High-Temperature Short-Time Extrusion Cooking of Wheat Starch and Flour. II. Effect of Protein and Lipid on Extrudate Properties[1]

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ABSTRACT

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The role of lipid and protein in the extrusion cooking of wheat starch and flour was studied. Effects caused by protein depended on protein type and concentration. When added to wheat starch at concentrations up to 11%, wheat gluten reduced expansion and texture. The ultrastructure of starch-plus-gluten extrudates changed gradually from starchlike to flourlike as gluten content increased. A specific gluten concentration could not be identified as the border between starchlike and flourlike structures. At equivalent concentrations, soy protein isolate increased expansion and texture. Textural measures increased even after expansion began to decrease at the highest soy concentration tested. At and above 5% soy protein isolate, starch extruded to produce ultrastructures different from both starch and flour. Removing free-flour lipids increased extruded flour texture and expansion. Adding flour lipids to all materials tested resulted in decreased extrudate expansion and texture. The magnitude of the changes depended on the material extruded. Changes in ultrastructure caused by adding or removing lipids were subtle and did not always reflect expansion and textural changes observed in the same sample.

The importance high-temperature short-time extrusion cooking as a means of processing cereal starches and flours into a wide variety of products is well documented (Smith 1976, Williams et al 1977). Likewise, the use of extrusion for texturization of oilseed proteins has been treated extensively in the literature (Cabrera et al 1979, Gueriviere et al 1978). A dearth of published information, however, exists on the effects of cereal flour components on the characteristics of the extruded product. Williams and Baer[4] reported that extruded flour was unable to achieve the expansion of a starch extrudate. More recently, Faubion and Hoseney (1982) established that wheat starch and flour extrude to produce different structures in the extrudate. When these materials were extruded at increasing moisture contents, changes in their expansion, texture, and ultrastructure differed. Results of that work also suggested that the quantity of gluten present has more effect on the characteristics of a flour extrudate than does its origin (ie, soft vs hard wheat).

The four components of flour (starch, protein, lipid, and moisture) can be fractionated and recombined so that the role of each can be assessed in many food systems (Finney 1943). Furthermore, nonwheat counterparts of each component can be substituted for native wheat components. We studied the effect of protein and lipid on the expansion, texture, and ultrastructure of extruded wheat starch and flour.

MATERIALS AND METHODS

Starch

Prime wheat starch was obtained from Midwest Solvents Co., Inc., Atchison, KS.

Flours

Medium-protein hard winter and high-protein hard wheat flours were the same as those used previously (Faubion and Hoseney 1982).

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[4] M. A. Williams and S. Baer. 1965. Introduction to grain expansion. Presentation to the American Society of Agricultural Engineers. December, 1965.

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Proteins

Vital wheat gluten was obtained from Midwest Solvents Co., Inc., Atchison, KS. Its protein content was 74.4%. Soy protein isolate (Edi-Soy brand) with a protein content of 90.2% (N × 6.25, db) was obtained from Ralston Purina Inc., St. Louis, MO.

Lipids

Dur-Em 114, a commercially available blend of monoglycerides and diglycerides was obtained from Durkee Foods Inc., Strongsville, OH.

Moisture and Lipid Determination

The moisture and lipid contents of materials to be extruded were determined according to AACC (1976) methods 44-19 and 30-25, respectively.

Tempering

The final moisture content of materials to be extruded was adjusted as described by Faubion and Hoseney (1982). For materials previously defatted, hydration in a humidified cabinet to approximately 17% moisture preceded final tempering.

Lipid Extraction and Recovery

Free flour lipids were extracted (Soxhlet) with petroleum ether (boiling range 35–60° C). Samples of 400 g of flour were extracted for 24 hr, with heating adjusted to allow a complete change of solvent every 30 min. After solvent had been removed from samples by vacuum evaporation, extracted lipids were stored at 4° C in flasks flushed with N_2.

Defatted materials were recovered by vacuum filtration, washed twice with 200 ml of extracting solvent, and air-dried at room temperature until solvent odor was no longer noticeable.

Reconstitution

Reconstituted flours were created by combining, on a 14% moisture basis, wheat flour or starch and the required components in amounts sufficient to produce the desired final concentrations. The ingredients were blended by continuous shaking in an inflated plastic bag for a minimum of 10 min.

Lipid Added to Starch or Flour

To assure uniform incorporation of lipid, a premix was prepared by placing 100 g of flour or starch and the necessary amount of lipid in a Stein mill (Fred Stein Laboratories, Atchison, KS) and grinding the mixture for 30 sec. The premix was added to a plastic bag containing the remaining material, and the bag was inflated and shaken for 10 min to ensure complete incorporation.

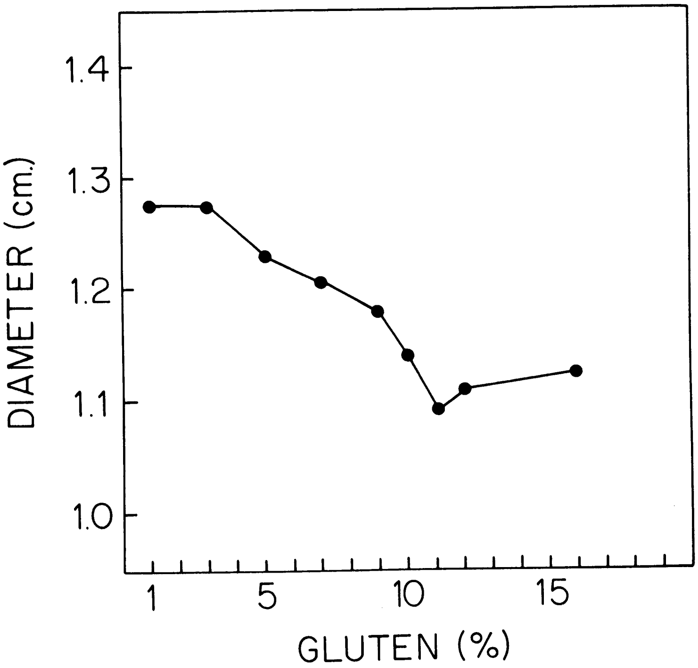

Fig. 1. Diameter of extruded starch supplemented with gluten vs. percentage of gluten in the feed material.

Extrusion Cooking

Extruder operating conditions, specifications, and sample collection procedures were as previously reported (Faubion and Hoseney 1982).

Extrudate Analysis

Samples of all materials extruded were analyzed for expansion, texture, and ultrastructure by the methods of Faubion and Hoseney (1982).

RESULTS AND DISCUSSION

Starch Plus Gluten

Expansion. Though the type or source of gluten is of little consequence in determining the characteristics of extruded flour, large differences in protein content (9 vs 15%) were found to be important (Faubion and Hoseney 1982). That fact prompted us to design a study to examine, in more detail, the effects of gluten on a starch system. A series of reconstituted flours were compounded from prime wheat starch plus vital wheat gluten in amounts of 1–16%. Those flours were then tempered to 19% moisture and extruded. Expansion of the extruded starch plus gluten decreased steadily as gluten content increased from 1 to 11% (Fig. 1). At low gluten concentrations (1–3%), expansion was equivalent to pure starch extruded at 19% moisture. Above 3% gluten, expansion declined to a minimum at 11% gluten. Even at that minimum, expansion exceeded that of hard wheat flour of the same protein content. Above 11% gluten, expansion increased and, at 16%, was equivalent to that of the 9% gluten sample. At and above 13% gluten, surging made collecting uniform samples difficult.

Power Consumption. The power required to extrude the starch-plus-gluten mixtures followed a U-shaped curve (Table I). Reconstituted, low-protein flours required approximately the same power for extrusion as did pure starch. With increasing gluten content, power requirements decreased up to a minimum value (5.2 A at 11% protein) that was substantially higher than the 4.5 A required to extrude a native 11% protein flour. Power consumption increased sharply above 12% protein and approached the capacity of the extruder at higher protein levels.

Texture. Results of shearing and breaking strength tests are presented in Fig. 2. Both textural measurements decreased as the amount of gluten in the extrudate increased. Low levels (1–3%) of supplementation produced breaking strengths near that of extruded starch.

Shearing strengths, even at the low supplementation levels, were greater than those for native flour. They were, however, much lower than those for pure starch values. Those textural changes occurred before noticeable changes in ultrastructure or expansion were found. Supplementation at 5% gluten gave shear strengths equal to those of low-protein, hard wheat flour, despite the fact that the gluten-plus-starch sample had greater expansion. As with shearing strength, minimum breaking strength was at 12% gluten.

TABLE I
Amperage Required to Extrude Starch-Gluten

Gluten (%)	Amperage
1	6.3
3	6.0
5	6.0
7	5.7
10	5.5
11	5.2
12	7.5
14	9.5
16	13.0+

Ultrastructure. As gluten content was increased from 1 to 16%, extrudate ultrastructures did not undergo sharp changes. Rather, subtle changes accumulated gradually and could be observed only by viewing several samples. The result was a gradual change from starchlike to flourlike ultrastructure.

At 1 and 3% gluten, structures mimicked those of pure wheat starch (Faubion and Hoseney 1982), with large, smooth-walled cells predominating. As gluten levels reached 5 and 8% (Fig. 3A and B), regions of smaller cells began to appear with roughened or torn cell walls. These are characteristic structural differences between extruded starch and flour. Figure 3 (A and B) also illustrates the difficulty in interpreting structural differences; a difference of 3% protein shows only subtle differences.

At 9 and 11% gluten, extrudate unltrastructure was similar to that previously described for extruded hard or soft wheat flour (Faubion and Hoseney 1982). Cell sizes varied, with pockets of large and small cells randomly intermingled. As with native flour, the proportion of large and small cells varied among samples. At this protein level (9 and 11%), the roughened and torn cell walls characteristic of flour became evident.

The highest protein levels tested (15 and 16%) produced extrudates that mimicked the high-protein wheat flour. Cell size was smaller than extruded starch, and cell walls were extremely rough. Cell walls had extensive regions of failure or shredding (Fig. 3C), as did the high-protein flour extrudates. In many high-protein samples, cell wall material bridged the cell (Fig. 3D). High magnification showed this to be fibrous material containing embedded remnants of starch granules. Such fibrous material was also evident on the surfaces of cell walls.

Starch Plus Soy Protein Isolate

Expansion. Extrudates containing 10–11% added gluten did not expand well and gave texturally weak products. Those results prompted us to test the generality of those observations. Soy protein isolate (SPI), widely used in foods, was chosen as an alternative nonwheat protein to use in combination with wheat starch. Because of its hydrophilicity, SPI could not be extruded at 19% moisture. Tempering to 20.5% allowed extrusion to proceed, although power requirement was high (7–10 A).

Expansion of starch-plus-SPI mixtures (Fig. 4) was excellent, and the response to increased protein concentration was the reverse of that found for gluten. Expansion increased as the level of SPI was increased from 1 to 8%. At those levels, expansion was above that of pure starch. Even though expansion decreased at the highest level tested (10%), it was still 35% greater than that for extruded wheat flour at approximately the same protein content.

Texture. Shearing and breaking strengths (Fig. 5) of starch-plus-SPI were determined. Shearing strengths at 1 and 3% protein were slightly below those for equivalent starch-plus-gluten samples. In direct contrast with starch-plus-gluten extrudates, shearing strengths increased with increased protein content. Breaking strength increased as protein increased, reaching levels near that of pure starch and twice that of extruded hard wheat flour. Interestingly, both measures of the textural strength continued to increase even after expansion of starch plus SPI had peaked and started to decline.

Ultrastructure. Starch-plus-SPI extrudates were different in their internal structures from those of starch or flour (Fig. 6). At

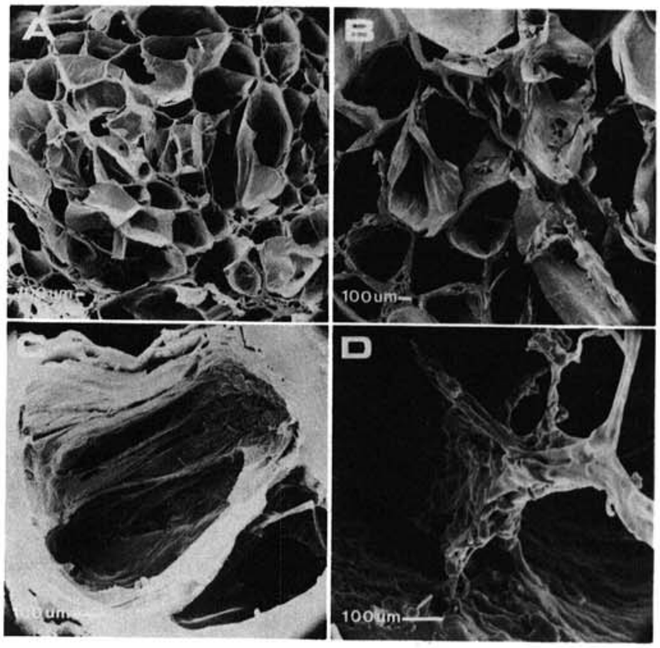

Fig. 3. Scanning electron micrographs of extruded starch plus gluten. **A,** starch plus 5% gluten; **B,** starch plus 8% gluten; **C** and **D,** starch plus 16% gluten. Initial moisture content of all samples, 19%.

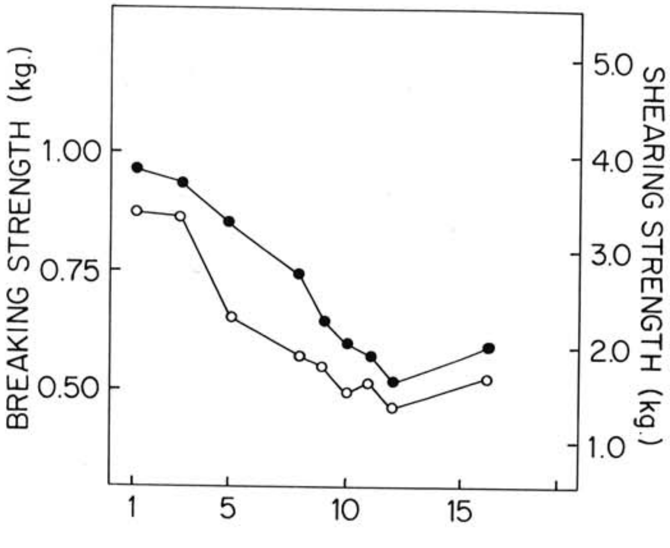

Fig. 2. Shearing and breaking strengths of extruded starch supplemented with gluten vs percentage of gluten in the feed material. ● = shearing strength, o = breaking strength.

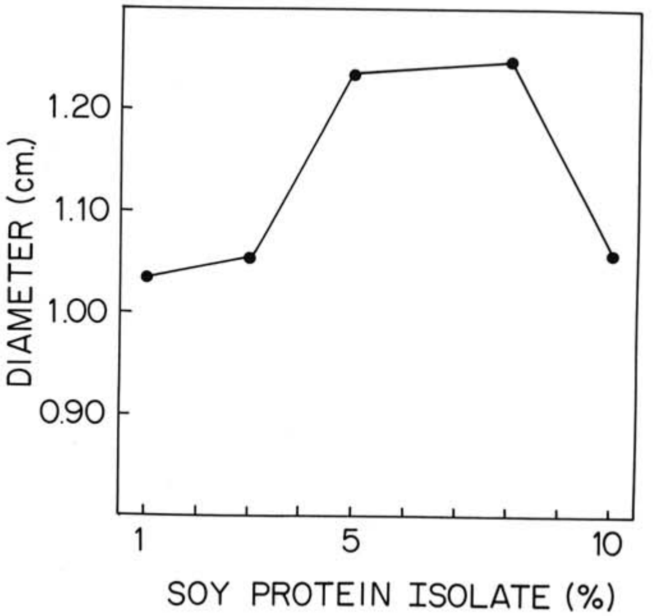

Fig. 4. Diameter of extruded starch supplemented with soy protein isolate vs percentage of soy in the feed material.

1%, extrudates resembled pure starch in cell size, distribution, and morphology. At and above 5% SPI, extrudate cells were larger in size and few in number (Fig. 6A). They appeared shallow rather than deep. The cell walls were not rough but were smooth or rippled, appearing similar to pure starch extrudates. Fibrous material was not evident in the cell walls (Fig. 6B). Despite the fact that expansion decreased at 10% SPI, extrudate ultrastructure was similar to that of starch supplemented with 5 or 8% SPI. The 10% soy extrudate was distinguishable only by its smaller diameter.

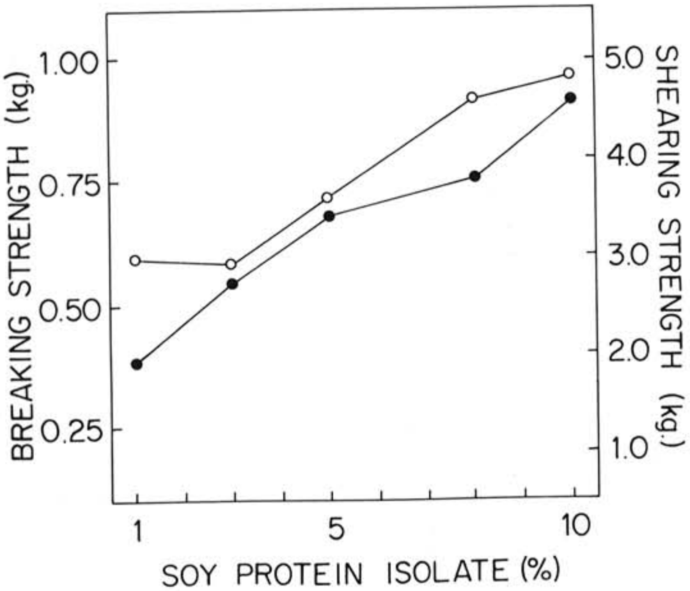

Fig. 5. Shearing and breaking strengths of starch supplemented with soy protein isolate vs percentage of soy in the feed material. ● = shearing strength, o = breaking strength.

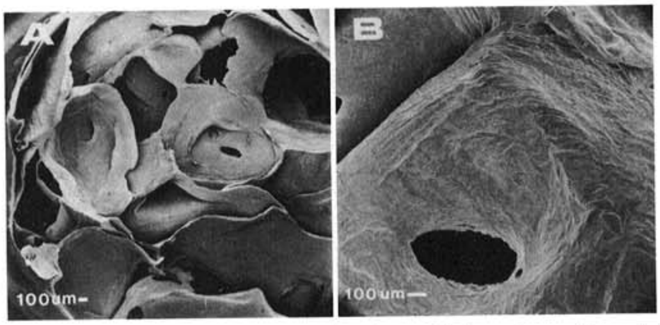

Fig. 6. Scanning electron micrographs of extruded starch supplemented with soy protein isolate. **A,** 8% soy; **B,** 5% soy. Initial moisture content of both samples, 20.5%.

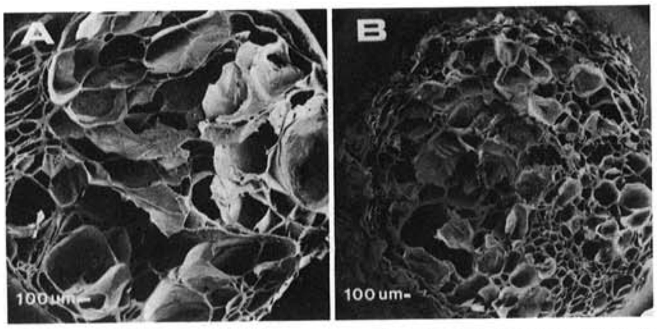

Fig. 7. Scanning electron micrographs of extruded defatted flour. **A,** defatted soft wheat flour; **B,** defatted high-protein flour.

Lipid

Expansion. Free lipids were removed from starch and flours by Soxhlet extraction (Table II). The expansion of defatted material is compared with that of their unextracted controls in Table III. Extracted starch did not change its expansion compared with that of unextracted starch. Adding 1% free flour lipids to starch decreased its expansion slightly. Defatted flour gave extrudates with increased expansion. The diameter of extracted low-protein hard wheat flour extrudates increased 28% (Table III). Defatted high-protein flour gave an 8.3% increase in extrudate expansion. Reconstituting either flour with lipids returned expansion to control levels. By exchanging the source of lipids and extruding the reconstituted flour (Table III), we observed that the differences were due to differences in the flour and not in the extracted lipids.

Texture. In general, the removal of free-flour lipids increased textural strength (Table IV). Likewise, reconstitution or adding of lipid decreased shearing and breaking strengths. The magnitude of these changes depended on the material extruded. Wheat starch,

TABLE II
Extraction of Free Lipids from Extruder Feed Materials

Material	Free Lipids (%, db)
Medium-protein hard wheat flour	1.01
High-protein flour	1.08
Prime wheat starch	0.01
Starch	
5% Soy protein isolate	0.05
11% Wheat gluten	0.14

TABLE III
Effect of Lipid Extraction and Reconstitution on Extrudate Properties

Material	Diameter (cm)	Percent of Control
Wheat starch	1.187	···
PE[a]-defatted	1.194	+0.586
Starch plus 1% medium-protein lipids	1.144	−3.64
Medium-protein flour	0.844	···
PE-defatted	1.075	+27.37
Reconstituted	0.860	+1.87
High-protein flour	0.987	···
PE-defatted	1.070	+8.39
Reconstituted	0.977	−1.02
PE medium-protein plus high-protein lipids	0.850	+0.70
PE high-protein plus medium-protein lipids	0.982	−0.506

[a] Petroleum ether.

TABLE IV
Effect of Lipid Source and Type on Texture of Extrudates

Material	Shear (kg)	Break (kg)	Percent of Control	
Wheat starch	5.51 (±0.19)	0.938 (±0.057)	···	···
PE[a]-defatted	5.51 (±0.10)	0.934 (±0.054)	···	99.57
Starch plus 1% medium-protein lipids	4.85 (±0.08)	0.844 (±0.060)	88.1	91.0
Medium-protein flour	2.56 (±0.14)	0.460 (±0.031)	···	···
PE-defatted	3.16 (±0.11)	0.543 (±0.040)	123.8	118.4
Reconstituted	2.53 (±0.11)	0.467 (±0.030)	98.77	98.41
High-protein flour	1.55 (±0.39)	0.404 (±0.081)	···	···
PE-defatted	2.77 (±0.42)	0.628 (±0.085)	172.3	155.3
Reconstituted	1.60 (±0.40)	0.405 (±0.079)	103.1	99.75
PE medium-protein plus high-protein lipids	2.68 (±0.08)	0.451 (±0.033)	104.71	98.0
PE high-protein plus medium-protein lipids	1.65 (±0.46)	0.409 (±0.085)	106.0	101.4

[a] Petroleum ether.

TABLE V
Effect of Lipids on the Expansion of Starch-Plus-Soy Protein

	Diameter (cm)	Isolate (percent change)
Starch, 5% soy	1.248	...
PE[a]-defatted	1.244	−0.32
1% Medium-protein lipids	1.130	−10.44
1% High-protein lipids	1.135	−10.42

[a] Petroleum ether.

TABLE VI
Effect of Lipid Source and Type on Texture of Extrudated Starch-Plus-Soy Protein Isolate

Material	Shear (kg)	Break (kg)	Percent Control	
Starch plus 5% soy	3.56 (±0.27)	0.688 (±0.095)	...	...
PE[a]-defatted	3.49 (±0.22)	0.651 (±0.101)	98.7	96.1
1% Medium-protein lipids	2.81 (±0.29)	0.530 (±0.084)	79.1	77.0
1% High-protein lipids	2.85 (±0.29)	0.516 (±0.084)	80.0	75.4
1% Dur-Em	2.39 (±0.17)	0.482 (±0.80)	67.1	70.0

[a] Petroleum ether.

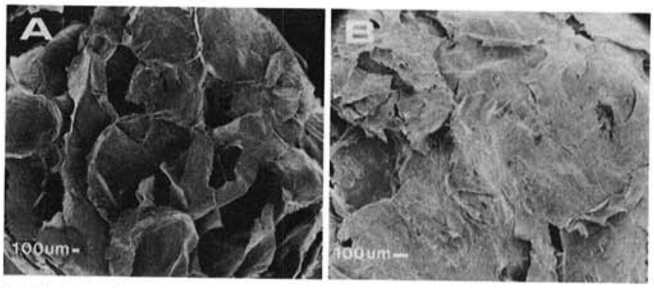

Fig. 8. Scanning electron micrographs of extruded starch plus 5% soy protein isolate supplemented with lipid. **A,** 1% free flour lipids; **B,** 1% Dur-Em 114. Initial moisture content, 20.5%.

which lost less than 5% in expansion upon adding 1% lipid, changed greatly in texture; shearing strength decreased 11.9%, and resistance to breaking nearly 10%.

Both defatted flours gave extrudates having greater textures than their unextracted controls (Table IV). With the high-protein flour, shearing and breaking strengths increased 72 and 55%, respectively. Extracted low-protein flours showed increases of 23 and 18% in shearing and breaking strength. Reconstitution of either flour with its extracted lipids returned textural measurements to control levels.

Ultrastructure. Reconstituting flours gave ultrastructures equivalent to those of their unextracted controls. Extraction of wheat starch had no effect on the ultrastructure of its extrudate. Defatting both low-protein hard and soft wheat flours gave similar changes in ultrastructure (Fig. 7). In extrudates from defatted flours, the internal structure was composed essentially of large cells. Sections completely devoid of small cells were not uncommon. The cell walls of extruded defatted flour were still rough and fibrous. Many larger cells had holes or tears, but whether the frequency or size of those holes differed between control and defatted extrudates could not be determined.

Extrudates from defatted, high-protein flour presented a confusing picture. Removing free lipids caused modest increases in expansion and large increases in texture. Only subtle changes were found in the structure of the defatted, high-protein flour extrudate (Fig. 7A). As with the other samples, cell walls were still rough.

Effect of Lipid on Starch-Plus-Soy Protein Isolate Expansion

Flour lipids were added to starch plus 5% SPI, and the resulting reconstituted flour was extruded (Table V). Adding flour lipids reduced expansion. The decrease was, however, only a third of that for similarly extracted hard wheat flour (10 vs 27%). Defatting did not affect expansion of starch plus 5% SPI.

Texture. Textural strength of starch plus 5% SPI did not change as a result of extraction (Table VI). Adding 1% flour lipids to starch plus 5% SPI resulted in reduced breaking and shearing strengths. The changes expressed as percentages of control were equivalent to the responses of hard wheat flour when extruded after defatting.

Ultrastructure. When 1% hard wheat flour lipids were added to starch plus 5% SPI, the arrangement and size of the cells making up the extrudate changed little, if at all (Fig. 8A). Cells were still large and shallow, with large expanses of cell wall material visible. The major change was in the surface of the cell walls. Rather than being smooth, as in control extrudates, walls were now roughened and often torn (Fig. 8B).

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