THE POTENTIAL OF MICRONIZING FOR PROCESSING SORGHUM INTO FOOD

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ABSTRACT

The Potential of Micronizing

for Processing Sorghum Into Food

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Micronizing is accomplished by heating the grain with infra-red burners and crushing the heated kernels between corrugated steel rollers. This study examined for the first time the chemical, physical, and structural changes that occur in the sorghum kernel during the micronizing process and related this information to the performance of the micronized sorghum grain in a food system.

A laboratory model Pierce micronizer was used to process three sorghum varieties with different endosperm characteristics: waxy, heterowaxy, and nonwaxy. A subsample of the nonwaxy variety was pearled prior to micronizing to remove the pericarp.

The waxy grain had the greatest expansion followed by the heterowaxy, and nonwaxy varieties; the pearled nonwaxy grain was more expanded than the unpearled grain. Changes in structure of the grain were observed with light and scanning microscopy. The greatest alteration in endosperm structure was seen in the waxy sorghum variety.

The extent of gelatinization, measured by loss of birefringence,

enzyme susceptibility, and viscosity values, occurred in the following decreasing order: waxy, heterowaxy, pearled nonwaxy and unpearled nonwaxy sorghum variety.

The chemical composition of the grain; including available lysine content, was unaffected by micronization.

The highly expanded waxy flake would be desirable as a ready-to-eat breakfast cereal, whereas the dense nonwaxy flake would be well suited for a cookie, pie or granola bar formulation. The pearled nonwaxy flake, white and bland in flavor, would perform well in a cooked cereal.

ACKNOWLEDGMENTS

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INTRODUCTION

Production of sorghum grain in the United States approaches 800 million bushels annually, making it the third largest cereal crop. Sorghum is a robust, hardy plant, able to grow and produce under a wide range of environmental conditions, particularly in warmer temperatures and tropical regions of the world. Sorghum provides a useful yield of grain under hazardous growing conditions which makes it a valuable cereal.

Historically, sorghum in the U. S. has been used for livestock feed, with only limited quantities used for industrial and food purposes. However, a considerable portion of the annual world-wide production is consumed directly for human food. Rachie (1969) discussed the role of sorghum as a food in various parts of the world and indicated that the food type grain grown in India and Pakistan is predominantly white, pearly and corneous in nature, and possesses a bland flavor. Germ plasm from these food types could be effectively utilized in breeding programs to improve the food quality of U. S. sorghum (Rooney et al., 1970).

Rooney et al. (1970) define "sorghum quality" as those properties of the grain which make it desirable for use as a human food. These attributes have not been clearly defined, but they can be expressed in terms of grain improvement. For example, U. S. Sorghum could be improved by reducing pericarp pigmentation associated with off color

and unacceptable flavor of sorghum products; eliminating the testa or undercoat which causes black or brown specks in flour and results in off-colored products; increasing the relative ease of separating the kernel into its structural portions by processing; increasing the availability of starch, and increasing the protein quality of sorghum (Rooney et al., 1970).

Within the past 10 years, intensive sorghum research programs have produced, varieties with improved "food quality". For example, Purdue Scientists (Singh and Axtell, 1973) found high lysine content in an Ethiopian sorghum and later "created" a more adaptable high-lysine line by chemically inducing a genetic mutation in a domestic line (Mohan, 1975). Experiment station scientist are also working on a food type sorghum with a thin pericarp (ovary wall). The grain is high quality and yields a high percentage of flour in the milling process.

Waxy sorghum starch is essentially 100% amylopectin in contrast to nonwaxy sorghum starch which is 25% amylose and 75% amylopectin. The waxy endosperm has an alteration in the structure of the endosperm. The peripheral endosperm of the waxy variety is less concentrated in protein and the protein is more evenly distributed throughout the starchy endosperm (Sullins and Rooney, 1975). The change in endosperm structure and increased susceptibility of the waxy starch to hydrolysis help account for the improved feed efficiency of waxy sorghum rations over normal sorghum rations when fed to beef cattle (Sullins et al., 1971).

Sorghum must be processed to achieve maximum utilization of its components by livestock. Numerous methods, including grinding, steam flaking, dry rolling, exploding, popping and micronizing have been designed to improve the availability of the starch in the sorghum kernel (Hale et al., 1966). Micronizing is a dry heat process using gas fired infra-red generators to heat the grain. The infra red rays penetrate the grain and excite the water molecules which vibrate at a frequency of 600 - 1,200 million mega cycles per second (Anon, 1977). Rapid internal heating occurs along with a rise in water vapor pressure. In effect, the grain is cooked from the inside out and each kernel subsequently expands almost to the point of eversion. Immediately prior to eversion, the heated kernels pass through corrugated rollers which are under pressure and are crushed into flakes.

Micronized grain has improved feed efficiency when fed to animals and the micronized grains have a good appearance, flavor and keeping characteristics. In addition, the process requires less energy than many other processing techniques like steam flaking, popping and extruding. These observations suggested that micronized grain might be useful in processing grains into human foods.

Therefore the objectives of the research reported in this paper were to utilize a laboratory scale micronizer to determine processing properties of several new, experimental sorghum varieties and to measure the physical, chemical and structural changes in the kernels. This information would establish the potential usefulness of micronizing

sorghum into acceptable products for use in foods. In addition, it would determine how sorghum varieties with different kernel characteristics responded to micronizing.

MATERIALS AND METHODS

Samples

Three sorghum varieties with differing endosperm characteristics were selected: a white waxy (TX 615 x NSA 954); a white heterowaxy (A 7504 x NSA 954), and a white nonwaxy (High lysine deriv. x a white pearly deriv.). A subsample of the nonwaxy variety was pearled with a Satake rice mill to remove the pericarp prior to micronization. The pearled grain was examined to determine whether processing sorghum prior to micronizing could be used to improve its properties for use in foods.

Apparatus and Processing Procedure

A laboratory model Pierce micronizer was used to process the four samples (Figure 1). The rollers were set at .003" clearance and adjusted to maintain a pressure of 50 psi. The gas flow was maintained at 6 psi pressure. Each burner generated approximately 25,000 Btu of energy. The feeder rate and rate of shaking were adjusted to obtain a flake density of 26.0 lb/bushel for a standard sorghum sample. Then 50 lbs. of each of the four samples were micronized and collected for further analysis. Each time samples were micronized the standard sample was always brought to 26.0 lb/bushel flake by proper adjusting of the micronizer. Then, the experimental samples were processed without changing the micronizer.

Proximate Analysis. Nitrogen content was assayed with a Technicon^{TM} Autoanalyzer II Continuous Flow Analytical System following digestion and sample preparation using a BD-40 Block Digestor (AACC, 1962). Crude protein was Nx 6.25. Fiber and fat content were determined according to standard AOAC methods (AOAC, 1970).

Amino Acid Analysis was performed with ion exchange chromatography (Moore, et al., 1952). Available lysine content was determined by the sodium borohydride method (Rhee et al., 1974).

Physical Analysis: Test weight on bulk density was taken with a Winchester bushel meter according to official U. S. Grain Standard procedures (U.S.D.A., 1974). An air compression pyncnometer was used to determine the specific gravity or density of the grain samples (Rooney and Sullins, 1970).

Gross Morphology of the whole grain and micronized samples were observed and photographed with the Zeiss Tessovar Stereoscope equipped with a Pentax K-2 Automatic 35 mm camera. High Speed Ektachrome (ASA 160) was used for color photos. Black and white photography utilized Plus-X Panchromatic (ASA 125) film.

Scanning Electron Microscopy (SEM). For SEM, the flakes were mounted on 9 mm aluminum stubs with silver conductive paint. Then, samples were coated with 200A^{o} of gold palladium and viewed with the Joel JSM35 Scanning electron microscope with an accelerating voltage of 25KV.

Photomicrographs were recorded on Tri-X Panchromatic film (ASA 400).

Starch Gelatinization

Loss of birefringence. The micronized samples were soaked in 0.5% sulfur dioxide solution for 12 hr. Starch was scratched from 5 steeped kernels and placed on a slide. Three fields per slide were examined for each of two replicates, and a count was taken of those granules without birefringence for each field. The number of granules exhibiting a loss of birefringence was expressed as a percentage. Each value is the mean of 6 fields.

Enzyme susceptibility. Digestion with alpha-amylase was used to determine the extent of starch gelatinization according to AOAC methods (AOAC, 1975). Commercial Alpha-amylase was obtained from Wallerstein Co., Staten Island, N. Y.

Apparent Viscosity. A Brookfield viscometer was used to determine the viscosity of the ground micronized sorghums. All measurements were taken on 11.5% (dry wt.) suspensions of the ground samples in 420 ml. of distilled water. Spindle No. 1 was inserted into the test material rotating at a speed of 20 RPM. Readings were taken at 1 minute intervals until there was no increase in viscosity. Viscosity in centepoise units was obtained by multiplying the readings by a factor of 5. Values at five minutes were selected as a representative sample illustrating differences in apparent viscosity. The micronized grain was ground with a Udy cyclone grinder.

Initial pasting viscosity. Starch dispersions of the ground, micronized and ground, whole sorghum samples are examined using a Brabender visco/amylo/graph (Mazurs et al., 1957). An 11.5% (dry wt.) suspension of each of the ground samples in 420 ml of distilled water was used to obtain the cooking curves. The visco/amylo/graph curves gave the temperature of initial viscosity increase.

RESULTS AND DISCUSSION

Structural changes

Each variety of sorghum had a different response to micronizing. For example, the waxy variety (Figure 2-A) of sorghum exhibited the greatest degree of expansion while the nonwaxy grain (Figure 2-B) was least expanded. The pearled nonwaxy grain (Figure 2-C) was more expanded than its whole grain counterpart.

The micronizing process decreased test weight and density of the whole grain (Table 1). The waxy variety had the greatest percentage decrease in test weight and density, followed in order by the heterowaxy and nonwaxy grains. These values were used as an indication of expansion i.e., a decrease in density corresponds to an increase in expansion. The waxy sorghum was more highly expanded than the heterowaxy and nonwaxy varieties. The pearled nonwaxy sample was more expanded than the micronized grain sample with the pericarp intact.

Scanning electron photomicrographs of the micronized waxy flakes (Figure 3A) illustrate that the integrity of the starch granule was lost and expansion occurred throughout the entire endosperm. The granules of the waxy sorghum greatly expanded into a starch network (Fig. 3D). However, in the nonwaxy flake (Fig. 3B) the majority of the starch granules are not expanded. Figure 3E confirms that the granules are not as throughly disrupted as they are in the waxy flake. When the micronized flakes were broken for internal examination, the entire

endosperm was seen in cross section, as well as the individual fractured starch granules viewed under a higher magnification. The pearled nonwaxy variety (Fig. 3C) expanded more than the unpearled grain. Due to this increased expansion; the spherical outline of the nonwaxy starch granule (Fig. 3F) is not as visible among the network of expanded starch granules.

Starch Gelatinization

The micronizing process caused starch gelatinization of all the varieties; but, the extent of gelatinization was affected by the endosperm characteristics of the sorghum variety.(Table 2). In general, loss of birefringence was greatest for waxy followed by heterowaxy, nonwaxy pearled and nonwaxy. The ground whole grain did not differ in extent of gelatinization.

Enzyme susceptibility data indicates that the waxy variety, with the greatest maltose production, was most susceptible to attack by alpha-amylase, despite the fact that it is comprised of 100% amylopectin. Alpha-amylase hydrolyzes alpha 1-4 linkages throughout amylose chains to ultimately yield a mixture of glucose and maltose. Alpha-amylase also attacks amylopectin, but it cannot hydrolyze the alpha 1-6 linkages at branch points. Therefore, one would expect the unprocessed nonwaxy sorghum variety would produce more maltose per gram than the waxy variety. The fact that the waxy flakes exhibited greater susceptibility and maltose production suggests that micronizing had the greatest effect on that variety.

Viscosity measurements are used as an indication of gelatinization in the following manner. Partially or completely gelatinized starch granules imbibe water more readily than undamaged granules. The granules swell and the starch water solution thickens. More rapid thickening and higher viscosity occurs with increased gelatinization.

The Brookfield measures of apparent viscosity of the ground micronized samples gave the same trend among the varieties. A higher viscosity value was obtained for the waxy variety, which indicates gelatinization was greater. The heterowaxy variety was intermediate between the waxy and nonwaxy grains. The pearled nonwaxy grain was more gelatinized than the unpearled grain. The viscosity of the ground, whole grain approached zero.

The visco/amylo/graph cooking curves represented viscosity increases in the starch-water solution upon heating. Heat further damages the starch granules and enhances the extent of gelatinization. Temperature of initial viscosity values derived from these cooking curves was correlated to extent of gelatinization in the following manner: Less heat, indicated by a lower temperature of initial viscosity, is required to thicken a more extensively gelatinized starch. The waxy sorghum variety reached its initial viscosity at a lower temperature than all of the other samples, suggesting that it was more extensively gelatinized than the heterowaxy, and nonwaxy flakes in that order. Again, the pearled nonwaxy was more gelatinized than the unpearled

counterpart, as evidenced by its lower temperature of initial viscosity.

Chemical Analysis

The slight apparent decrease in fat, fiber and protein content between the whole grain and the micronized was because of a loss of pericarp tissue during sieving procedures prior to the analysis. The pericarp tissue contained sufficient amounts of proteins, fiber and fat to explain these results. Therefore, the micronizing process did not significantly affect the fat, fiber and protein content.

Lysine reacts with carbohydrates in the presence of heat and becomes nutritionally unavailable. The available lysine content in the whole grain and micronized sorghum was significantly different in the waxy and heterowaxy grain, indicating that the micronizing process did affect the nutritive value of these varieties. However, the pearled and unpearled nonwaxy sorghum showed no change in the available lysine content in the whole grain and micronized sample. The grain is subjected to this high heat treatment for only a short (1 minute) period of time, which may be insufficient for the lysine-carbohydrate reaction to occur to an appreciable extent in these nonwaxy grains. Lysine is the first limiting amino acid in sorghum. Therefore, the nutritional value of the micronized sorghum would be equivalent to that of the original grains in the nonwaxy sorghum varieties.

CONCLUSION

A direct correlation existed between the amount of waxy gene present in a sorghum and the effect on endosperm structure due to micronizing. The waxy sorghum endosperm, possessing a lesser concentration of protein in the peripheral endosperm and a more even distribution of the starch granules throughout the entire endosperm, was expanded and gelatinized to a greater extent than the nonwaxy variety, with the heterowaxy variety intermediate between the two. The pearling process enhanced the effect of micronizing on the nonwaxy sorghum variety. In every test, the pearled version exhibited greater expansion and increased gelatinization over the unpearled grain.

The much greater expansion of the waxy grain during micronizing suggests that the waxy grain is easier to process and would require less energy for processing into food or feed to reach a certain gelatinization level. Thus considerable savings in energy might occur because sorghum requires the most rigorous processing of all cereals.

Based on the results of this study: (1) The more highly expanded micronized waxy flake would be desirable as a sugar-coated puffed breakfast cereal. (2) The more dense nonwaxy variety, would be suited for a cookie, pie, or granola bar formulation. (3) The pearled nonwaxy sorghum flake, white and bland in flavor, performs well as a cooked cereal, very similar in flavor and appearance to cream of wheat.

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TABLE I

Physical Properties of Whole Grain (W. G.) and Micronized (M.) Sorghum

	Test Weight (lb. / bu.)		Density (g / cc)	
	W. G.	M.	W. G.	M.
Waxy	60. 7	22. 9	1. 34	0. 97
Heterowaxy	61. 3	32. 3	1. 35	1. 20
Nonwaxy	58. 2	35. 9	1. 29	1. 35
Pearled Nonwaxy	61. 7	32. 6	1. 34	1. 23

TABLE 2

EXTENT OF STARCH GELATINIZATION IN THE MICRONIZED GRAIN

Sample	Loss of Birefringence (%)	Enzyme Susceptibility (mg. maltose/gram)	Apparent Viscosity (CP)[a]	Temperature of Initial Viscosity (°C)[b]
waxy	57 ± 3%	533	55.0	56.0 ± 2.3
heterowaxy	39 ± 4%	481	20.0	61.0 ± 0.0
nonwaxy	20 ± 3%	367	7.5	71.0 ± 0.4
pearled nonwaxy	41 ± 3%	383	45.0	69.0 ± 1.4

[a] Determined w/the Brookfield Viscometer
[b] Determined w/the Brabender visco/amylo/graph

TABLE 3

CHEMICAL COMPOSITION OF THE WHOLE GRAIN (WG) AND MICRONIZED (M) SORGHUM[1/]

Variety	Fiber %		Fat %		Protein %		Lysine Content % Protein		Available Lysine Content % Protein	
	WG	M	WG	M	WG	M	WG	M	WG	M
waxy	2.0	1.8	4.3	3.9	11.4	11.2	2.10	1.94	2.33	1.75
heterowaxy	1.9	1.7	4.1	3.5	11.2	10.6	2.17	1.74	2.06	1.73
nonwaxy	2.1	1.8	3.9	3.5	15.8	15.6	1.94	1.78	1.78	1.70
pearled nonwaxy	.6	.5	2.5	2.0	14.9	15.2	1.44	1.38	1.48	1.36

[1/] all values expressed on a dry weight basis

Figure 1: The Pierce Laboratory Micronizer.

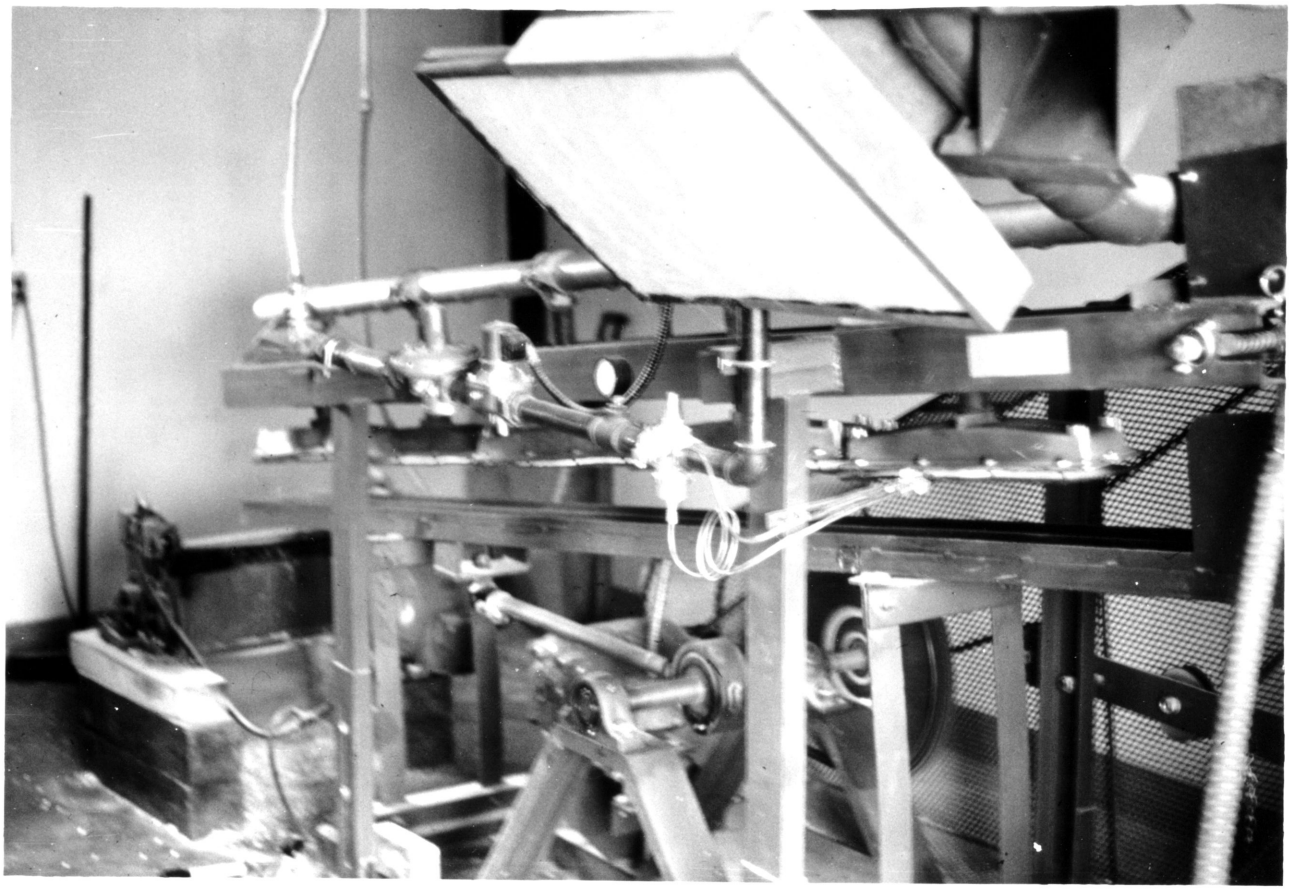


Figure 2: Gross Morphology of the whole grain and micronized sorghum. (A) White Waxy Sorghum, (B) White nonwaxy sorghum, (C) pearled white nonwaxy sorghum.

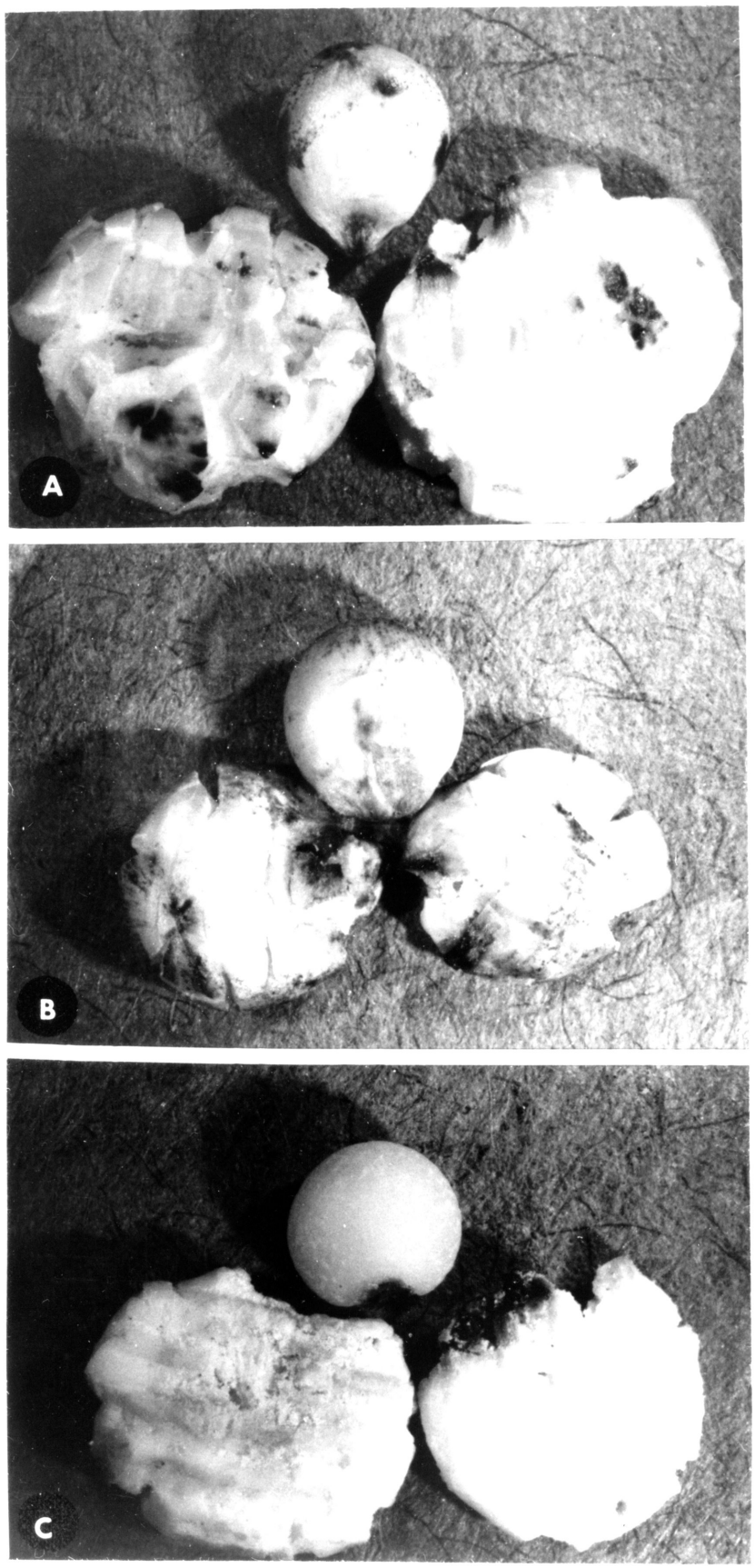
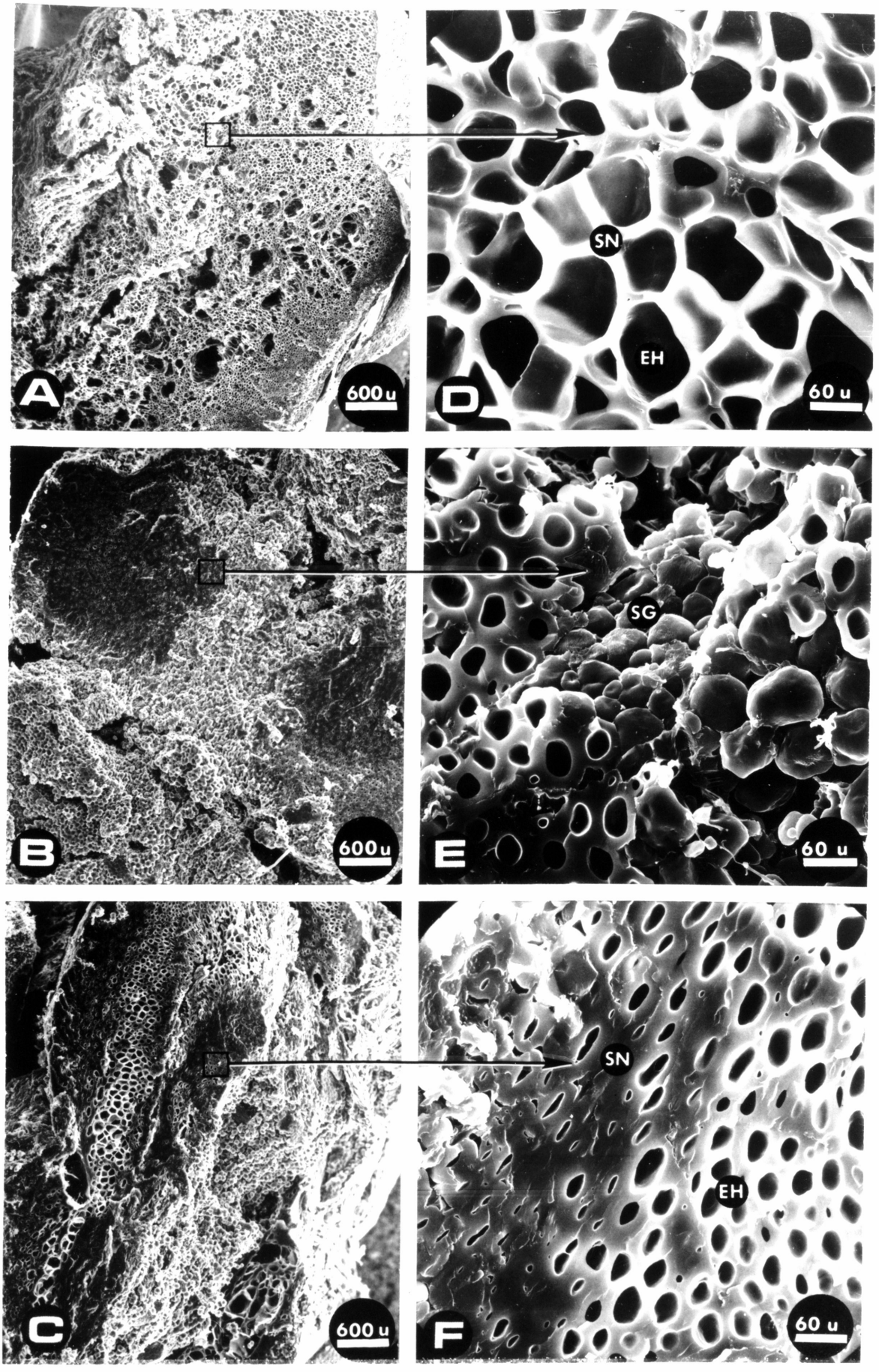

A
B
C

Figure 3: Photomicrographs taken with the SEM of micronized sorghum flakes. Cross sections (A) and (D) of waxy micronized flake. (B) and (E) Nonwaxy micronized flake. (C) and (F) Pearled nonwaxy micronized flakes. SG - starch granule, SN - starch network, EH - expansion hole. A, B, and C = 50x, D, E, and F = 500x.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