrical gel was placed upright on a metal plate and compressed at a rate of 1.0 mm/sec to 30% of its original height using a 5-cm diameter metal disk. The compression was repeated twice to generate a force-time curve from which hardness (height of the first peak) and springiness (ratio between recovered height after the first compression and the original gel height) were determined. Cohesiveness was calculated as the ratio between the area under the second peak and the area under the first peak (Bourne 1968, Friedman et al 1968).

Starch Gel Clarity

The clarity of the starch gel, which was prepared and stored as described for texture measurement, was measured using a Minolta CM-2002 spectrophotometer (Minolta Camera Co., Ltd., Chuo-Ku, Osaka, Japan). A slice of gel (8 mm thick) was placed on a black background and illuminated diffusely by the pulsed xenon arc lamp. The spectral reflectance was measured from the top surface of the gel. A white reflectance tile was used as a calibration standard. Higher CIE-Lab L^* values on a positive number scale indicated a higher degree of opaqueness.

Statistical Analyses

All physical and chemical measurements of samples at each treatment were performed at least in duplicate. Analysis of variance (ANOVA) and least significant differences (LSD) were calculated by the Statistical Analysis System (SAS Institute, Cary, NC). Significance was defined at the 5% level.

RESULTS AND DISCUSSION

Characteristics of Starches

Chemical compositions and starch damage of both prime and tailings starches separated from garbanzo beans and peas are summarized in Table I. Starch content of prime starch determined by enzymatic assay ranged from 97.5% in Scout to 99.4% in SS Alaska. Protein and ash contents of prime starches from garbanzo beans and smooth peas were <0.35% and <0.19%, respectively, indicating that isolated starches were very pure. The prime starch of wrinkled pea had significantly higher protein (0.96%) and ash (0.31%) content than did the prime starch from garbanzo beans and smooth peas. This result could be explained by the difficulty in the fractionation process of wrinkled pea due to its high fiber content and composite starch granules (Otto et al 1997a).

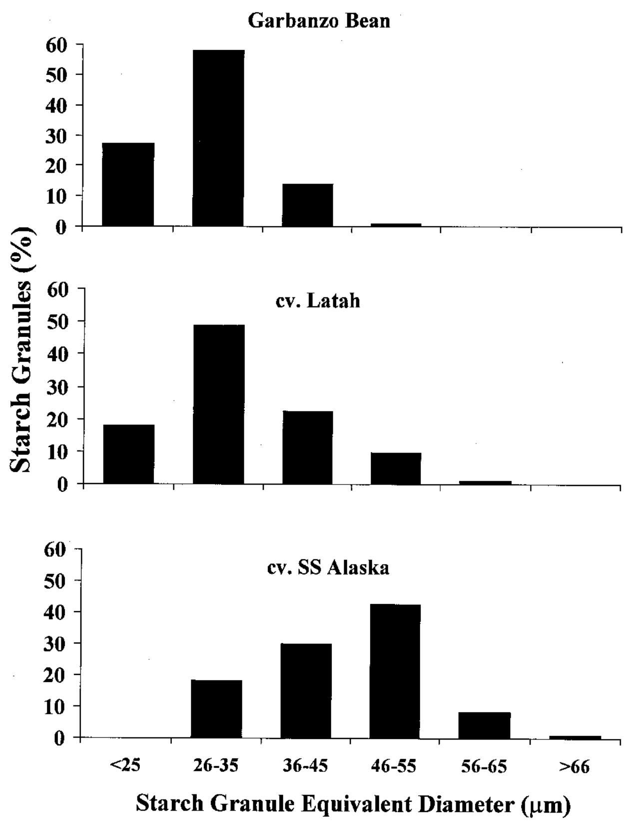

Fig. 1. Size distribution of prime starch granules from garbanzo beans and smooth pea cvs. Latah and SS Alaska, determined by image analysis.

Contrary to the high purity of prime starches, tailings starches from garbanzo beans and peas contained considerable amounts of protein, ash, and fiber. Starch content of isolated tailings starches was >63.2% in the two smooth peas, 45.1% in wrinkled pea, and 38.5% in garbanzo beans. The protein content of tailings starches ranged from 4.6 to 10.2%, ash from 1.21 to 2.08%, and fiber from 26.2 to 51.9%. The high concentration of these components indicates that tailings starches are a mixture of starch granules, cell wall materials, and insoluble proteins.

Starch damage was significantly higher in tailings starch than in prime starch, indicating that broken and cracked starch granules were trapped in tailings starch during the fractionation process. Prime starch represents primarily intact pure starch granules, while tailings starch contains small or broken starch granules and many proteinous materials (Otto et al 1997b). These differences between prime and tailings starches were observed in both smooth and wrinkled pea cultivars.

Amylose content was 35.9% for garbanzo bean prime starch, 44.5% for Latah and 48.8% for SS Alaska (Table I). Scout had the highest amylose content (86.0%) in prime starch. Amylose content of tailings starch was always higher by at least 8% than that of prime starch in both garbanzo beans and pea cultivars. This can be explained by the large population of small-sized granules within the tailings starch. The smaller starch granules are typically higher in amylose than are larger granules (Szczodrak and Pomeranz 1991, MacGregor and Fincher 1993).

Size distributions of prime starch granules from garbanzo beans and the two smooth pea cultivars, determined by image analysis, are graphically presented in Fig. 1. Size distribution of starch granules affects the rate of hydration during processing and thermal behavior. Garbanzo bean prime starch granules were smaller than those of smooth peas and ranged from 25 to 55 μm in diameter. Granules <35 μm represented 85% of total garbanzo bean starch. While granules <25 μm made up 27.2% in garbanzo bean starch, granules >45 μm were only 1%. Prime starch from Latah repre-

TABLE I
Characteristics (%, dwb) of Prime and Tailings Starches from Garbanzo Beans and Peas

	Starch	Protein[a]	Ash	Total Fiber	Starch Damage	Amylose
Prime starch						
Garbanzo bean[b,c]	99.1	0.17	0.17	Trace	1.23	35.9
Smooth pea						
cv. Latah[b,c]	99.0	0.33	0.01	Trace	0.43	44.5
cv. SS Alaska[b,c]	99.4	0.35	0.08	Trace	0.58	48.8
Wrinkled pea						
cv. Scout[b,d]	97.5	0.96	0.31	Trace	1.27	86.0
LSD[e]	0.66	0.28	0.01	· · ·	0.03	0.54
Tailings starch						
Garbanzo bean[b,c]	38.5	7.22	2.08	51.9	3.46	49.1
Smooth pea						
cv. Latah[b,c]	64.8	7.61	1.29	26.2	2.74	52.6
cv. SS Alaska[b,c]	63.2	4.55	1.37	30.6	2.96	57.0
Wrinkled pea						
cv. Scout[b,d]	45.1	10.20	1.21	43.1	2.76	94.0
LSD[e]	0.42	1.19	0.11	0.69	0.04	0.75

[a] N × 6.25.
[b] Fractionated using patented method of Czuchajowska and Pomeranz (1994).
[c] Water-to-flour ratio 2:1.
[d] Water-to-flour ratio 2.5:1.
[e] Least significant difference ($P = 0.05$). Differences between two means exceeding this value are significant.

sented a broader range of granule size than that from garbanzo beans, ranging from 25 to 65 µm, with a dominant granule size of 26–35 µm. Starch from SS Alaska covered the broadest range of granule size, from 26 µm to >66 µm, with 40% of the granules ranging from 46 to 55 µm. Distribution of starch granules from Scout was not determined, as many of the compound granules were broken, leaving small granular pieces that were difficult to distinguish from the intact granules.

Thermal Behavior of Starches

The thermal behavior of prime and tailings starches was evaluated by DSC, swelling power, and amylograph tests. DSC transition temperatures and enthalpy values of prime and tailings starches are given in Table II. The onset temperature of prime starch of garbanzo beans did not differ significantly from that of smooth or wrinkled peas. However, the transition temperature of wrinkled pea starch was ≈6°C higher than for garbanzo beans and the two smooth peas. Garbanzo beans had the highest endothermic enthalpy value of starch (14.2 J/g), followed by SS Alaska (12.8 J/g) and Latah (12.1 J/g). Prime starch of Scout gave the lowest enthalpy value of 1.1 J/g due to its high amylose content (86%). The highest enthalpy value of garbanzo bean starch was due to its high amylopectin content. Prime starches from the two smooth peas, which had a lower enthalpy value by at least 1.4 J/g than that of garbanzo beans, also had ≈10% more amylose content (Table I). These results corresponded well with a report for smooth and wrinkled peas by Kosson et al (1994), who obtained a strong positive correlation (r = 0.985) between the amylopectin content of pea starch and transition enthalpy.

Transition enthalpies of tailings starches were significantly lower than those of corresponding prime starches. Several factors can explain the differences in enthalpy values between prime and tailings starches: total starch content (Table I), size and mechanical damage of starch granules (Otto et al 1997b), amylose content (Table I), and interactions between other tailings starch components. These differences in

TABLE II
Differential Scanning Calorimetry Characteristics[a] of Prime and Tailings Starches from Garbanzo Beans and Peas

Starch	T_o (°C)	T_p (°C)	ΔH (J/g)
Prime starch			
Garbanzo bean	62.8	68.1	14.2
Smooth pea			
cv. Latah	62.1	68.6	12.1
cv. SS Alaska	61.4	67.7	12.8
Wrinkled pea			
cv. Scout	62.4	74.7	1.1
LSD[b]	0.87	1.33	1.83
Tailings starch			
Garbanzo bean	60.5	73.2	1.5
Smooth pea			
cv. Latah	58.0	69.5	5.4
cv. SS Alaska	56.6	67.2	4.6
Wrinkled pea			
cv. Scout	70.9	86.8	0.8
LSD	2.26	3.45	1.22

[a] T_o = onset temperature. T_p = peak temperature. ΔH = transition enthalpy. Values are averages of two replicates.
[b] Least significant difference (P = 0.05). Differences between two means exceeding this value are significant.

TABLE III
Amylograph Pasting Properties and Swelling Power of Prime and Tailings Starches from Garbanzo Beans and Peas

	Viscosity (BU)				
	93.5°C		50°C		
Starch	0 min	30 min	0 min	30 min	Swelling Power[a]
Prime starch					
Garbanzo bean	395	495	740	800	13.6
Smooth pea					
cv. Latah	305	377	655	750	13.5
cv. SS Alaska	470	540	910	1,050	13.5
Wrinkled pea					
cv. Scout	0	0	5	10	4.8
Tailings starch					
Garbanzo bean	80	170	218	200	7.2
Smooth pea					
cv. Latah	370	455	595	575	9.6
cv. SS Alaska	255	337	417	405	9.4
Wrinkled pea					
cv. Scout	5	5	18	18	6.2

[a] Calculated according to Crosbie (1991).

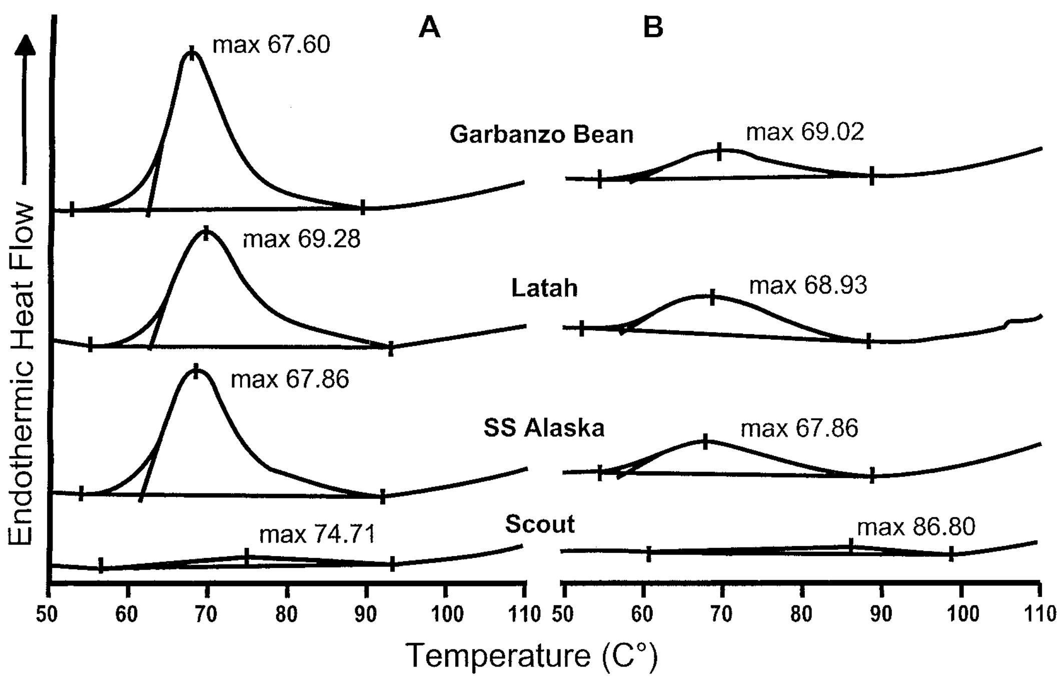

Fig. 2. Differential scanning calorimetry thermograms of prime starch (A) and tailings starch (B) from garbanzo beans, smooth pea cvs. Latah and SS Alaska, and wrinkled pea cv. Scout.

TABLE IV
Texture Profile Analysis Parameters and Water Loss of Prime Starch Gels Stored at 22 and 4°C for 24 hr[a]

Starch Sample	Hardness (N)		Cohesiveness (ratio)		Springiness (ratio)		Water Loss (%)	
	22°C	4°C	22°C	4°C	22°C	4°C	22°C	4°C
Garbanzo bean	7.9	11.7	0.95	0.94	0.99	0.98	5.1	20.2
Smooth pea								
cv. Latah	11.4	17.7	0.88	0.84	0.96	0.95	6.3	20.7
cv. SS Alaska	11.1	19.5	0.91	0.85	0.98	0.97	5.8	19.4
Wrinkled Pea								
cv. Scout	1.0	1.1	0.39	0.43	0.66	0.64	. . .	. . .
cv. Scout (ac)[b]	21.8	26.5	0.29	0.29	0.82	0.76	2.0	2.9
LSD[c]	0.96	1.35	0.05	0.03	0.02	0.04	0.5	0.7

[a] Gels contain 8% starch on a dry weight basis.
[b] Autoclaved at 126°C for 1 hr.
[c] Least significant difference ($P = 0.05$). Differences between two means exceeding this value are significant.

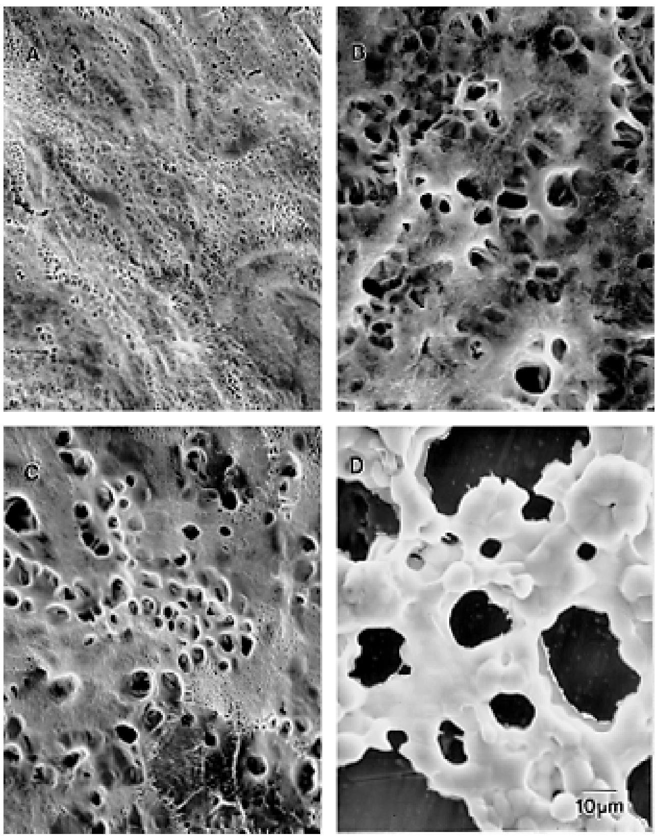

Fig. 3. Scanning electron micrographs of prime starch pastes from garbanzo beans (**A**), smooth pea cvs. Latah (**B**) and SS Alaska (**C**), and wrinkled pea cv. Scout (**D**). Starch pastes (8% starch) were prepared by heating to 93.5°C for 10 min.

transition enthalpy between prime and tailings starches from garbanzo beans and peas are shown in the size and shape of DSC enthalpy curves (Fig. 2). Prime starches from garbanzo beans and smooth peas, consisting of pure and undamaged granules with at least 52% amylopectin, showed narrow and well-defined endothermic peaks. Tailings starches contained small and damaged granules admixed with insoluble protein and fiber, and showed rather flat and broad DSC endothermic curves. A similar result was reported by Szczodrak and Pomeranz (1991) for barley and by Erdogdu et al (1995) for wheat.

Pasting characteristics of the legume starches, as determined by amylograph, are shown in Table III. Prime starches of garbanzo beans and both varieties of smooth peas had similar patterns of pasting curves. Pasting viscosity at 93.5°C was 395 BU in garbanzo beans and 305 and 490 BU in Latah and SS Alaska, respectively. During 30-min holding at 93.5°C with constant shear, viscosity increased by over 70 BU. This result is consistent with the viscosity pattern of the type C starch for restricted-swelling or of cross-linked starches as described by Schoch and Maywald (1968). During the cooling period from 93.5 to 50°C, set-back was extensive, as shown by the large increases in viscosity. Pasting viscosity further increased during the holding period at 50°C with constant shear. Scout showed no viscosity development, as temperatures were not high enough for the starch granules to fully swell and gelatinize the granules (Schoch and Maywald 1968, Stute 1990). Schoch and Maywald (1968) described this behavior as a viscosity pattern of type D starch, characteristic of very high amylose starches.

The paste viscosities of tailings starches from garbanzo beans and smooth peas were generally lower than corresponding prime starches and showed lower stability during the holding period at 50°C (Table III). The viscosities of tailings starches from the smooth peas were higher than that of garbanzo beans, which could be due to their higher starch content. The viscosity development in the tailings starch of Scout was due to protein and cell wall components, since starch did not contribute to any viscosity as shown in prime starch (Table III).

The swelling power test, commonly used to characterize tuber and cereal grain starches that are high in amylopectin, was applied to evaluate prime and tailings starches from legumes. The swelling powers of prime starches from garbanzo beans and the two smooth peas were similar, ranging from 13.5 to 13.6 (Table III). The wrinkled pea had a distinguishably lower swelling power value of 4.8. This result is in agreement with reports that starches higher in amylopectin exhibit a higher swelling power than those low in amylopectin (Ott and Hester 1965, Orford et al 1987, Tester and Morrison 1990). The swelling power of tailings starches, except Scout, was significantly lower than for prime starch, ranging from 6.2 to 9.6. Tailings starches contain cell wall materials (high in fiber), insoluble protein, and damaged starches, which absorb a high amount of water but still exhibit a lower degree of swelling than prime starches when heated.

SEM pictures of prime starch paste, sampled after 10 min of heating at 93.5°C, showed uniform gel network in garbanzo beans (Fig. 3A) and in smooth peas (Fig. 3B,C) without visible starch granules. Prime starch paste from wrinkled pea contained easily visible intact starch granules (Fig. 3D) in a loose gel network. This observation for wrinkled pea corresponds with the low swelling and low viscosity development previously discussed.

Characteristics of Starch Gels

The TPA parameters, hardness, cohesiveness, and springiness of starch gels varied broadly among starches within each storage temperature (Table IV). Hardness of prime starch gels, an important textural parameter reflecting the strength of gel, was 7.9 N in garbanzo beans, 11.4 N in Latah and 11.1 N in SS Alaska, when stored at 22°C. The prime starch gel of Scout showed a significantly lower hardness value of only 0.98 N because of incomplete gelatinization of starch at 93.5°C, as shown by SEM (Fig. 3D). However, when the prime starch slurry of Scout was autoclaved at 126°C for 1 hr, a strong gel with a hardness value of 21.8 N was formed. The hardness of gels stored at 4°C followed the same pattern

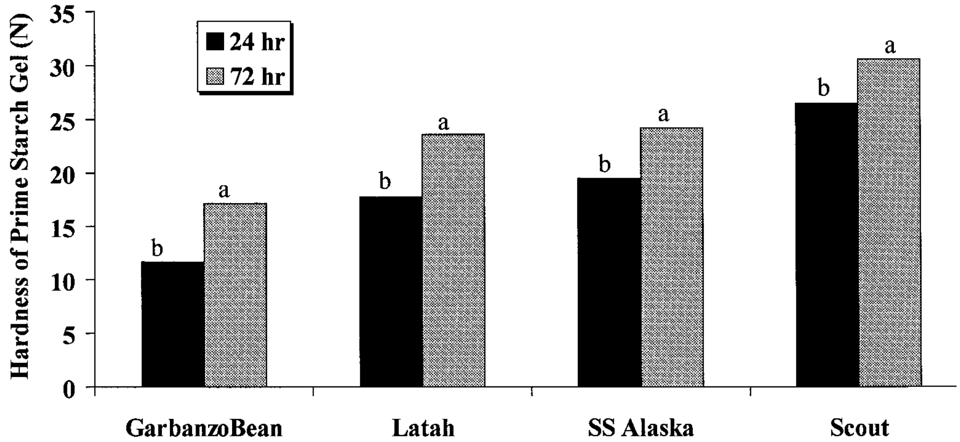

Fig. 4. Hardness of prime starch gels from garbanzo beans, smooth pea cvs. Latah and SS Alaska, and wrinkled pea cv. Scout stored at 4°C for 24 and 72 hr. Gels for each legume starch were prepared by heating to 93.5°C for 10 min, except Scout, which was prepared by autoclaving at 126°C for 1 hr. Letters indicate significant differences at the 5% level.

as those stored at 22°C. However, due to facilitated retrogradation at 4°C, the hardness of gels increased by 3.8 N for garbanzo beans, 5.3 N for Latah, 8.4 N for SS Alaska and 4.7 N for autoclaved starch of Scout. A strong positive correlation was obtained between amylose contents and hardness of gels. Correlation coefficients were 0.965 for gels stored at 22°C and 0.967 for gels stored at 4°C. Cohesiveness, which reflects gel structure, was highest in garbanzo beans (0.95), followed by SS Alaska (0.91) and Latah (0.88). Storing gels at 4°C did not significantly affect cohesiveness. The lowest gel cohesiveness value (0.29) for Scout indicated that the gel was very strong but brittle. Springiness of gels from garbanzo beans and smooth peas was >0.96, indicating high recovery of gel height after first compression. Gels from Scout showed a much lower springiness value than others, as could be expected from its low cohesiveness value.

The increase in hardness due to accelerating retrogradation during storage at 4°C for all legume starch gels is shown in Fig. 4. Statistically significant increases in gel hardness were obtained for all gels by extending storage from 24 to 72 hr. Changes in hardness of gel during storage could also be related to water loss. The percentage of water loss of prime starch gels stored for 72 hr at 22°C and at 4°C is shown in Table IV. Garbanzo beans and Latah and SS Alaska showed similar water loss of starch gels during storage at 22°C. Water loss in starch gels stored at 4°C was four times higher than in those stored at 22°C, due to the accelerated retrogradation of starch. High amylose gel of Scout showed water loss (<3%) independent of storage temperature. It appears that, during autoclaving, starch from Scout forms a strong gel network that withstands the force of gravity and allows the water to remain within the network, resulting in increased gel hardness and small water loss during storage. This phenomenon could also be due to differences in the molecular structure of Scout starch as compared to that of Latah and SS Alaska. Colonna and Mercier (1984) reported the presence of intermediate amylopectin fractions (18.9%) of low molecular weight only in the wrinkled pea starch, with a ratio between short and long chain of 3.6. In spite of complex changes in gels and independence of percentage of water loss during storage, the positive relationship between hardness and amylose content is very clear.

Prime starch gels were also evaluated for clarity during storage. A slice of gel was placed on a black background, and the L^* value was determined with a Minolta spectrophotometer. Therefore, the clearer the gel, the lower the L^* value. Garbanzo beans produced the clearest starch gel having the lowest L^* value, followed by SS Alaska and Latah (Fig. 5). Scout starch gave opaque gels (L^* = 65). The L^* value of Scout starch gel remained stable over storage for 72 hr, while other gels, probably due to water loss, showed increased L^* value with time. Gels of garbanzo bean and SS Alaska and Latah starches stored at 4°C showed increased opaqueness when compared to those stored at 22°C. The gel of Scout showed similar L^* values at both storage temperatures.

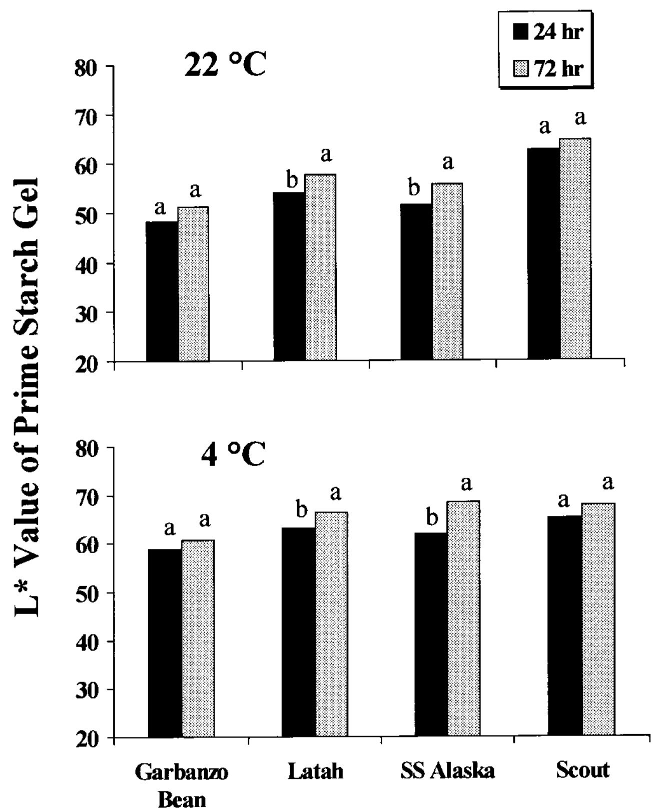

Fig. 5. Lightness (L^*) values of prime starch gels from garbanzo beans and peas after storage. Letters indicate significant differences at the 5% level.

Gel hardness of tailings starches from smooth and wrinkled peas stored at 22 and 4°C for 24 and 72 hr are shown in Fig. 6. Garbanzo bean tailings starch, containing <40% starch, did not form a gel. The large differences in composition of tailings starches originating from different legumes (Table I) make it difficult to compare gel texture. The hardness of tailings starch gels stored at 4°C was higher than for those stored at 22°C. Storage time also had a significant effect on gel hardness (except Latah). These changes in hardness due to storage temperature and time indicate that starch plays an important role in the textural properties of tailings starch gel.

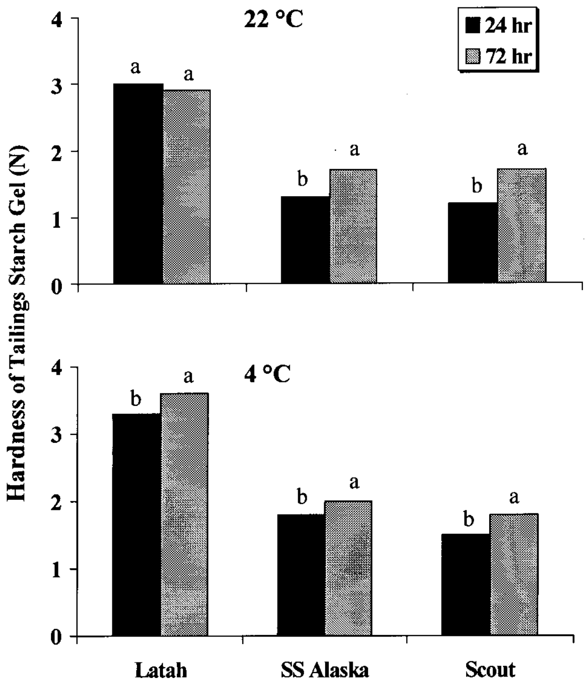

Fig. 6. Hardness of tailings starch gels from smooth pea cvs. Latah and SS Alaska and wrinkled pea cv. Scout stored at 22°C and 4°C for 24 and 72 hr. Gels prepared by heating to 93.5°C 10 min, except cv. Scout, which was autoclaved at 126°C for 1 hr. Letters indicate significant differences between storage times at the 5% level.

SUMMARY

Prime starches obtained from garbanzo beans, smooth pea cvs. Latah and SS Alaska, and wrinkled pea cv. Scout by the wet-fractionation process are high purity products, as indicated by low ash and protein content. Granule size distribution and amylose content of starch differs widely between garbanzo beans and peas and between types and cultivars of peas. Scout had >86% amylose, while amylose content of garbanzo beans and Latah and SS Alaska ranged from 35.9 to 48.8%. Tailings starch always had higher amylose content than the corresponding prime starch. Prime starch from Scout, with 86% amylose, had 1.1 J/g of enthalpy and developed no viscosity when tested by amylograph. Amylose content of prime starch showed significant relationship to DSC endothermic enthalpy and amylograph pasting properties. Transition enthalpy of tailings starch was significantly lower than that of the corresponding prime starch, ranging from 0.81 to 5.42 J/g. Texture, water loss, and clarity of prime starch gels were strongly related to the composition and structure of starch granules.

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LITERATURE CITED

American Association of Cereal Chemists. 1995. Approved Methods of the AACC, 9th ed. Method 44-15A, approved October 1975, revised October 1981; Method 08-01, approved April 1961, revised October 1981; Method 30-25, approved April 1961, revised October 1976, October 1981; Method 76-31, approved September 1992, revised October 1994. The Association: St. Paul, MN.

Beck, H., and Kevin, K. 1995. Foods of tomorrow. Patent tracker. Food Proc. 2:58.

Bourne, M. C. 1968. Texture profile of ripening pears. J. Food Sci. 33:223-226.

Chavan, J. K., and Kadam, S. S. 1989. Biochemistry and technology of chickpea (*Cicer arientinum* L.) seeds. CRC Crit. Rev. Food Sci. Nutr. 25:107-122.

Colonna, P., Gallant, D., and Mercier, C. 1980. *Pisum sativum* and *Vicia faba* carbohydrates: Studies of fractions obtained after dry and wet protein extraction processes. J. Food Sci. 45:1629-1636.

Colonna, P., and Mercier, C. 1984. Macromolecular structure of wrinkled- and smooth-pea starch components. Carbohydr. Res. 126:233-247.

Comer, F. W., and Fry, M. K. 1978. Purification, modification, and properties of air-classified pea starch. Cereal Chem. 55:818-829.

Crosbie, G. B. 1991. The relationship between starch swelling properties, paste viscosity and boiled noodle quality in wheat flours. J. Cereal Sci. 13:145-150.

Czuchajowska, Z., and Pomeranz, Y. 1994. Process for fractionating legumes to obtain pure starch and a protein concentrate, U.S. patent 5,364,471.

Deshpande, S. S., and Damodaran, S. 1990. Food legumes: Chemistry and technology. Pages 147-241 in Advances in Cereal Science and Technology, Vol. 10. Y. Pomeranz, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.

Erdogdu, N., Czuchajowska, Z., and Pomeranz, Y. 1995. Wheat flour and defatted milk fractions characterized by differential scanning calorimetry. I. Differential scanning calorimetry of flour and milk fractions. Cereal Chem. 72:70-75.

Friedman, H. H., Whitney, J. E., and Szczesniak, A. S. 1968. The texturometer—A new instrument for objective texture measurement. J. Food Sci. 28:390-396.

Gujska, E., Reinhard, W. D., and Khan, K. 1994. Physicochemical properties of field pea, pinto and navy bean starches. J. Food Sci. 59:634-637.

Hoover, R., and Sosulski, F. 1986. Effect of cross-linking on functional properties of legume starches. Starch/Staerke 38:149-155.

Knutson, C. A., and Grove, M. J. 1994. Rapid method for estimation of amylose in maize starches. Cereal Chem. 71:469-471.

Kooistra, E. 1962. On the differences between smooth and three types of wrinkled peas. Euphytica 11:357-373.

Kosson, R., Czuchajowska, Z., and Pomeranz, Y. 1994b. Smooth and wrinkled peas. 2. Distribution of protein, lipid, and fatty acids in seed and milling fractions. J. Agric. Food Chem. 42:96-99.

Leloup, V. M., Colonna, P., and Buleon, A. 1991. Influence of amylose-amylopectin ratio on gel properties. J. Cereal Sci. 13:1-13.

Lineback, D. R., and Ke, C. H. 1975. Starches and low-molecular-weight carbohydrates from chick pea and horse bean flours. Cereal Chem. 52:334-347.

Lloyd, J. B., and Whelan, W. J. 1969. An improved method for the enzymatic determination of glucose in the presence of maltose. Anal. Biochem. 30:467-470.

MacGregor, A. W., and Fincher, G. B. 1993. Carbohydrates of the barley grain. Pages 73-130 in: Barley Chemistry and Technology. A. W. MacGregor and R. S. Bhatty, eds. Am. Assoc. Cereal Chem.: St. Paul, MN.

Orford, P. D., Ring, S. G., Carroll, V., Miles, M. J., and Morris, V. J. 1987. The effect of concentration and botanical source on the gelation and retrogradation of starch. J. Sci. Food Agric. 2:169-177.

Ott, M., and Hester, E. E. 1965. Gel formation as related to concentration of amylose and degree of starch swelling. Cereal Chem. 42:476-484.

Otto, T., Baik, B.-K., and Czuchajowska, Z. 1997a. Wet fractionation of garbanzo bean and pea flours. Cereal Chem. 74:141-146.

Otto, T., Baik, B.-K., and Czuchajowska, Z. 1997b. Microstructure of seeds, flours, and starches of legumes. Cereal Chem. 74:445-451.

Prosky, L., Asp, N. G., Schweizer, T. F., Devries, J. W., and Furda, J. 1988. Determination of insoluble, soluble, and total dietary fiber in foods and food products: Interlaboratory study. J. AOAC 71:1017-1023.

Schoch, T. J., and Maywald, E. C. 1968. Preparation and properties of various legume starches. Cereal Chem. 45:564-573.

Shuey, W. C., and Tipples, K. H., eds. 1980. The Amylograph Handbook. Am. Assoc. Cereal Chem.: St. Paul, MN.

Stute, R. 1990. Properties and applications of pea starches. 1. Properties. Starch/Staerke 42:178-184.

Swanson, B. G. 1990. Pea and lentil protein extraction and functionality. J. AOCS 67:276-280.

Szczodrak, J., and Pomeranz, Y. 1991. Starch and enzyme-resistant starch from high-amylose barley. Cereal Chem. 68:589-596.

Tester, R. F., and Morrison, W. R. 1990. Swelling and gelatinization of cereal starches. I. Effects of amylopectin, amylose, and lipids. Cereal Chem. 67:551-557.

Vose, J. R. 1977. Functional characteristics of an intermediate amylose starch from smooth-seeded field peas compared with corn and wheat starches. Cereal Chem. 54:1141-1151.

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