Effect of Germination on Physicochemical and Bread-Baking Properties of Yellow Pea, Lentil, and Faba Bean Flours and Starches[1]

M. M. MORAD, H. K. LEUNG, D. L. HSU,[2] and P. L. FINNEY[3]

Cereal Chem. 57(6):390–396

ABSTRACT

The physicochemical properties of flours and starches from ungerminated and germinated yellow pea, lentil, and faba bean were investigated. The α-amylase activity of the legume flours increased about 8.1 times for yellow peas, 2.4 times for lentils, and 1.5 times for faba beans after four days of germination. Scanning electron microscopy indicated some alteration of starch granule surfaces after germination. Germination caused changes in starch pasting properties of the legume flours and their starch fractions. Replacing wheat flour by legume starches affected loaf volume, crumb grain, and crust color of the breads. Germination appeared to have more detrimental effects on the baking properties of yellow pea starches than on those of lentil and faba bean starches.

Food uses of legume flours and their protein concentrates have received much attention in recent years (D'Appolonia 1977, Jeffers et al 1978, Sosulski et al 1978, Sosulski and Fleming 1979). However, little research has been done to evaluate the potential uses of legume starches. Because legumes are high in starch, utilization of this fraction will be economically important if legume protein concentrates are used in foods.

The chemical compositions of several legume starches have been determined (Bhatty and Slinkard 1979, Naivikul and D'Appolonia 1979, Samuel et al 1977, Sosulski and Youngs 1979, Vose et al 1976). Lineback and Ke (1975) and Lorenz (1979) discussed the properties of faba bean starch isolated by wet-milling and by air-classification, respectively. Lineback and Ke (1975), Sosulski and Youngs (1979), Lai and Varriano-Marston (1979), and Lorenz (1979) reported that the Brabender viscosity pattern of the starches appeared to be determined by the extent of swelling of the starch granules and the resistance of the starch granules to rupture by heat. The presence of soluble starch leached from the granules upon heating was also reported by Miller et al (1973), Allen et al (1977), and Lai and Varriano-Marston (1979). An interaction or cohesion between the swollen granules was suggested by Leach (1965). Schoch and Maywald (1968) classified the viscosity patterns of "thick-boiling" starches. They found that navy bean and lentil starches give type C Brabender curves that show no pasting peak but rather a high viscosity that remains constant or increases during cooking. The same type of peak was also observed with black beans (Lai and Varriano-Marston 1979) and other legume starches (Naivikul and D'Appolonia 1979).

Wide variations in amylose content of legume starches were reported by Lineback and Ke (1975), Vose et al (1976), Bhatty and Slinkard (1979), Kawamura (1969), and Naivikul and D'Appolonia (1979). Kawamura (1969) found that the estimation of amylose content in legume starches may vary depending on the methods used for determination. Bhatty and Slinkard (1979) reported that starch isolated from three varieties of lentils had similar pasting characteristics and contained about 35% amylose.

Starch granules isolated from legume flours were examined by a number of workers using scanning electron microscopy (SEM) (Bhatty and Slinkard 1979, Fuwa et al 1979, Hall and Sayre 1971, Kawamura et al 1955, Lorenz 1979, McEwen et al 1974, Rockland and Jones 1974). They found that the starch granules are generally ellipsoid, kidney-shaped, or irregularly swollen, with an elongated hilum. The effects of germination on the morphological changes of starch granules in the cotyledon cells of red kidney beans and mung beans were examined by Silva and Luh (1978) and Endo et al (1978), respectively. Some alterations of the starch granule surfaces caused by germination were reported. Virtually no SEM information is available in the literature regarding germinated peas, lentils, and faba beans.

We recently investigated the effect of germination on the nutritive value and bread-baking properties of dry peas, lentils, and faba beans (Hsu et al 1980). Germination was found to adversely affect the baking properties of yellow peas and lentils but not of faba beans. The present study was designed to provide some explanations of our previous findings by examining the physicochemical and bread-baking properties of both starches and

[1]Scientific paper 5596. College of Agriculture Research Center, Washington State University, Pullman 99164.

[2]Research associate, assistant professor, and graduate research assistant, respectively. Department of Food Science and Technology, Washington State University, Pullman 99164. Dr. Morad's present address: Department of Food Science, Cairo University, Cairo, Egypt.

[3]Research food technologist, USDA-SEA, Western Wheat Quality Laboratory, Pullman, WA 99164.

Mention of a trademark or proprietary product does not constitute a guarantee or warranty of the product by the USDA and does not imply its approval to the exclusion of other products that may also be suitable.

flours prepared from the ungerminated and germinated yellow peas, lentils, and faba beans.

MATERIALS AND METHODS

Sample Preparation

Dry yellow peas (plain Latah), lentils (common Chilian), and faba beans were used in this study. The legume samples, germination process, and method of sample preparation have been described previously (Hsu et al 1980).

The starch fractions of the germinated and ungerminated legumes were isolated according to Sosulski et al (1978) with some modification. The legume flour was suspended in distilled water and the pH adjusted to 8.5 with 1*N* NaOH. After stirring for 30 min at 40°C, the extract was separated from the insoluble fraction by centrifuging at 200 × *g* for 15 min. The supernatant and sludge were removed. The extraction procedure was repeated, and the residue was collected and washed three times with distilled water. The insoluble material (starch fraction) was freeze-dried and passed through a 70-mesh sieve.

Chemical Analysis

Proximate analyses of the ungerminated and germinated legume flour and starch samples were conducted by AACC (1962) procedures. Moisture content was determined by the air-oven method (130°C for 60 min). Crude protein was determined by the macro-Kjeldahl procedure (N × 6.25), and ash was determined by igniting the samples at 600°C for 3 hr. Starch content of the samples was determined polarimetrically (AOAC 1975). Amylose content was determined colorimetrically as described by Juliano (1971). Reducing and nonreducing sugars were determined according to the AOAC (1975) procedure. Water hydration capacity was determined by the AACC (1962) method.

Duplicate samples of α-amylase crude extracts from the germinated and ungerminated legume flours were prepared by the method of Swain and Dekker (1966). The α-amylase activity was assayed according to the procedure of Whelan (1964).

SEM

The germinated and ungerminated legume flours were sprinkled onto double-coated tape (Scotch No. 416) mounted on aluminum specimen stubs. The mounted samples were then fixed in 2% osmium tetroxide (OsO_4) vapor for 2 hr. The dehydrated samples were coated with approximately 300-nm thickness of gold using a Technics-Hummer 5 sputter coater (Technics Inc., Alexandria, VA). The coated samples were viewed and photographed with an ETEC Autoscan scanning electron microscope (ETEC, Hayward, CA) at an accelerating voltage of 10 kV.

Starch Pasting Properties

A VISCO/amylo/GRAPH™ (Brabender Instruments, Inc., South Hackensack, NJ) equipped with a 700 cm-g sensitivity cartridge, was used to determine the pasting properties of legume flour and starch samples (Medcalf and Gilles 1965). Fifty-five grams of flour or starch was suspended in 460 ml of distilled water and poured into the amylograph bowl. The flour or starch suspension was heated uniformly from 22 to 95°C, held at 95°C for 15 min, and then cooled uniformly to 50°C.

The information obtained from the amylograph curve included pasting temperature (the temperature at which an initial increase of 10 Brabender units [BU] in viscosity is reached), peak height (the maximum viscosity at 95°C), height at 15 min (the viscosity of the sample after a 15-min holding period at 95°C), and the 50°C height (the viscosity of the sample after it was cooled to 50°C). Because no definite peak was obtained in this study, the viscosity at 95°C was reported as height.

Mixing Properties

The 10-g mixograph was used to study physical dough properties, including mixing time, mixing tolerance, and water absorption of the legume starch/wheat flour blends (Finney and Shogren 1972).

Baking Studies

A microbake (10 g) system was adopted using the procedure developed by Shogren et al (1969). An unmalted, commercial straight grade baker's flour with a medium mixing time of 4 min and good loaf volume potential was used throughout the study. Bread-baking formula included 10 g of legume starch/wheat flour blend (14% mb), 0.76 g of fresh baker's yeast (Fleischmann's Standard Brands), 0.15 g of NaCl, and 0.30 g of vegetable shortening (Crisco). Baking absorption, mixing time, and oxidation (ascorbic acid and potassium bromate) were optimized for each formulation. The legume starches were formulated on a replacement basis at 5, 10, 15, or 20%. Doughs were fermented at 30°C for 70 min before panning and for 45 min after panning. Doughs were degassed after 40 and 60 min and immediately before panning. Breads were baked at 232°C for 14 min and weighed. Loaf volume was determined by rapeseed displacement immediately after removal from the oven. Crumb grain, crust color, and overall appearance of breads were subjectively evaluated by members of the Western Wheat Quality Laboratory.

TABLE I

Chemical Analysis, Water Hydration Capacity, and α-Amylase Activity of Ungerminated and Germinated Legume Flours and Their Starch Fractions

Legume	Sample[a]	Moisture (%)	Protein[b] (%)	Ash (%)	Starch (%)	Amylose (%)	Reducing Sugar (%)	Nonreducing Sugar (%)	Water Hydration Capacity (%)	α-Amylase Activity (unit/g of flour)
Faba bean										
Ungerminated	Flour	9.3	31.35	4.40	46.4	12.38	2.13	1.85	90.8	27.5
	Starch	3.6	5.73	0.82	90.8	33.69	0.00	0.10	197.3	···
Germinated	Flour	4.2	32.05	3.65	43.9	11.52	3.85	2.37	151.4	42.0
	Starch	3.0	3.88	1.13	90.2	33.94	0.56	0.24	253.6	···
Lentil										
Ungerminated	Flour	7.8	27.81	3.03	58.5	13.23	0.65	2.56	104.1	22.0
	Starch	3.3	5.43	0.82	91.3	28.57	0.31	0.15	203.9	···
Germinated	Flour	4.9	29.34	3.05	51.5	10.67	4.18	1.77	174.1	54.0
	Starch	3.2	5.22	0.93	90.6	28.57	0.41	0.05	240.2	···
Yellow pea										
Ungerminated	Flour	7.9	27.88	3.04	55.8	13.23	0.85	3.28	101.8	6.0
	Starch	3.0	4.10	0.62	91.5	28.57	0.31	0.34	199.8	···
Germinated	Flour	3.9	27.22	2.49	51.0	10.67	3.15	2.97	150.1	49.0
	Starch	6.1	5.10	0.52	89.9	28.57	0.71	0.52	258.8	···

[a] Dry weight basis.
[b] N × 6.25.

RESULTS AND DISCUSSION

Chemical Characteristics

Table I shows the chemical composition of ungerminated and germinated faba bean, lentil, and yellow pea flours and their starch fractions. The faba beans contained more protein than did yellow peas and lentils in both germinated and ungerminated forms. The starch content of the three legumes ranged from 43.9 to 58.5%. The legume starch fractions contained about 90% starch and 4–6% protein. Ash content ranged from 2.49 to 4.40% in the ungerminated and germinated legume flours and was reduced to 0.52–1.13% in the starch fractions. The results indicated that most of the ash was removed with the protein fraction. This agrees with the findings reported by Vose et al (1976), D'Appolonia (1977), Samuel et al (1977), Lorenz (1979), and Sosulski and Youngs (1979).

As shown in Table I, ash, starch, amylose, and nonreducing sugars of the three legume flours decreased after germination, whereas the reducing sugars increased. The increase in reducing sugars and the decrease in starch and amylose were probably caused by the increased amylase activity during germination. Only small amounts of the reducing and nonreducing sugars were present in the starch fractions.

The amylose content of the legume flours ranged from 10.7 to 13.2%. The starch fractions isolated from the germinated and ungerminated yellow peas and lentils contained 28.6% amylose. The starch fraction for faba bean was higher in amylose (33.9%) than was that for peas or lentils (28.6%). The amylose content of the faba bean starch fraction was similar to those found by Lineback and Ke (1975) and Vose et al (1976) but higher than the 20.5% reported by Kawamura (1969). The amylose content of lentil starch in this study was lower than the 35% reported by Bhatty and Slinkard (1979). The differences in amylose content could be ascribed to the different methods of determination or to varietal differences.

Water hydration capacities were 90.8, 104.1, and 101.8% for faba bean, lentil, and yellow pea flours, respectively (Table I). The values after germination increased to 151.4% for faba bean, 174.1% for lentil, and 150.1% for yellow pea. The water hydration capacities were 197.3, 203.9, and 199.8% for the starch fractions from ungerminated faba bean, lentil, and yellow pea, respectively. These values also increased in the starch fractions isolated from the germinated faba bean, lentil, and yellow pea to 253.6, 240.2, and 258.8%, respectively. This indicates that the legume starches absorbed more water after germination.

The α-amylase activity (unit per gram of flour) of the legume flours increased about 8.1 times for yellow peas, 2.4 times for lentils, and 1.5 times for faba beans after four days of germination (Table I). Young and Varner (1959) also reported that the amylase activity in pea cotyledons increased many times during germination.

SEM Study

Figure 1A, C, and E shows the starch granules in flours from ungerminated faba beans, yellow peas, and lentils, respectively. In each flour, the starch granules were variable in size, and generally round or ellipsoidal with relatively smooth surfaces. Similar morphological characteristics of legume starch granules were reported by other workers (Endo et al 1978; Sefa-Dedeh and Stanley 1979; Silva and Luh 1978, 1979). After fours days of germination, surfaces of some starch granules in the legume flour samples became rough (Fig. 1B, D, and F). Silva and Luh (1978, 1979) and Endo et al (1978) also observed similar structural alteration in starch granules of germinating legumes. Repeated SEM observations indicated that the modification of starch granule surface in the germinated pea and lentil samples was greater than that in the germinated faba bean samples.

Starch Pasting Properties

The initial pasting temperatures of the legume flours were higher than those of their corresponding starch fractions (Table II). The values decreased after germination except for the faba bean flour. Lentil and yellow pea starches showed higher pasting temperatures than those of faba bean starches, in agreement with the data obtained by Naivikul and D'Appolonia (1979). Germination affected the pasting properties of lentil and yellow pea flours but had little or no effect on those of faba bean flour. The decrease in starch granule resistance to swelling for germinated peas and lentils may have been caused by increased amylase activity during germination (Table I). Since the α-amylase activity of faba bean did not increase substantially during germination, little change in starch properties was expected.

The ungerminated legume flours and their starches did not show any maximum viscosity at 95°C, but rather a continuous increase

TABLE II
Amylograph Characteristics of Ungerminated and Germinated Legume Flours and Their Starch Fractions

Legume	Sample	Pasting Temperature (°C)	Height at 95°C (BU)	15-min Height (BU)	Height at 50°C (BU)
Control (wheat flour)		67.0	290	220	510
Faba bean					
Ungerminated	Flour	75.3	230	280	450
	Starch	68.0	1,310	1,320	2,500
Germinated	Flour	76.0	80	120	210
	Starch	70.8	1,440	1,480	2,180
Lentil					
Ungerminated	Flour	74.5	215	225	400
	Starch	71.5	1,520	1,520	2,480
Germinated	Flour	70.8	190	140	170
	Starch	71.5	1,570	1,480	2,180
Yellow pea					
Ungerminated	Flour	76.0	180	220	350
	Starch	73.8	1,220	1,220	2,000
Germinated	Flour	73.8	300	280	325
	Starch	73.8	1,210	1,210	1,450

TABLE III
Mixograph Characteristics of Wheat Flour-Legume Starch Blends

Legume	Starch Replacement Level (%)	Mixing Time (min)	Center of the Curve at Peak (unit)	Water Absorption (%)
Control (100% wheat flour)		4:20	5.50	68.0
Ungerminated				
Faba bean	3.5	4:40	5.50	68.0
	7.0	5:10	5.20	67.0
	14.0	5:40	4.50	65.5
Lentil	3.5	4:20	5.50	68.0
	7.0	5:30	5.10	69.5
	14.0	5:50	4.50	71.0
Yellow pea	3.5	4:20	5.50	68.0
	7.0	4:30	5.10	69.0
	14.0	5:20	4.50	70.0
Germinated				
Faba bean	3.5	4:00	5.20	68.0
	7.0	3:40	5.30	68.0
	14.0	3:40	5.30	70.0
Lentil	3.5	4:40	5.50	68.0
	7.0	4:40	5.10	69.5
	14.0	5:40	4.50	72.0
Yellow pea	3.5	4:50	5.50	68.0
	7.0	4:50	5.10	69.0
	14.0	5:50	4.50	72.0

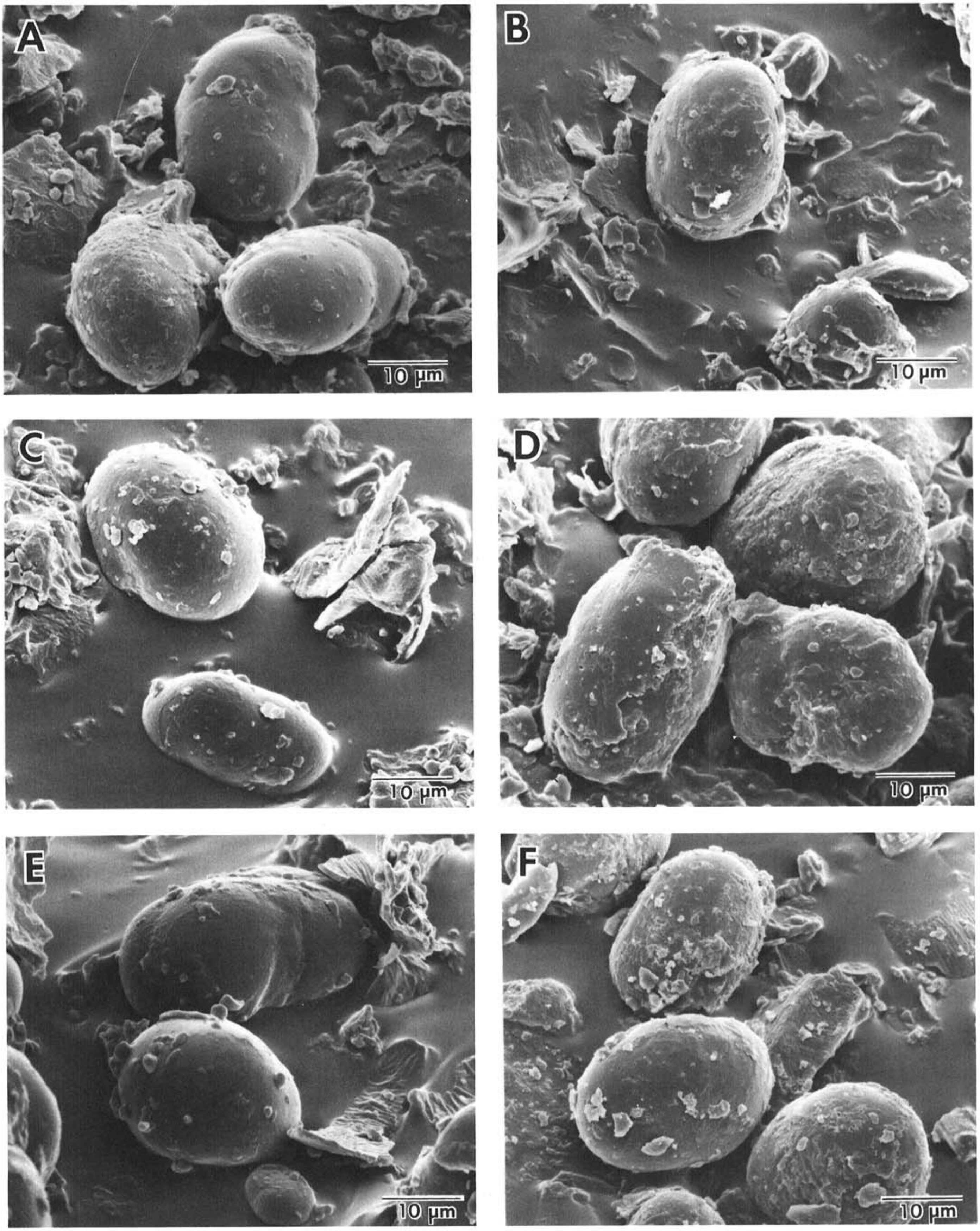

Fig. 1. Scanning electron micrographs of starch granules in: **A,** faba bean flour; **B,** germinated faba bean flour; **C,** yellow pea flour; **D,** germinated yellow pea flour; **E,** lentil flour; and **F,** germinated lentil flour.

in viscosity throughout the heating period. Similar findings were reported by D'Appolonia (1977), Sosulski and Youngs (1979), Lai and Varriano-Marston (1979), Lineback and Ke (1975), Kawamura (1969), McEwen et al (1974), and Naivikul and D'Appolonia (1979) for different legume starches. On the other hand, the germinated legume flours and their starch fractions showed peak viscosity at 95° C. This indicates that germination of the legumes resulted in decreased resistance of the starch granules to swelling. The effect on faba beans was less pronounced than that on peas and lentils (Table I). The restricted swelling pattern and stable hot-paste consistency obtained with legume starches could also be explained by their high amylose contents (Table I). Lineback and Ke (1975) stated that the shapes of the amylogram curves of the various legume starches during the holding period at 95° C are similar (no peak viscosity), indicating that the pastes are relatively stable and that the granules do not rupture during stirring. This is not the case with wheat starches (Medcalf and Gilles 1966).

A continual increase in the peak height after cooling occurred for all the starch fractions isolated from germinated and ungerminated legumes. Similar values were obtained with both faba bean and lentil, but the value for yellow pea was low. The 50° C heights of the starch fractions isolated from germinated legume were lower than the values obtained from the ungerminated samples. This indicates changes in the starch granules during germination because of increased enzyme activity. The decrease in viscosity was small for faba bean and lentil, but large for yellow pea (Table I). Naivikul and D'Appolonia (1979) suggested that faba bean, lentil, and mung bean might change the staling properties of bread because of the marked increase in viscosity during the cooling stage.

Physical Dough Tests

The mixograph characteristics and the mixograms that reflect the dough properties of the commercial straight grade control flour and the legume starch fractions-wheat flour blends are shown in Table III and Fig. 2. Water absorption increased as the supplementation level increased except for the ungerminated faba bean starch fraction. At 14% replacement, the starch fractions from germinated legumes absorbed more water than did those from the ungerminated legumes. This observation contrasts with the results we previously reported (Hsu et al 1980) for the germinated and ungerminated legume flours. The results of the present study emphasize the role of starch and germination in increasing water absorption of dough. Recently Hsu et al (1980) found that germinated lentil flour blends absorbed slightly more water than did the ungerminated samples, as indicated by the mixograph.

Mixogram peak mixing time increased with increases in supplementation level of all legume starches except germinated faba bean starch (Fig. 2). The height of the mixogram peak, which indicates flour strength, remained unchanged at 3.5% supplementation. The peak height decreased with further increases in supplementation level of starches except for starches from faba bean. Larsen (1964) showed that starch and its hydration properties play an important role in dough development.

Baking Studies

The data obtained from comparative baking studies on wheat flour supplemented with starch fractions from germinated and ungerminated legumes at 5, 10, 15, and 20% levels are shown in Table IV and Fig. 3. No appreciable change in baking absorption occurred when pea, lentil, or faba bean starches replaced wheat flour at the 5 and 10% levels in the U.S. type of straight dough bread. At 15 and 20% supplementation, baking absorption increased slightly for faba bean starches and more for lentil and yellow pea starches. Our previous study (Hsu et al 1980) indicated a decrease in baking absorption with increasing level of supplementation when the germinated and ungerminated flour of the same legumes were used. Again, the results in the present study show that the legume starches tended to absorb more water than did the whole legume flours.

Loaf volumes did not change appreciably with 5% legume starch supplementation for either ungerminated or germinated samples (Table IV and Fig. 3). Loaf volumes decreased with further increases in level of supplementation. With germinated samples, the loaf volumes were smaller than those of the ungerminated ones. Germination affected the baking properties of yellow pea starches

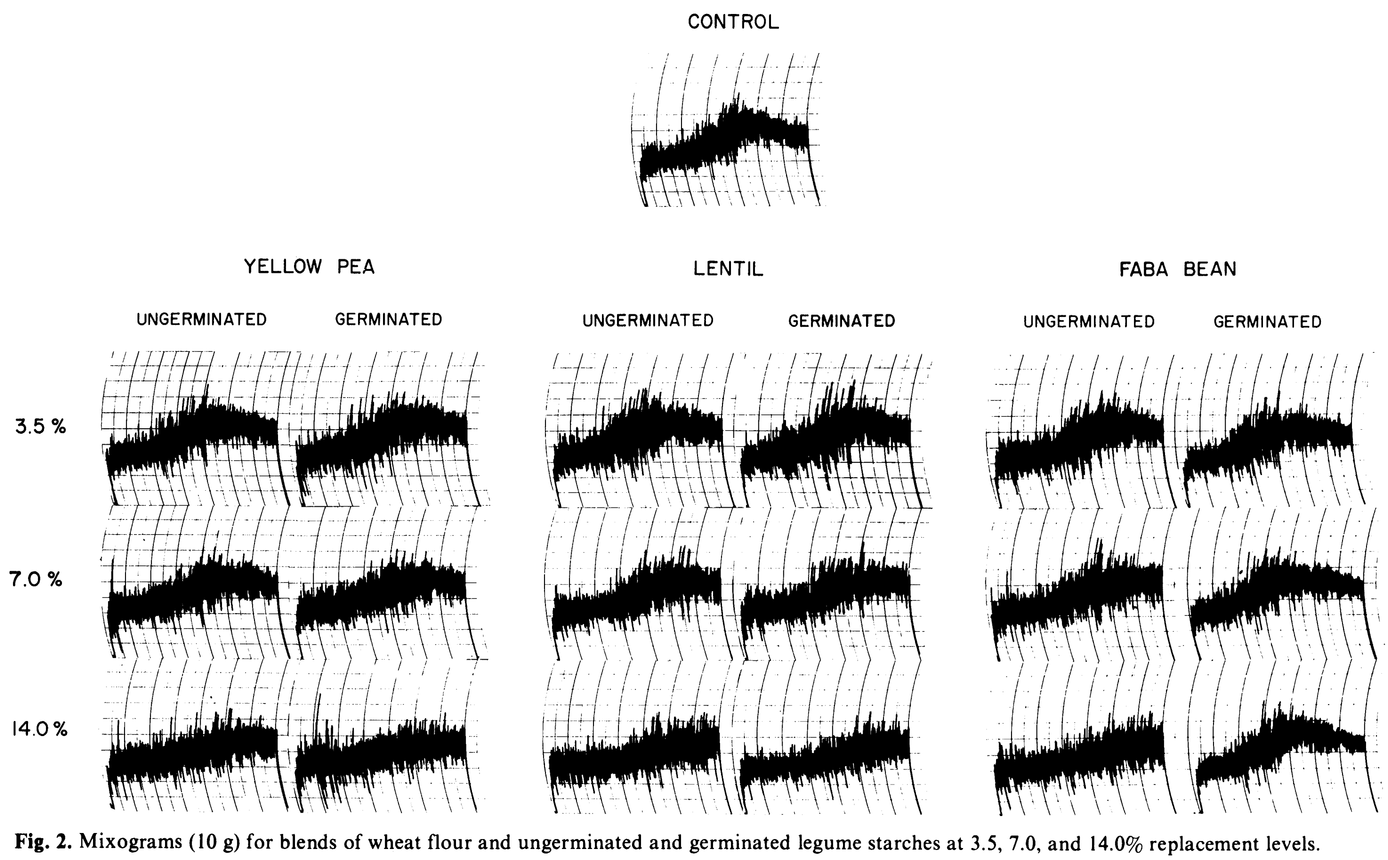

Fig. 2. Mixograms (10 g) for blends of wheat flour and ungerminated and germinated legume starches at 3.5, 7.0, and 14.0% replacement levels.

TABLE IV
Baking Data of Wheat Flour Supplemented with Legume Starches

Starch Sample	5: Baking Absorption[a] (%)	5: Loaf Volume (cc)	5: Crumb Grain[b]	10: Baking Absorption[a] (%)	10: Loaf Volume (cc)	10: Crumb Grain[b]	15: Baking Absorption[a] (%)	15: Loaf Volume (cc)	15: Crumb Grain[b]	20: Baking Absorption[a] (%)	20: Loaf Volume (cc)	20: Crumb Grain[b]
Control (commercial standard)	65.7	97	S	65.7	95	S	65.7	94	S	65.7	95	S
Faba bean												
Ungerminated	65.7	93	S	65.7	83	S	65.7	71	Q-S	66.7	62	Q
Germinated	64.7	96	Q-S	64.7	80	S+	65.7	65	Q-S	66.7	60	Q-U
Lentil												
Ungerminated	65.7	95	Q-S	65.7	82	Q-S	66.7	70	Q	68.7	67	Q
Germinated	65.7	92	Q-S	65.7	85	Q-S	66.7	65	Q	68.7	60	Q
Yellow pea												
Ungerminated	65.7	102	Q-S	65.7	88	S	66.7	71	Q-S	68.7	70	Q-S
Germinated	65.7	95	Q-S	65.7	85	S	66.7	61	Q-U	68.7	53	Q

[a] 14% mb.
[b] S = satisfactory, Q = questionable, U = unsatisfactory.

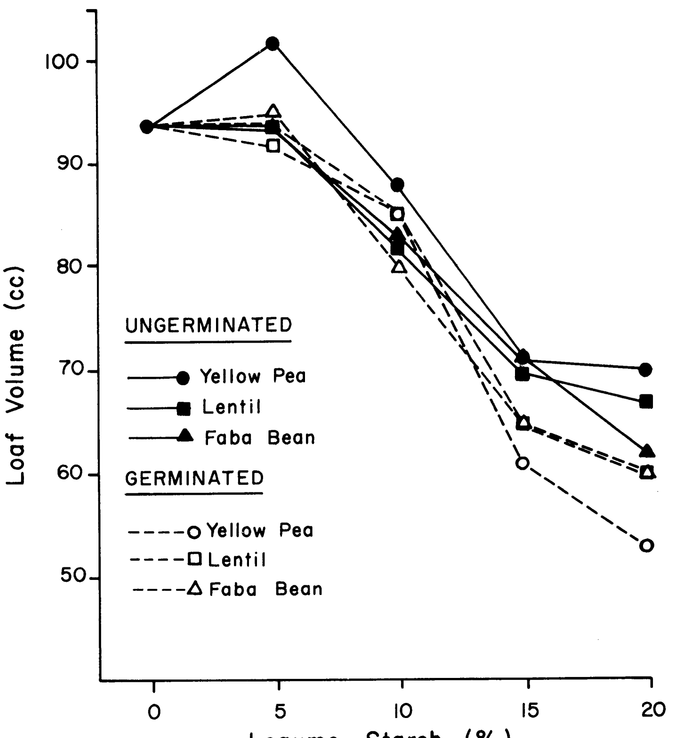

Fig. 3. Effect of legume starch replacement on loaf volume of bread.

more than those of lentil and faba bean starches.

The crust color of the breads decreased in darkness with increased level of supplementation in all cases. This was probably because of the low reducing sugar and protein contents of the starch fractions (Table I). The crust color at 10, 15, and 20% legume starch supplementation were pale.

Crumb grain was inferior to that of the control loaf at all levels of lentil starch supplementation; it was acceptable for starches from ungerminated and germinated yellow peas and faba beans at 5 and 10% supplementation. No off-flavor, beany odor, or bitterness was detected in breads supplemented with starch fractions of the germinated and ungerminated legumes. The components responsible for off-flavor were probably leached out during the preparation of the starch fractions.

CONCLUSIONS

Ash, starch, amylose, and nonreducing sugars of the legume flours decreased after germination, whereas the reducing sugars and water hydration capacity increased. The α-amylase activity of the legume flours increased about 8.1 times for yellow peas, 2.4 times for lentils, and 1.5 times for faba beans after germination. The different increases in α-amylase activity from germination of the three legumes were consistent with the degrees of starch degradation, as reflected in the starch pasting properties.

Replacement of 10, 15, and 20% wheat flour by the legume starches generally resulted in decreased loaf volume, inferior crumb grains, and pale crust. However, no off-flavor or odor was detected in the breads. Loaf volume was smaller for the germinated legume starches than for the ungerminated legume starches. Germination appeared to have more deleterious effects on the bread-making properties of yellow pea starches than on those of lentil and faba bean starches. The results of this study indicate that the physicochemical changes in legume starches caused by germination are mainly responsible for the deleterious effects of germinated legume flours on bread-making properties as reported in our previous study.

ACKNOWLEDGMENT

We thank David Bentley of the Electron Microscope Center, Washington State University, for his technical assistance and valuable suggestions. This work was partially supported by a grant from the Dumas Seed Co., Moscow, ID.

LITERATURE CITED

ALLEN, J. E., HOOD, L. F., and CHABOT, J. F. 1977. Effect of heating on the freeze-etch ultrastructure of hydroxypropyl distarch phosphate and unmodified tapioca starches. Cereal Chem. 54:783.

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1962. Approved Methods of the AACC. The Association: St. Paul, MN.

ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS. 1975. Official Methods of Analysis (12th ed.). The Association: Washington, DC.

BHATTY, R. S., and SLINKARD, A. E. 1979. Composition, starch properties and protein quality of lentil. J. Inst. Can. Sci. Technol. Aliment. 12(2):88.

D'APPOLONIA, B. L. 1977. Rheological and baking studies of legume-wheat flour blends. Cereal Chem. 54:53.

ENDO, K., SUGIMOTO, Y., TAKAYA, T., and FUWA, H. 1978. Scanning electron microscopic observations of starch granules of mung bean cotyledons during germination. J. Jpn. Soc. Starch Sci. 25(1):24.

FINNEY, K. F., and SHOGREN, M. D. 1972. A ten-gram mixograph for

determining and predicting functional properties of wheat flours. Bakers Dig. 46(2):32.
FUWA, H., SUGIMOTO, Y., and TAKAYA, T. 1979. Scanning electron-microscopy of starch granules, with or without amylase attack. Carbohydr. Res. 70:233.
HALL, D. M., and SAYRE, J. G. 1971. A scanning electron microscope study of starches. III. Miscellaneous starches. Textile Res. J. 41:880.
HSU, D., LEUNG, H. K., FINNEY, P. L., and MORAD, M. M. 1980. Effect of germination on nutritive value and baking properties of dry peas, lentils and faba beans. J. Food Sci. 45:87.
JEFFERS, H. C., RUBENTHALER, G. L., FINNEY, P. L., ANDERSON, P. D., and BRUINSMA, B. L. 1978. Pea: A highly functional fortifier in wheat flour blends. Bakers Dig. 51(5):36.
JULIANO, B. 1971. A simplified assay for milled rice amylose. Cereal Foods World 16:334.
KAWAMURA, S. 1969. Studies on the starches of edible legume seeds. J. Jpn. Soc. Starch Sci. 17:19.
KAWAMURA, S., TUBOI, Y., and HUZII, T. 1955. Studies on legume starches. I. Microscopic observation on the granules of starches from some Japanese legumes. Tech. Bull. Kagawa Agric. Coll. 7:87.
LAI, C. C., and VARRIANO-MARSTON, E. 1979. Studies on the characteristics of black bean starch. J. Food Sci. 44:528.
LARSEN, R. A. 1964. Hydration as a factor in bread flour quality. Cereal Chem. 41:181.
LEACH, H. W. 1965. Gelatinization of starch. Page 289 in: Whistler, R. L., and Pashcall, E. F., eds. Starch Chemistry and Technology, Vol. I. Academic Press: New York.
LINEBACK, D. R., and KE, C. H. 1975. Starches and low-molecular-weight carbohydrates from chick pea and horsebean flours. Cereal Chem. 52:125.
LORENZ, K. 1979. The starch of the faba bean (Vicia faba). Staerke 31:181.
McEWEN, T. J., McDONALD, B. E., and BUSHUK, W. 1974. Faba bean (Vicia faba minor)—Physical, chemical and nutritional properties. Proc. IV Int. Cong. Food Sci. and Technol. 5:40.
MEDCALF, D. G., and GILLES, K. A. 1965. Wheat starches. I. Comparison of physico-chemical properties. Cereal Chem. 42:558.
MEDCALF, D. G., and GILLES, K. A. 1966. Effect of lyotropic ion series on the pasting characteristics of wheat and corn starches. Staerke 18:101.
MILLER, B. S., DERBY, R. I., and TRIMBO, H. B. 1973. A pictorial explanation for the increase in viscosity of heated wheat starch-water suspension. Cereal Chem. 50:271.
NAIVIKUL, O., and D'APPOLONIA, B. L. 1979. Carbohydrates of legume flours compared with wheat flour. II. Starch. Cereal Chem. 56:24.
ROCKLAND, L. B., and JONES, F. T. 1974. Scanning electron microscope studies on dry beans. Effect of cooking on the cellular structure of cotyledons in rehydrated large lima beans. J. Food Sci. 39:342.
SAMUEL, K., DAVID, W. S., ROGERNALD, J., and CHARLES, C. H. 1977. Air classification of bean flour. J. Food Process. and Preserv. 1:69.
SCHOCH, T. J., and MAYWALD, E. C. 1968. Preparation and properties of various legume starches. Cereal Chem. 45:564.
SEFA-DEDEH, S., and STANLEY, D. W. 1979. Microstructure of cowpea variety Adua Ayera. Cereal Chem. 56:367.
SHOGREN, M. D., FINNEY, K. F., and HOSENEY, R. C. 1969. Functional (breadmaking) and biochemical properties of wheat flour components. I. Solubilizing gluten and flour protein. Cereal Chem. 46:93.
SILVA, H. C., and LUH, B. S. 1978. Scanning electron microscopy studies on starch granules of red kidney beans and bean sprouts. J. Food Sci. 43:1405.
SILVA, H. C., and LUH, B. S. 1979. Changes in oligosaccharides and starch granules in germinating beans. Can. Inst. Food Sci. Technol. J. 12(3):103.
SOSULSKI, F. W., CHAKRABORTY, P., and HUMBERT, E. S. 1978. Legume-based imitation and blended milk products. Can. Inst. Food Sci. Technol. J. 11(3):117.
SOSULSKI, F. W., and FLEMING, S. E. 1979. Sensory evaluation of bread prepared from composite flours. Bakers Dig. 53(3):20.
SOSULSKI, F. W., and YOUNGS, C. G. 1979. Yield and functional properties of air-classified protein and starch fractions from eight legume flours. J. Am. Oil Chem. Soc. 56:292.
SWAIN, R. R., and DEKKER, E. E. 1966. Seed germination studies. I. Purification and properties of an α-amylase from the cotyledons of germinated peas. Biochim. Biophys. Acta 122:75.
VOSE, J. R., BASTENECHEA, M. J., GORIN, P. A., FINLAYSON, A. J., and YOUNGS, C. G. 1976. Air classification of field peas and horsebean flours: Chemical studies of starch and protein fractions. Cereal Chem. 53:928.
WHELAN, W. G. 1964. Hydrolysis with α-amylase. Page 253 in: Whistler, R. L., ed. Methods in Carbohydrate Chemistry, Vol. IV. Academic Press: New York.
YOUNG, J. L., and VARNER, J. E. 1959. Enzyme synthesis in the cotyledons of germinating seeds. Arch. Biochem. Biophys. 84:71.

[Received March 14, 1980. Accepted June 5, 1980]