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Correlation of Product Quality of Extruded Sorghum Products to Extent of Starch Gelatinization[1]

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Abstract

A comparison was made of extrudes made from pure sorghum flour (L187), wheat flour (biscuit) and composites of the two flours containing various percentages of sorghum. The different parameters which were contrasted included expansion and density, mechanical strength (shear) and colour. Correlation of these properties to the extent to which starch was gelatinized at the extrusion temperature was made. Amount of gelatinized starch was monitored by Direct Scanning Calorimetry (D.S.C) in conjunction with Scanning Electron Microscopy (S.E.M). Results indicated that there is a direct relationship between extent of product expansion and extent of gelatinization, loss of shear with extent of gelatinization; increase in expansion with increased moisture content for sorghum products and decrease of colour (tannin content) with increased gelatinization. The ability of wheat and sorghum to gelatinize at different temperatures was identified as the main setback to production of good composite extrudes.

Key words: Sorghum, wheat, extrusion, Direct Scanning Calorimetry (D.S.C), Scanning Electron Microscopy (S.E.M)

Introduction

The importance of sorghum as a cereal to Africa can never be overemphasized, but sorghum use on the world market is still limited. Its colour, texture and off flavour still render many of its products unacceptable to the more affluent communities. Modern processing technology has been recommended for the processing of sorghum products so as to give it a place in the world market of instant foods and beverages (Novellie, 1976). Prior to this it was found that for many industrial and food applications, it was necessary to alter the properties of sorghum endosperm fractions by cooking them to different degrees of gelatinization. In that form sorghum products could take the place of corn (Anderson *et al* 1969). Extrusion cooking has to this end been found to be the most appropriate technology.

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It has also been reported that gelatinization changes physical properties of starch and affects their use (Chiang and Johnson, 1977). In fact, gelatinization properties of starches under extrusion cooking have been investigated by several workers including Anderson *et al* (1969) and Mercier *et al* (1979), but not much effort has been made to correlate extent of starch gelatinization to the physical properties of the resultant extruded product.

Methods of measuring total gelatinized starch have been listed and proposed by Chiang and Johnson (1977). In this particular research, however, Differential Scanning Colorimetry (D.S.C) was used in conjunction with Scanning Electron Microscopy (S.E.M) to determine the extent of gelatinization of starch obtained from pure wheat and sorghum extrudates. An attempt was then made to correlate this to the observed characteristics of the pure extrudates and composites obtained at the two temperatures of extrusion.

Materials and methods

Materials used

Sorghum flour was obtained by roller milling sorghum (L187), wheat flour was obtained from Allied Millers at Uxbridge, Composite flours were made by substituting biscuit flour with definite percentages of white sorghum flour (L187) as follows 10%, 20%, 30%, 40%, and 50% sorghum.

Extrusion

Extrusion of the above samples was performed in an APV Baker-Perkin co-rotated twin-screw extruder (model MP 50) under two operating conditions, barrel temperature 130 and 160°C, screw speed 350 rpm and feed moisture 20-28.6%. The feed rate was 555.6 g/min. Extruder specifications and screw configurations were as follows: barrel length 49½ inches spacer, total length of screw configuration 29½ inches; screw configuration ¼ inch spacer, 16 inch blank spacer, 14 inch feed screw, reversing paddles, 3 inch single lead screw, 4x60 degree reversing paddles, 2x1 single lead screw, die opening 3.0mm (each blank spacer, 4 inch length, paddle 0 = ½ inch length).

Expansion and Density

Expansion was determined by diameter/volume ratio for each sample and the plot against the percentage of sorghum incorporated was made in each case.

Mechanical strength (shear)

The shear was obtained using Stevens C.R. Analyzer, cell 50 kg speed setting 30mm/min., distance 20mm and a plot of average mechanical strength against composition was made.

Colour determination

This was based on the colour chart of the Royal Horticultural Society, London on Fan 4.

Differential Scanning Calorimeter (D.S.C)

A Perkin - Elmer D.S.C-7 differential scanning calorimeter was used. The calorimeter was purged with dry nitrogen gas. It was interfaced to a 380 Z micro computer via 13- bit analogue to a digital converter. This system allowed direct data reduction and analysis. The thermograms were obtained at a heating rate of 10 degrees C/min, over a nominal temperature range of 25°C to 125°C. The samples were equilibrated to 25°C for 1 min in each case. To 1g of each sample 2 mls of water were added in a sterilized bottle (sterilin) to give a sample/water ratio of 1:2.

The sample was intimately mixed with water and 5 to 10 mg of this mix were weighed into previously weighed D.S.C. pans. The sample pan was immediately automatically sealed, reweighed and scanned. Data obtained from the analysis included area, peak (T1 degrees C), onset (To degrees C), end (T2 degrees C) and Hg (Enthalpy).

Scanning Electron Microscopy (S.E.M.)

The dried starch samples were in each case adhered to a double sided adhesive tape attached to specimen stabs. They were coated *in vacuo* with approximately 60Å of carbon and then with 30mm of gold palladium. The samples were

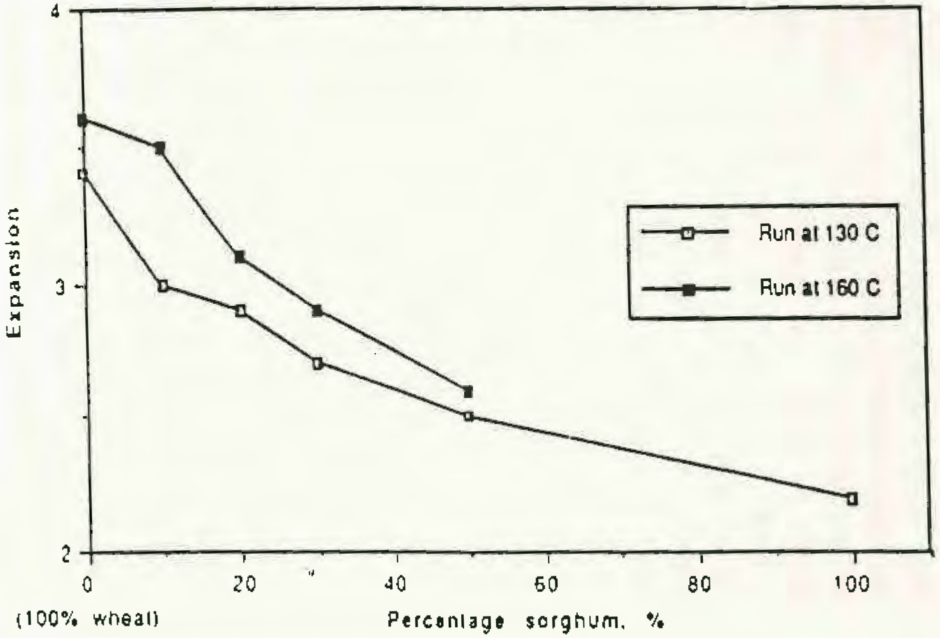


Figure 1: Plot of expansion against % sorghum content

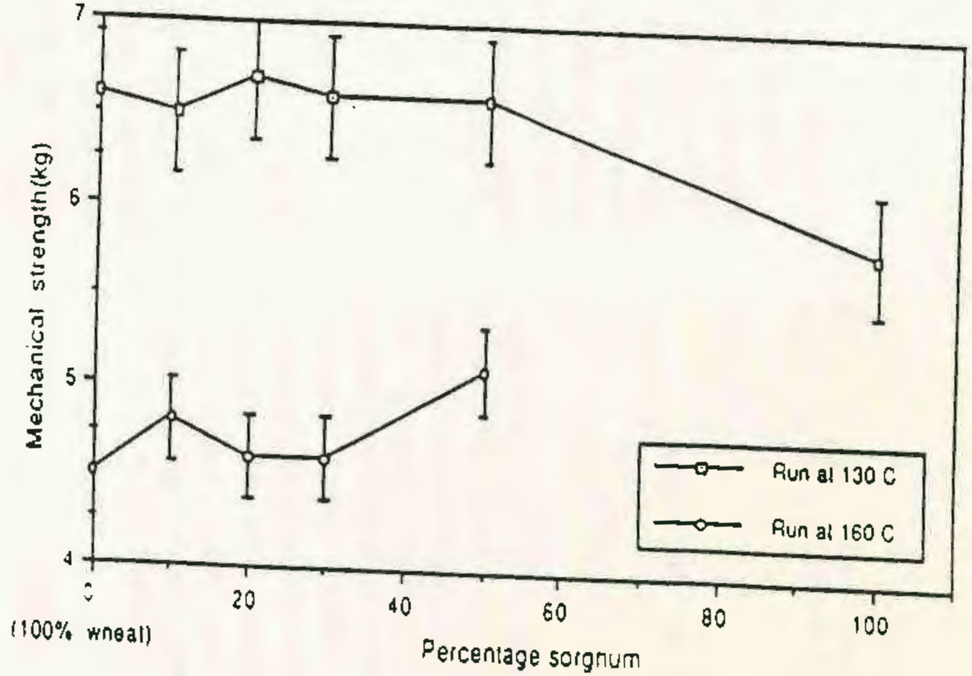


Figure 3: Plot of mechanical strength/shear (kg) against % sorghum

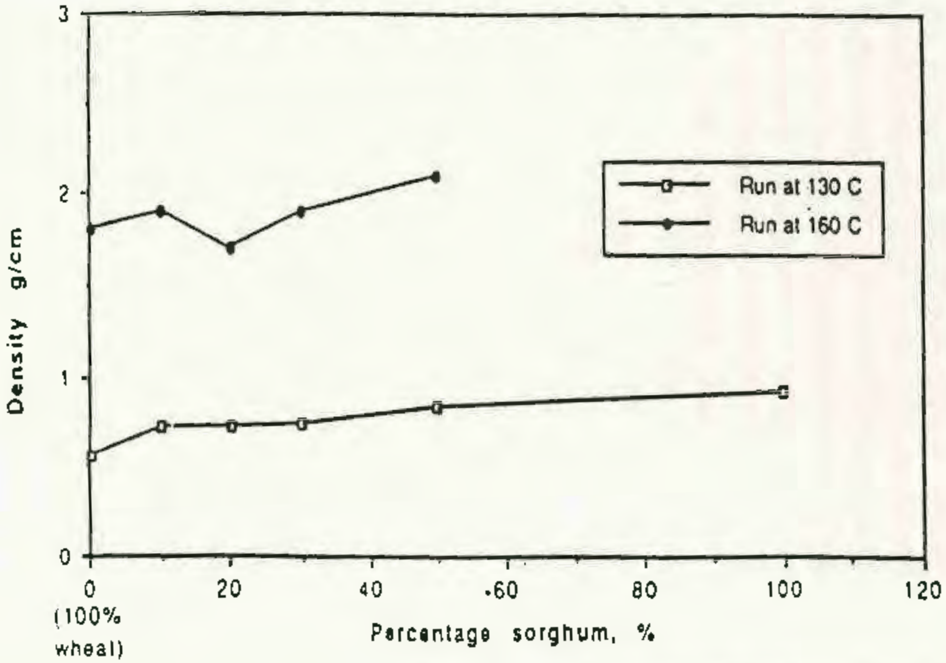


Figure 2: Plot of density against % sorghum content

viewed with Joel T20 kv accelerating voltage. Images were photographed on film type PX P220 at magnifications of 500 and 2,000 and in some cases 750 and 1500.

Results and discussion

Expansion

Both at 130°C and 160°C there was as expected a decrease in expansion with increasing amounts of incorporated percentage sorghum with a cut off point of 30% sorghum. The extrudates prepared at the higher temperature (160°C), however, attained higher diameter of expansion. The 100% sorghum products attained poor expansion except at 160°C after the moisture content had been raised in which case it obtained better expansion than the composite products (Fig. 1 and Photo 1,2 & 3).

Density

From Table 1 and Fig. 2 incorporation of increasing amounts of sorghum into wheat does not appear to have had any pronounced impact on the density of the product. The density, therefore cannot be correlated to the lack of expansion. The products which were prepared at 160°C, however, were denser than those prepared at 130°C. Increasing the moisture content, however, offset the density of the 160°C product because it was ultimately less than that of the composite and even less dense than that of pure wheat. This may, however, be due to extent of gelatinization.

Mechanical Strength

For products extruded at the same temperature, there was no remarkable trend with regards to shear. The standard deviation for extrudates of the same composition extruded at the same temperature was also quite wide. Generally extrudates prepared at 130°C exhibited higher shear than those of 160°C (Fig.3). This suggested loss of shear with increased extent of gelatinization. Micrographs SIsa and SIsb as compared to SIIsc and SIIsd help to illustrate the features possibly responsible for the mechanical strength.

Colour

There was no obvious difference in colour between the pure wheat product and the composite until 30% sorghum had been added to the wheat. Beyond 30% the typical grayed tint of the sorghum product became more obvious. The more expanded sorghum products (160°C) however, tended towards white. This may be due to changes in protein tannin bodies (Fapojuwo *et al* 1987).

Sorghum

The experimental value for gelatinization range of unextruded sorghum starch (SFs) was 74.7 - 88 (Lit. value 67.5 - 75°C Leach, 1965). This discrepancy may, however, be due to variety characteristics but also possibly due to distribution of christallinity (Lund, 1984). It has been stated that the enthalpy of gelatinization was a linear function of the degree of gelatinization (Lund, 1984). Consequently, the observed endotherm values (Table 2 & 3) can be taken to correspond to the degree of gelatinization. The observed decrease in ΔHq with increasing temperature of extrusion (i.e decrease of Hq in the order SFs > SIs > SIIs) also subscribes the above observations and agrees with the findings of Zobel (1984) that there is an increase in the degree of gelatinization with increasing extrusion temperature. The sequential decrease in Hq was further supported by micrographs SF (a+b) and SII (a->d) in contrast to SF (a+b). In the micrographs of extruded starch, modified or partially gelatinized starch granules were clearly visible underneath the gelatinized mass depicting a honeycomb type of structure. They were, however, more distinct in SI(a+b) than SIIs (d1 & d2). SII(a+c) in fact illustrated a case of high degree of gelatinization with only isolated cases of partially gelatinized starch. On the contrary, the observed endotherm shift to high temperatures with increasing processing temperature (Tables 2 & 3) i.e gelatinization ranges SFs (70.65 - 74.68°C) as compared to SIs (88.92 - 94.61°C) and SIIs (95.58 - 97.81°C) implied the observed ΔHq to be that of high melting crystallites (Donovan *et al* 1983 and Camire *et al* 1990).

Photo 1: Extrudates at 160°C. From left to right: BII, 10%, 20%, 30%, and 50% composite extrudates. On the extreme right is SII.

Photo 2: Extrudates at 130°C. From left to right: BI, 10%, 20%, 30%, and 50% composite extrudates, SI unexpended and SI expanded product.

Photo 3: 100% sorghum extrudates. From left: unexpended extrudate at 160°C (at the 20% moisture content), SI, SII.

Table 1: Relative value of expansion, density, mechanical strengh, and colour as functions of temperature and moisture content.

Percentage sorghum	Parameter for extrudate processed at 130°C and 160°C									
	Expansion		Density (g cm^{-3})		Mechanical strength/shear (kg)		Colour (greyed yellow range)		Moisture content of extrudate	
	130	160	130	160	130	160	130	160	130	160
Wheat(100%)	3.4	3.6	0.56	1.8	6.6 ± 0.7	4.5 ± 0.8	161C	161C	20.5	20.5
10%	3.0	3.5	0.73	1.9	6.5 ± 0.9	4.8 ± 0.8	161C	161C	20.5	20.5
20%	2.9	3.1	0.72	1.7	6.7 ± 1.2	4.6 ± 0.7	161C	161C	20.5	20.5
30%	2.7	2.9	0.74	1.9	6.6 ± 0.9	4.6 ± 0.7	161C	161C	20.5	20.5
50%	2.5	2.6	0.84	2.1	6.6 ± 1.0	5.1 ± 0.5	161D	161D	20.5	20.5
100%	2.2	3.6	0.93	1.5	5.8 ± 1.3	5.3 ± 0.6	161D	161D	20.5	20.5

Table 2: Summary of sorghum endotherm results

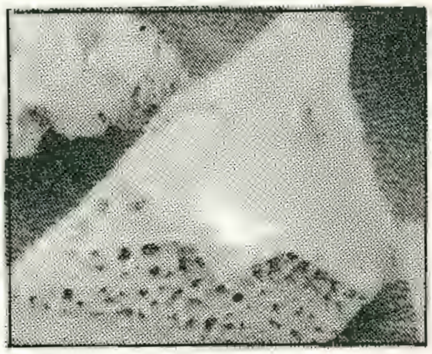
Sample	Enthalpy ΔHq J/g	Percentage gelatinized	Endotherm Temp °C		
			TO	TI	T2
Sorghum starch (SFs)	12.3	-			
130°C extruded starch (SIs)	5.30	58.0	70.65	74.68	87.95
160°C extruded starch (SIIs)	1.42	89.0	95.58	97.81	100.2

Table 3: Summary of wheat endotherm results

Sample	Enthalpy ΔHq J/g	Percentage gelatinized	Endotherm Temp °C		
			TO	TI	T2
Biscuit flourstarch (BFs)	4.8	-	54.9	62.0	71.3
130°C extruded starch (BIs)	0.60	87.5	83.0	86.0	89.4
160°C extruded starch (BIIs)	2.10	62.0	92.6	96.8	107.1

Extruded Sorghum Products

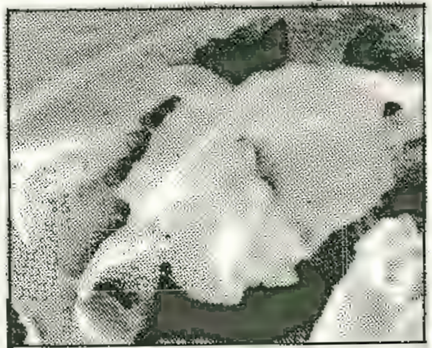
Sorghum Product (SI); Starch (SIs)



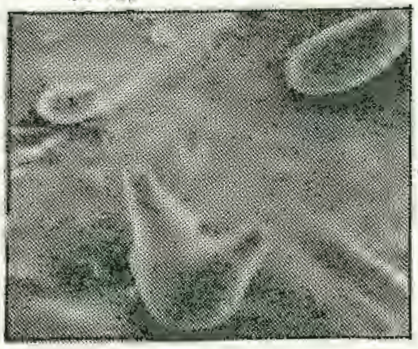
SIsa

SIsb

Sorghum Product (SII); Starch (SIIs)

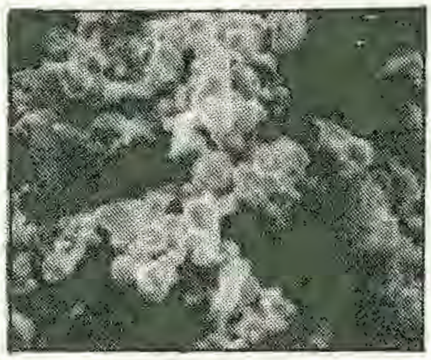


SIIsc

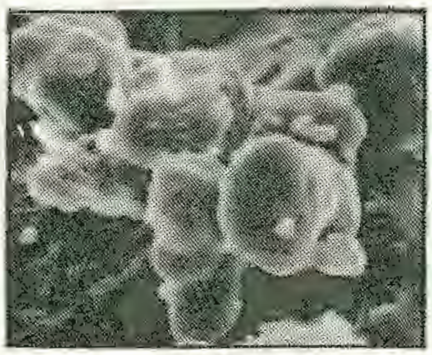


SIIsd

F l o u r s: Sorghum (L187); Flour (SF)

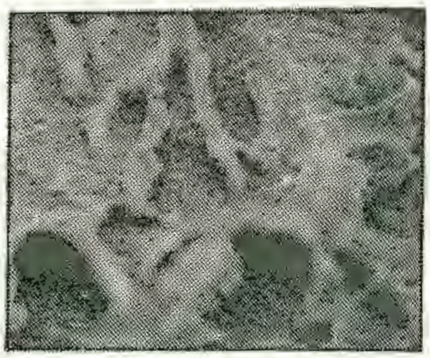


SF_a



SF_b

$SIIsd_1$



$SIIsd_2$

Key to electron micrographs: a1 = x 350; a = x 500; b = x 2000; c = 750; d = 1500; s = starch

Abbreviations

SF = Sorghum Flour	BF = Wheat (Biscuit) Flour
SFs = Sorghum Starch (isolated flours SF)	BFs = Starch isolated from BF
SI = Sorghum Product at 130°C	BI = Wheat Product at 130°C
SIs = Isolated Starch from SI product	BIs = Isolated Starch from BI
SII = Sorghum Product at 160°C	BII = Wheat product at 160°C
SIIs = Isolated Starch from SII product	BIIs = Isolated Starch from BII

Wheat

The literature values for the gelatinization endotherm for wheat ranges between 52 - 63°C (Leach, 1965) but the observed value of pure wheat starch ranged between 56.5 - 74°C. The high (To - Tc°C) value could be attributed to the form of starch. ΔHq for unprocessed wheat starch is lower than that of sorghum and the micrograph of wheat starch granules are quite different from those of sorghum.

While sorghum starch granule were more uniform the wheat starch granules were more varied in size from very small to very big [micrograph SFs (a+b)]. The low ΔHq for wheat has been explained by Zobel (1984). At 130°C the wheat product attained a higher degree of gelatinization as compared to sorghum products [Tables 2 & 3 and micrographs SIs(a+b) and BIs(a+b)]. Hq for BIIs (160°C) was contrary to that of sorghum was much higher than that for BIs. This could be due to the melting of high melting point crystallites (Zobel, 1984) but bears no relationship to extent of gelatinization as micrographs BII(a+b) clearly indicate a very extensive gelatinized starch picture. The micrographs, however, also reveal a greater extent of degradation or fragmentation of starch in wheat than in sorghum starch and more so at 160°C than 130°C. This suggests that degradation may be responsible for the observed reduced extent of gelatinization and consequential high endotherm value. It is nonetheless noteworthy that while the gelatinized range infact decreased after extrusion at 130°C, at 160°C it was almost the same as that of the unprocessed starch.

Possible Effects on Composites

Results of the D.S.C. endotherms and those of micrographs show that sorghum and wheat suffered different extents of transformation during the extrusion processes. Wheat gelatinized faster but also appeared to have degraded more under shear and increased cooking. Sorghum attained maximum gelatinization only with increased temperature and moisture content. The wheat content of the composites, therefore, would have contributed better to the physiochemical characteristics of the composite products at 130°C than at the higher temperature when starch degradation appeared to have set in. Conversely the sorghum fraction would have contributed better at the higher temperature especially if increases in moisture content had been effected. This suggests that the two cereals require different processing conditions to attain maximum gelatinization and consequently a maximally expanded product from composites of the two may not be easy to realize.

Sorghum products extruded at 160°C from D.S.C. measurements and S.E.M. observations reached a higher degree of gelatinization than those extruded at 130°C. This affected the physical properties in the following way:

(i) Expansion was a direct function of gelatinization.
(ii) The density of the products increased slightly with increasing extent of gelatinization.
(iii) The shear was lost with increasing extent of gelatinization. But the expanded pure sorghum product at 160°C displayed greater mechanical strength than the pure wheat product.
(iv) For the same percentage composition the more gelatinized products effected a lighter colour.

The production of physically attractive and acceptable product from sorghum is, therefore, possible through extrusion cooking. Higher temperatures and moisture content above those required for wheat are, however, necessary. That sorghum and wheat required different extrusion conditions for effective gelatinization rendered attempts to produce good quality composite products incorporating more than 30% sorghum unsuccessful.

Acknowledgement

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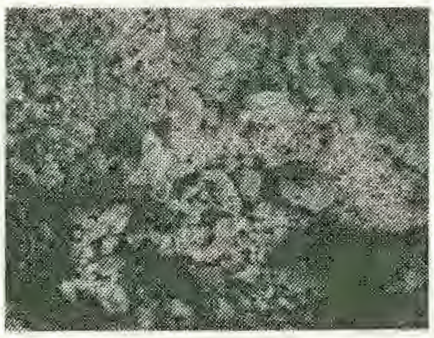
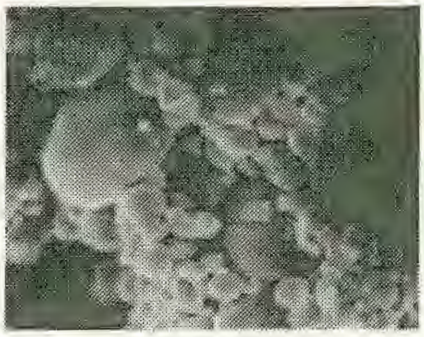
Extruded Sorghum Products

Wheat (Biscuit) Flour - Starch (BFs)

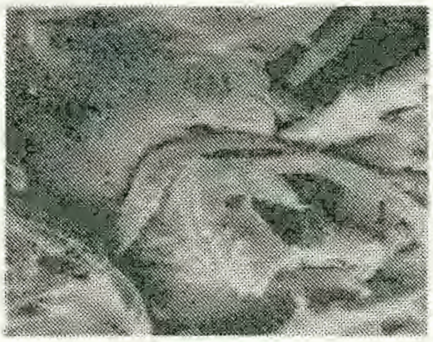


BFsa



BFsb

Wheat Product (BI) - Starch (BIs)

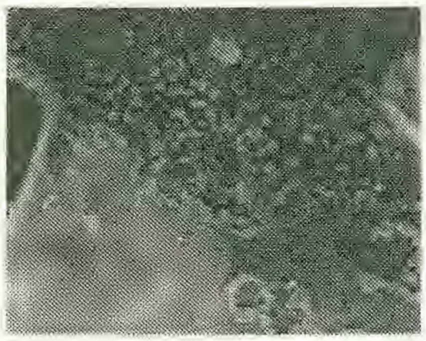


BIsa

BIsb

Wheat Product (BII) - Starch (BIIs)

BIIsa



BIIsb

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