CHEMICAL CHARACTERIZATION OF SORGHUM AND MILLET GRAIN AND THEIR USE IN BAKED PRODUCTS

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INTRODUCTION AND LITERATURE REVIEW

Origin and Botanical Classification of Sorghum and Millet.

Carvings depicting sorghum plants in Assyrian ruins indicate that the grain was known as early as 700 B.C. (1). Although it is believed to have originated in Africa, similar grain was cultivated in Manchuria and Central, Western, and Northern China (2, 3). Karper and Quinby (4) reported the local names for edible varieties of sorghum as: dura, kafir, milo, shallu, koliang feterita, and hegari.

Indeed, while sorghum constitutes a major food grain in most of Africa and India, it is also grown in Asia Minor, Iran, Turkestan, Korea, Japan, Australia, Southern Europe, Central America, some islands of the East Indies (4), and the United States (2).

Sorghum belongs to the family Graminae, tribe Andropogonae (5). All the annual sorghums have ten pairs of chromosomes and belong to one species, Sorghum bicolor, which includes: grain sorghums, sudan grass, broomcorn, and tall sorghums that are grown for silage or syrup.

Sorghum is a coarse grass that varies in height from two to more than fifteen feet. The widely cultivated varieties are usually between two and five feet tall. The stems are similar to those of corn and may be fine in grass sorghums or more than an inch in diameter in some grain and forage types. Some varieties of grain sorghum have juicy stalks and midribs while others are dry and pithy (3, 6). The leaves are smooth and have a waxy surface. The leaf structure is such that water loss is reduced to a minimum. The inflorescence is a loose to a dense panicle that may bear as many as 2,000 seeds. The seeds of different varieties vary greatly in size, pigmentation and other characteristics (4).

In several parts of the world the name millet is applied to different cereals including Sorghum bicolor (7). Millet is a robust annual grass usually reaching a height of six to fifteen feet when mature. It is highly drought resistant and well adapted to poor sandy soil (8).

The economically important millets belong to the Chlorideae tribe of the grass family, although the Paniceae tribe includes several species which are grown for food and feed in various parts of the world (7).

The millet that was used in this study was pearl millet (Pennnesitum typhoideus), one of the important small millets of the tropical and subtropical regions of Asia and Africa (8). It is grown extensively in Egypt and India as human food (7, 9). It is also grown in some of the European countries such as Germany and Hungary (6).

The origin of the plant is unknown but it probably originated in Egypt or Arabia (6, 7).

Gross Composition.

Sorghum grain ranks second behind corn in the amount of total available energy among common cereal grains (5). Rooney and Clark (10) reported that the sorghum grain kernel measures about 4 mm long by 3.5 mm wide by 2.5 mm thick and varies in weight from 8 to 50 mg with an average of 28 mg.

The chemical composition of sorghum resembles that of corn (3, 5, 6). Like corn and wheat, sorghum is low in fiber and ash because the glumes are readily removed from most varieties (5). The protein content is generally slightly higher than corn or rice. The grain has a lower oil content than that of corn or oats, but higher than wheat, barley, and rice (3, 5, 6). Compared to corn, sorghum has about the same carbohydrate

components, and more tannins and wax. Except for new yellow endosperm varieties, sorghum contains no xanthophyls or carotenoid pigments (6).

The mineral content of the grain reflects to some extent the soil on which the crop was grown and the characteristics of the species (6).

Approximate analysis of selected sorghum grains are given below (5).

Sample	Protein* %	Ether Ext. %	Ash %	Crude Fiber %	Calcium Mg%	Phosphorous Mg%
Hybrids						
RS 620	8.5	4.4	3.42	2.7	16.45	595
RS 610	7.6	3.7	2.97	2.6	19.23	542
HII X71	10.4	3.2	1.39	2.0	22.31	238
Varieties/Combine						
Kafir 60	8.1	3.5	2.77	2.9	13.48	536
Caprock	10.0	3.4	3.07	3.0	21.19	512
Westland	9.0	3.3	3.74	2.6	45.53	1,097
Norghum	9.0	3.9	2.43	2.8	17.18	479
Martin	8.5	3.1	2.09	2.1	14.59	373
Hegari	8.2	3.5	2.33	2.5	17.12	416

* All values expressed on 14% M.B., protein = N X 6.25.

Ross and Wall (5) attributed the variation in grain composition to the variation in percentages of different parts of the kernel (bran, germ, or horny and floury endosperm). Bidwell et al. (11) reported that 70% of the oil, 15% of protein and 20% of ash in the sorghum kernel are in the germ. Following the germ, horny endosperm has a higher protein content than the floury endosperm. The starchy or floury endosperm was richer in ether extract than the horny endosperm. The bran fraction accounted

for most of the fiber in the grain. The chemical composition and yield of the grain are influenced by the soil and weather (5).

Millet is somewhat higher in protein and oil than rice, sorghum, corn, and oats (6). It is a good source of thiamin and probably contains appreciable amounts of other B-vitamins (6, 7). Similar varieties of millet grown in different parts of the world do not vary greatly in composition (12, 13, 14).

The chemical composition of millets (15) in comparison to other cereals is as follows:

Cereal Grain	H_2O %	Protein %	Oil %	Ash %	Ca Mg%	P Mg%
Pearl millet	10.1	16.0	4.5	2.2	46	314
Hard red spring wheat	13.0	14.0	2.2	1.7	36	383
Winter wheat	12.5	12.3	1.8	1.7	46	354
Soft red winter wheat	14.0	10.2	2.0	1.7	42	400
Field corn	13.8	8.0	3.9	1.2	22	268
Rice - Brown	12.0	3.5	1.9	1.2	32	221
Rice - White	12.0	6.7	0.4	0.5	24	94
Sorghum	11.0	11.0	3.3	1.7	28	287

Carbohydrates. Like other cereals sorghum grains are valued for their high content of energy mainly in the form of starch. Edwards and Curtis (16) found that the starch content of sorghums ranged between 68 and 73%.

Deatherage et al. (17) reported that, in normal varieties of sorghum, amylose (glucose units united exclusively by α-1, 4 linkages) ranged from

23 to 28%. The remainder of the starch is amylopectin which has about 5% α-1, 6 bonds that give it a branched structure. The starch from waxy sorghum varieties contain essentially all amylopectin.

Amylose complexes with iodine to give a blue color. The amylose content of starch can be determined by measuring the blue color formed with iodine or by precipitation with butanol and weighing (18, 19). The amylopectin fraction gives a red color with iodine (5). It can be precipitated with methanol after the amylose has been precipitated with butanol (18, 19).

Amylose molecular weight ranges from 2 to 7 X 10^5 while amylopectin ranges in molecular weight from 1 to 10 X 10^6 (20).

Microscopically both regular and waxy sorghum starch granules appear almost identical. The average granule size (15μ) is slightly larger than that of corn (10μ), (21).

The gelatinization temperature range of sorghum starch is from 62^{o} to 72^{o}C. Those gelatinization temperatures can be markedly changed by adding certain chemicals. Some adjuncts accelerate the disruption of hydrogen bonding, and these enhance gelatinization, whereas others inhibit gelatinization (22).

Starch has the property of swelling and producing a viscous paste when heated. Bechtel and Fischer (23), using the corn industries and stormer viscometer, found that starch pastes of corn, wheat rice, and milo show a continuous viscosity decrease during the pasting process, with the greatest decrease occurring in the first hour. Fairly constant viscosity value was obtained with most of the samples after cooking for one hour at 90^{o} to 95^{o}C.

Using stormer viscometer, Kerr (24) obtained variable results for sorghum varieties. Barham et al. (25) reported viscosity ranges from 42 to 211 stormer units for nonwaxy varieties of sorghum. Marzus et al. (26) using Brabender viscometer confirmed those results. Bechtel and Fischer (23) reported higher viscosity with milo starch than that with corn, wheat, or rice. Waxy sorghum starches show a rapid rise to higher viscosity because of the unrestricted swelling of its granules which are composed entirely of branched starch molecules. Peak viscosity is followed by a sharp reduction in viscosity. Regular sorghum starch shows a somewhat restricted viscosity increase during heating to 95°C, some viscosity loss during the 95°C holding period, followed by larger increase during cooling (5).

The sugars of sorghum grains were identified by Nordin (27) as a trisaccharide (raffinose), a tetrasaccharide (stachyose), in addition to sucrose, fructose and glucose. Watson and Hirata (28) reported 1.2% sugars in sorghum. The major fractions were sucrose 0.85%, D-glucose 0.09% D-fructose 0.09% and raffinose 0.11%.

Little has been reported concerning the carbohydrates of millets, the average carbohydrate content ranged from 60 to 65% (7). Rakhimbaev (29) reported that in seven Russian varieties the amylose content ranged from 12 to 19%.

Millet starch granules are smaller than those of corn or sorghum, generally about 1/3 to $\frac{1}{2}$ as large in diameter (30). Freeman (30) reported that Pearl millet starches are similar to corn and sorghum starches in most aspects. The major observed differences were lesser tendency of cooked millet to retrograde or thicken upon cooling, and smaller granule size.

Proteins. Osborne (31) classified the sorghum proteins as: A) albumin soluble in water, B) globulin, soluble in solution of salts, C) prolamines, soluble in aquous ethyl alcohol and D) glutelins, soluble in dilute alkali.

The prolamines of sorghum were the predominent protein. Unlike corn zein, little of the prolamine was extracted with 70% alcohol at room temperature. Boiling 70% alcohol can yield up to 67% of the total proteins (32). Virupashka and Sastry (33) found 30 to 60% of the proteins are soluble in 60% hot ethanol. Those proteins have a unique property of forming gels at low protein concentrations in a variety of solvents. They undergo noncovalent interaction even in solvents as strong as 6M guanidine hydrochloride (34).

Glutelin is the second major fraction. The insolubility of glutelins in neutral solvents has been attributed to their high molecular weights caused by disulfide bonds in the amino acid cystine, which chemically link different protein chains. Those bonds are labile to alkali (5). Virupaksha and Sastry (33) analysed protein fractions isolated from sorghum for amino acid and reported that glutelin has a higher content of lysine, threonine, arginine, and methionine than the prolamines. They also observed that high content of prolamines is generally accompanied by high levels of protein.

A major factor that determines the amino acid composition of the protein of sorghum grain is the variety and hybrid. Deyoe and Shellenberger (35) showed the variation in protein content and demonstrated significant differences in amino acid composition of the protein of 15 varieties of sorghum at two locations. They stated that the correlations of lysine,

arginine, and glycine to the amount of protein were negative. Waggle and Deyoe (36) showed that hybrids developed in the United States resulted in higher levels of proteins deficient in certain essential amino acids. Virupaksha and Sastry (33) established a correlation between high protein content and a low proportion of lysine in the protein. They also stated that essential amino acids are higher in the germ than the endosperm. Next to the aleurone layer is the periphery of horny endosperm, a layer rich in prolamines.

Millet is generally somewhat higher in protein than rice, sorghum, corn, and oats. Its protein content ranges from 10.6 to 15.2% (37). Generally the protein content of cereal grains is negatively correlated with grain yield. Phul et al. (38) found that this pattern holds true for pearl millets. Burton et al. (15) reported that some millet samples grown in India research stations contained up to 23% protein. Those high protein samples had a high percentage of prolamines which are known to be deficient in lysine and therefore give a lower content of lysine in the total protein of the millet (30).

Recent data (15, 37, 39, 40, 41) show lysine is the most limiting amino acid in pearl millet and tryptophane is present at higher level than found in other cereals (15). Jones et al. (9) reported that millet prolamines are soluble in t-butyl alcohol. Prolamine from white dehulled millet contained less lysine, arginine, and glycine and more alanine, methionine, and leucine than did globulins or albumins (9, 42).

Lipids. Hubbard (43) reported that the nonpolar lipids in five varieties of sorghum grain and their hand-disected fractions closely resemble those of corn. The average oil content of the whole grain was

3.6%, the endosperm contained 13%, the germ 76%, and the bran 11% of the total oil. An appreciable amount of wax was concentrated in the bran.

Wall (44) reported the triglycerides constituted the largest fraction of sorghum nonpolar lipids, while smaller amounts of hydrocarbons, sterol esters fatty acids, monoglycerides, diglycerides, sterols and phospholipids were present.

Kumonerow (45, 46) reported that sorghum grain oil was slightly less saturated than corn oil and contained more oleic and stearic acid and less linoleic, myristic, and palmitic acid than corn oil. Neither corn nor sorghum oil contained linolenic acid or fatty acids above C_{18}, but Denisenko and Volkova (47) and Bertoni et al. (48) reported that sorghum oil contained from 1 to 2% linolenic acid.

Kumonerow (45) found that the wax content of sorghum (0.25%) is 50 times more than that of corn, and the wax can be easily removed by extracting unground whole grain with hot hexane. Dalton and Michel (49) fractionated sorghum wax with tricalcium phosphate and salicilic acid columns and found 5% paraffins, and 49% esters of long chain fatty alcohols.

The major component of bound sorghum lipids (extractable by methanol: chloroform) are phospholipids (5). Boissy and Perles (50) fractionated the phospholipids into a fraction soluble in 95% ethanol (lecithin) and an insoluble fraction (cephalin). Yash Paul et al. (51) identified cerebrocides and phosphatidyl serine by two dimensional thin layer chromatography of polar lipids from sorghum.

Pruth and Bhatia (52) reported that the free lipid content of millet was 5.0 to 5.23%, significantly higher than that of sorghum and wheat. Using TLC, they identified the major component of nonpolar lipids as triglycerides. Sterol esters and hydrocarbons, free fatty acids, free sterols, and diglycerides were also identified.

Jellum et al. (53) found that the millet oil had a higher level of palmitic and stearic acid, and lower level of oleic acid than either corn or sorghum. Freeman (30) agreed with those results.

Sharma and Goswami (54) showed that the high yielding hybrids of millet are highest in lipids, lowest in acid value and moderate in iodine value.

Phenolic Pigments. The sorghum grains vary in color from white to dark brown depending on the presence of phenolic pigments (5). Nip and Burns (55) investigated the pigments found in several red varieties of sorghum. Blessin et al. (56) detected anthocyanogens in yellow milo and red kaffir but not in white, waxy, or yellow endosperm varieties.

Those sorghum grains which have brown seeds are characteristically high in tannins. Chang and Fuller (57) showed that high levels of tannins in the grain retarded the growth of chicks. Barham et al. (25) found that sorghum tannins do not react with tannic acid, and concluded that sorghum tannins consist of condensed flavonoids.

Carotenoids. Blessin et al. (58) stated that the common varieties of sorghum contained about 1.5 ppm total carotenoids and those with yellow endosperm contained as high as 10 ppm; however yellow corn contained up to 21 ppm. Chromatographic separation showed the major carotenoids of yellow endosperm sorghum: Zea-xanthin, 2.8 ppm; lutein, 2.2 ppm, and β-carotene, 0.8 ppm (5).

Vitamins. Hubbard et al. (43), Tanner et al. (59) and Naik and Abhyankar (58), comparing corn and sorghum, agreed that they contain approximately the same quantities of riboflavin and pyridoxine but sorghum contains more nicotinic acid, panthothenic acid and biotin.

Naik and Abhyankar (60) reported that sorghum grain compares favorably with wheat and rice in the amount of thiamine and niacin but the level of riboflavin is lower.

Grain Minerals. Pinta and Busson (61) showed that the major minerals present in sorghum grain are phosphorus, magnesium, potassium and silicon. Lesser amounts of calcium and sodium are present.

Goswami et al. (62, 63, 64) analyzed American, African, and Indian millets, and reported that phosphorous ranged from 0.65 to 0.96, calcium 0.02 to 0.053, and iron 0.0035 to 0.0117%. Indian varieties were highest in phosphorous and the American highest in calcium.

Enzymes. Norris and Viswanath (65) reported two amylases in sorghum grain and called them amylase and dextrinase. Dube and Nordin (66) isolated and purified α-amylase from sorghum grains.

Kneen (67) reported that sorghum serves as a source of saccharification enzymes in the fermentation of African beers. Novellie (68) and Botes et al. (69) isolated and concentrated β-amylase from sorghum grains and it accounted for 18% of the total amylase activity. Miller and Kneen (70) reported the presence of a high molecular weight organic acid in certain sorghum varieties that inhibit amylases activity. The inhibitor was concentrated mainly in the bran and germ.

Chandrasekhara and Swaminathan (71) reported that ungerminated millet has very little amylase activity, but unlike barley malt, malted ragi (finger millet) contained a large proportion of α-amylase. They (72) also found that germinated millet has greatly increased activity of both pyro and glycerophosphatases. The latter is strongly inhibited by fluoride ion. In later work (73) they found that malted pearl millet had a large increased α-amylase activity but only slightly increased β-amylase activity.

Dry Milling. Most milling of sorghum has been with wheat roller mills (5). Shoup et al. (74) gave a detailed breakdown of sorghum grains. They stated that bran and germ were 19.3%, break flour 12.0%, flour less than 100 mesh 29.1%, endosperm retained on 100 mesh (10XX) 34.2% and endosperm over 70 mesh grit gause (70GG) 5.1%. Improvement of the color was obtained by modifications of the flow sheet and proper tempering. Peplinski (75) air classified commercially produced sorghum flours. Little or no work has been reported on the milling of millet.

Use in Baked Products.

Rooney et al. (76) formulated yeast leavened bread, cakes, and cookies containing sorghum flour. They stated that the products were acceptable when small quantities of sorghum flour were substituted for wheat flour. Hart et al. (77) made acceptable pan bread from sorghum by adding a gum, 4000 cps Methocel, and using a batter system of 55% moisture.

Attempts have been made to produce cookies from 100% sorghum flour (78). They reported that the cookies were acceptable although they were

inferior to the wheat cookies, due to their grittiness, mealy taste and pronounced spicy flavor and taste caused by addition of ginger powder to mask the sorghum flavor.

Kim (79) stated that in making hard biscuits from composite flour such as millet and sorghum, it may be necessary to improve the coherence of the biscuit dough by cooking or fermenting (yeast sponge) part of the flour before mixing the complete dough.

MATERIALS AND METHODS

Two varieties of sorghum and one variety of millet (2 crop years) were used for the analyses and baking tests. The sorghums were a bulk red seeded commercial sample and a yellow seeded (C-42Y) sample obtained from DeKalb.

The millet was derived from two open pollinated varieties from Uganda, which were grown interspersed with Tift 238 and Tift 239 millets (dwarf forage types from U.S.D.A. program), F_3 and F_4 seed from combine height plants were used in this study.

Scanning Electron Micrographs.

The sorghum and millet kernels were cross sectioned at the center with a razor blade which produced a fracture rather than a smooth clean cut. After cutting the half kernels were mounted on aluminium stubs with Delco. No. 93 colloidal silver, coated with a 150 Å thick gold-palladium layer and viewed and photographed in an ETEC Autoscan scanning electron microscope at an accelerating voltage of 20 KV.

Isolated starches were dusted on double sided scotch tape, mounted on the aluminium stubs and coated, viewed and photographed under the same conditions as the kernels.

Starch Gelatinization.

A Thomas microscope (Model AHT) equipped with a Model 40 micro hot stage was used to determine gelatinization temperature.

The hot stage was regulated to give a $1^{\circ}C$ rise in temperature per minute. The sample (1% starch suspension) was placed on a glass slide

and covered with a glass cover outlined with mineral oil to prevent evaporation. The gelatinization temperature range was determined by the loss of birefrigance.

Wet Milling of the Starch.

Samples ranging from 500 - 1000 gm of cleaned grain were steeped in distilled water. Ratio of grain to water was 1 to 2 (gm/ml). Steeping was in a refrigerator at 40°F for a period of 24 - 28 hrs. After steeping, the excess water was decanted and the grain washed several times with distilled water.

The grain was rough ground in a waring blender (low speed) with enough distilled water to just cover the grain, and then sieved through a 60-mesh nylon bolting cloth. The overs (hulls, germ, and endosperm) were slurried with distilled water and the germs and hulls floated off. Rough grinding was repeated once more using the same procedure.

After separating hulls and germs, the endosperm was blended at high speed, and sieved on the 60-mesh cloth. The overs were again blended as before and the process repeated until no more starch was obtained.

The starch and protein slurry was centrifuged at 2000 rpm (1000 X G) for 20 min. After each centrifugation the supernatants were discarded. As the result of centrifugation the protein formed a layer on top of the starch. The protein was removed with a spatula, and the starch was washed by redispersing in distilled water and centrifuging as above.

The starch was air dried on a glass tray for 12 hrs., redispersed in water, and wet sieved through a 100-mesh sieve. The sieved slurry was centrifuged at 1000 X G for 15 min., the water decanted, and the starch air dried for further studies.

Visco-amylograph.

Amylograms were prepared on a Brabender Visco-amylograph, type VA-V, 700 cm.g. sensitivity cartridge at 75 r.p.m. and the AACC method was used.

Forty gm. (14% MB) of starch or fifty gm. (14% MB) of flour were suspended in 460 ml. of diluted buffer, and the slurry was heated with a temperature rise of 1.5°C per minute in the visco-amylograph cup.

The temperature of the suspension was raised to 95°C, maintained at that temperature for one hour, then cooled at the rate of 1.5°C per minute to 50°C and held for one hour.

For the determination of the relative enzyme activity of malt and millet flour, various amounts were added to a constant wheat flour (60 gm. 14% MB).

Amylose and Amylopectin Determination.

Sorghum and millet starches were fractionated into their amylose and amylopectin fractions by the methods of Lansky, Kooi and Schoch (18) as modified by Montgomery and Senti (19). Starch (20 gm) was suspended in 400 ml. of 80% n-butanol in a three-necked 2-liter flask equipped with a thermometer and a stirrer. The system was buffered at pH 6.2 - 6.3 with 6.6 ml. of phosphate buffer (16.4 gm. of anhydrous KH_2PO_4 and 3.6 gm. K_2HPO_4/100 ml. distilled water).

The flask was heated in a water bath regulated to rise from 30°C to 89°C in 1 hr, to 1½ hr. and held at that temperature for another hour. After cooling to 25°C, the starch was separated by filtration and washed with ethanol.

The washed starch was made to a 2% suspension in water and heated with continuous stirring at 98°C for 11 - 15 minutes. The solution was

cooled quickly by dipping the flask into ice water.

After cooling, the solution was centrifuged at 2000 X G for 30 min. and the crude amylopectin separated as a gel. That gel was purified two more times by reprecipitation as outlined above. The amylopectin gel was dried by blending with an excess of methanol in a waring blender for three min.

The amylose in the combined supernatants from above was precipitated with several volumes of n-butanol and dried by washing with acetone. The amylose content was determined by the iodine blue value at 610 nm in a Beckman Quartz spectrophotometer (29).

Dry Milling of Sorghum and Millet.

Sorghum and millet samples used for protein and amino acid analyses were milled on a Quadramat junior experimental mill. The flow sheet shown in Fig. I was used and the products were collected as bran, a high ash flour, and two low ash flours.

The millet flour used for baking tests was milled on a Buhler experimental mill (Fig. 2). A straight grade flour yield of 63.4% was obtained.

Sorghum was milled on a KSU experimental mill with the flow sheet shown in Fig. 3. The straight grade flour extraction was 60%.

Amino Acid Analyses.

Amino acid composition of grain and milled fractions was determined using a 120 B Beckman Amino Acid Autoanalyzer. Samples were hydrolyzed for 22 hours with 6N HCL at 110°C in sealed tubes.

Preparation of the Lipid Samples.

All extracted lipids were evaporated under vacuum below 40°C. Lipids

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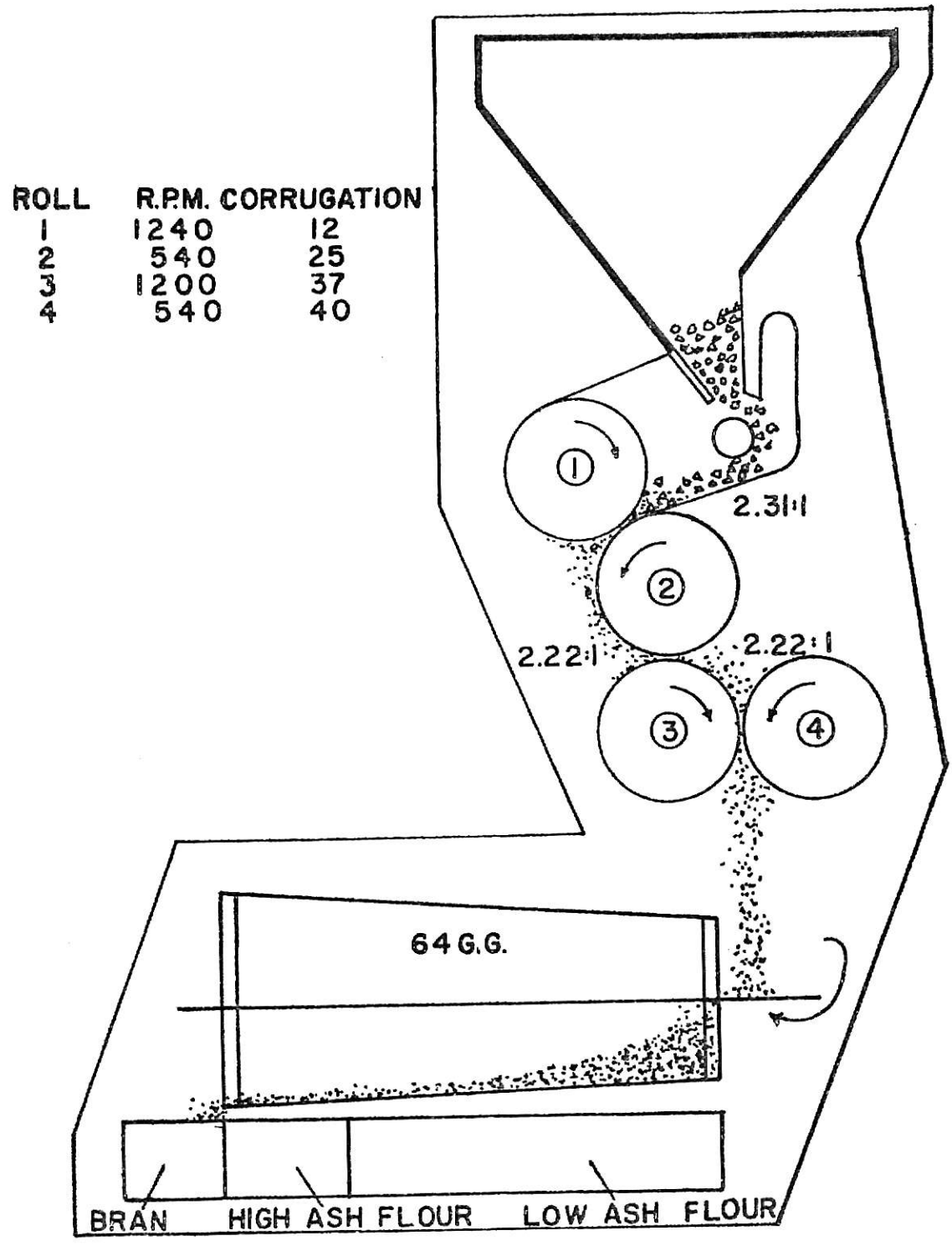
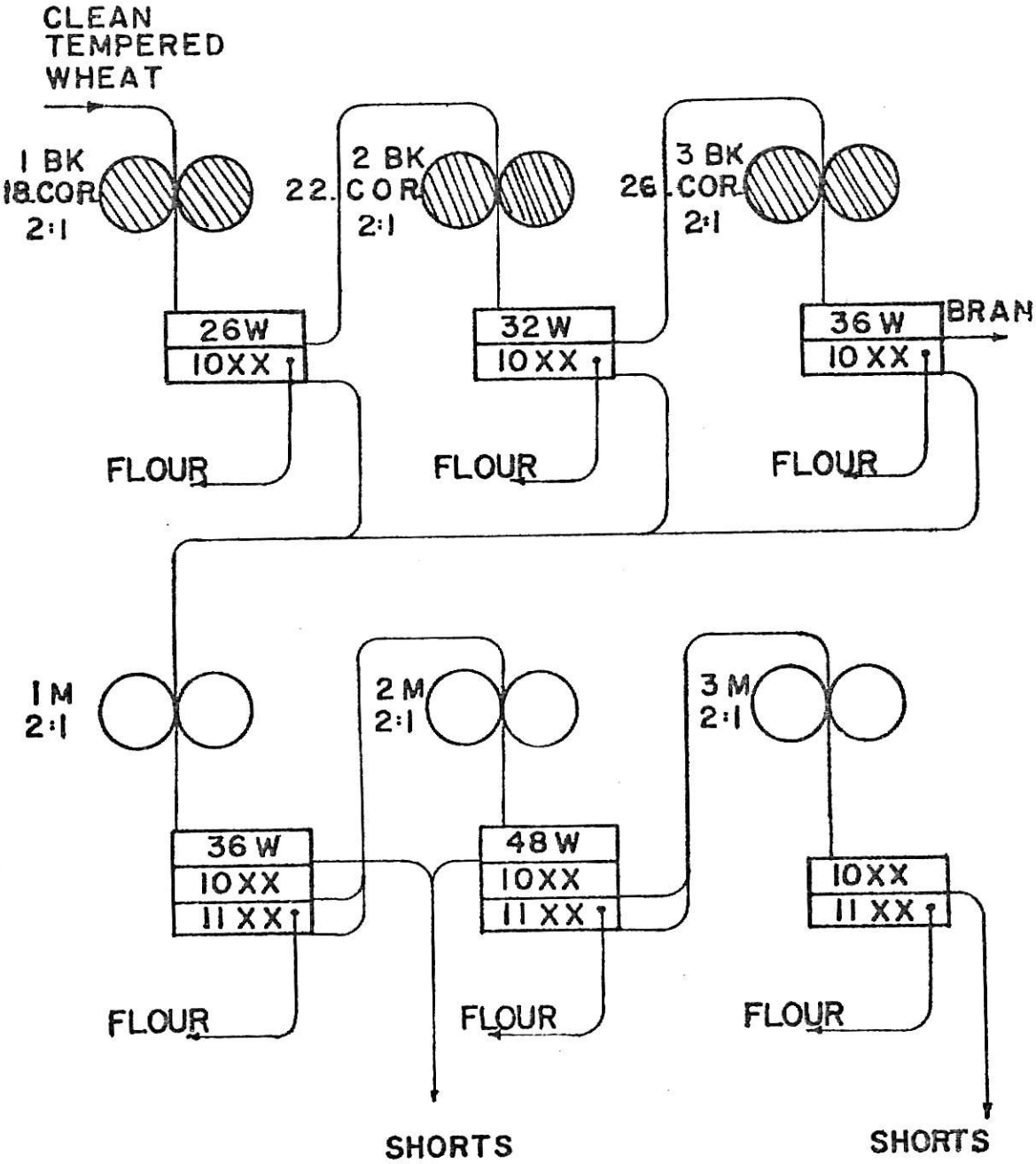
Fig. 1. A flow diagram of the Quadramat Junior Experimental Mill.



QUADRUMAT JUNIOR EXP. MILL

Fig. 2. A flow diagram of the Buhler Experimental Mill.



FLOW SHEET FOR BUHLER EXPERIMENTAL MILL

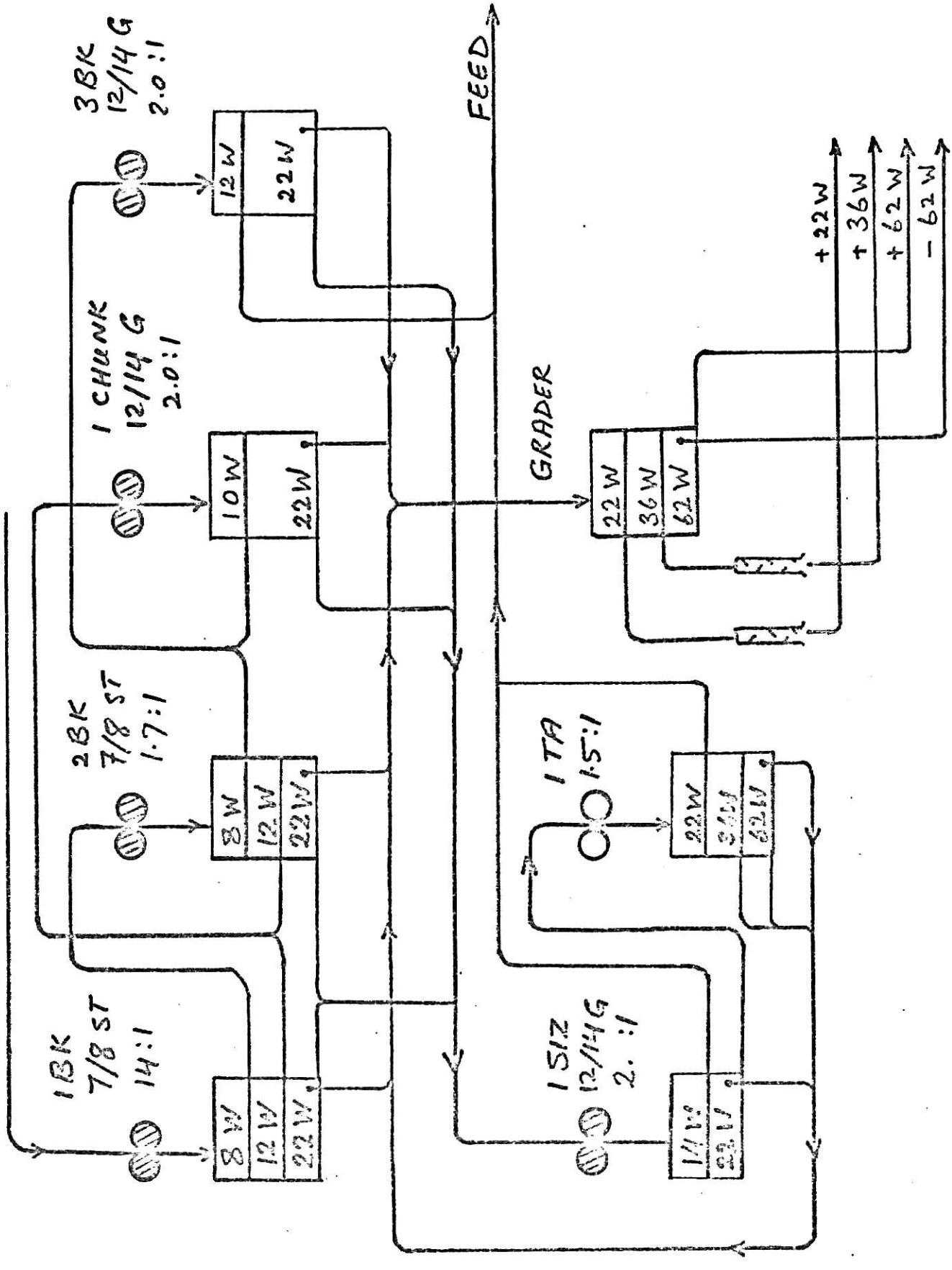


Fig. 3. A flow diagram for the KSU Experimental Mill.

that were extracted with water-saturated butanol were purified by dissolving in petroleum ether.

Total free lipids were extracted with petroleum ether (b.p. 35 to 60°C) in a Soxhlet apparatus. The lipid fractions were characterized by thin layer chromatography.

Thin Layer Chromatography.

Glass plates (20 X 20 cm) were coated with 50 mm layer of Silica gel G for TLC. The plates were air dried and activated for 2 hrs. at 110°C and cooled in a desiccator.

Thin layer chromatography was performed with 100γ of lipids. One plate was developed with chloroform for nonpolar lipids. A second plate was developed with chloroform - methanol - water (65:25:4) for polar lipids. Plates were sprayed with a saturated solution of $K_2Cr_2O_7$ in 55% (V/V) of aqueous sulphuric acid, charred at 150°C for 30 min., and photographed under ultraviolet light.

The Cookie Test.

The micro cookie test, described by Finney et al. (80) was used with slight modifications. A Hobart N50 mixer with a cake paddle was used for creaming and mixing.

A cream was prepared by mixing 900 g sugar, 450 g shortening, 45 g NFDM, and 15 g $NaHCO_3$ for 0.5 min. at low speed, 0.5 min. at medium speed, and 4 min. at high speed with scraping every 0.5 min.

To 112.8 g of the creamed mass, 12 ml of solution A (79.8 g $NaHCO_3$/1000 ml water), 9 ml of solution B (67.765 g of NH_4CL and 59.235 Na CL in 1000 ml water), and optimum water were added. The

mixture was mixed for 30 sec. at low speed and 45 sec. at medium speed. Thereafter, 120 g of flour (14% MB) was added and the dough was mixed at low speed for 15, 5, 5, and 5 seconds with scraping between each interval.

The dough was divided into six equal parts on a greased cookie sheet, and then rolled out with one movement to 0.60 cm thickness. The dough was cut with a 5.75 cm cutter. The cookies were baked at 400°F for 10 min., cooled for 5 min., and then removed from the sheet. The spread was determined by averaging the diameter of two cookies measured in two directions at 90° to each other.

Bread Baking.

The baking procedure described by Finney and Barmore (81, 82, 83) and Finney (84). Sorghum and millet flours were added at various levels (5, 10, 15, and 20% of the wheat flour weight) and absorption and mixing time were optimized for each dough. Sodium stearyl-2-lactylate (SSL) and soybean oil (0.5% each), both separately and combined, were added with the shortening. Loaf volume and weight were measured immediately after baking, usually within 3 min. Loaves were scored after cooling.

RESULTS AND DISCUSSION

Grain Characterization.

Scanning electron micrographs of cross sections of sorghum grain approximately at the center are shown in Fig. 4. The hard or translucent endosperm portion of the sorghum grain (Fig. 4, top) is characterized by a tightly packed structure with no air spaces. Also clearly visible are the protein bodies and starch granules. The starch granules are polygonal with an average diameter of 15 - 25μ. They appear to be covered with a thin layer of protein matrix in which protein bodies are embedded. In some areas indentations on the starch granules are seen. Those indentations are from the protein bodies removed when the kernal fractured.

The soft or opaque endosperm (Fig. 4, bottom) is characterized by relatively large intergranular air spaces, and loosely packed, mostly spherical starch granules. The starch granules are 10 - 20μ in diameter and covered with a thin layer of protein in which is occasionally embedded small spherical protein bodies.

The endosperm of the sorghum grain consists of cells which store the starch. The endosperm is divided into an outer horny region and an inner floury region. Outside the endosperm is an aleurone layer which has thick cell walls and is filled with protein bodies. Figure 5 shows clearly the testa or subcoat layer beneath the pericarp and outside the aleurone layer. The cells are greatly elongated and thought to be reminants of the nucleus. The testa is a characteristic of some sorghum grain varieties, such as Feterita, while it is absent in others. Outside of the testa is the pericarp.

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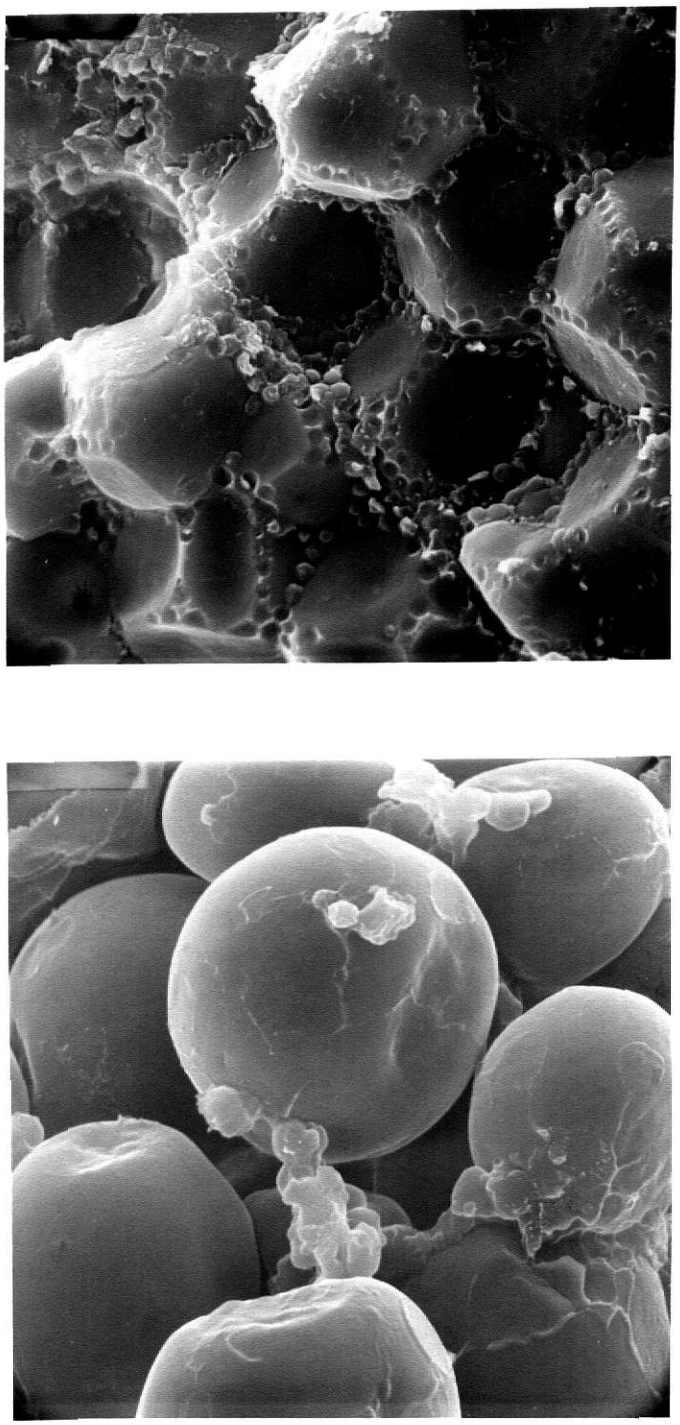


Fig. 4. Scanning electron photomicrograph (SEM) of grain sorghum endosperm. Top, the hard endosperm (2000x); bottom, the soft endosperm (4000x).

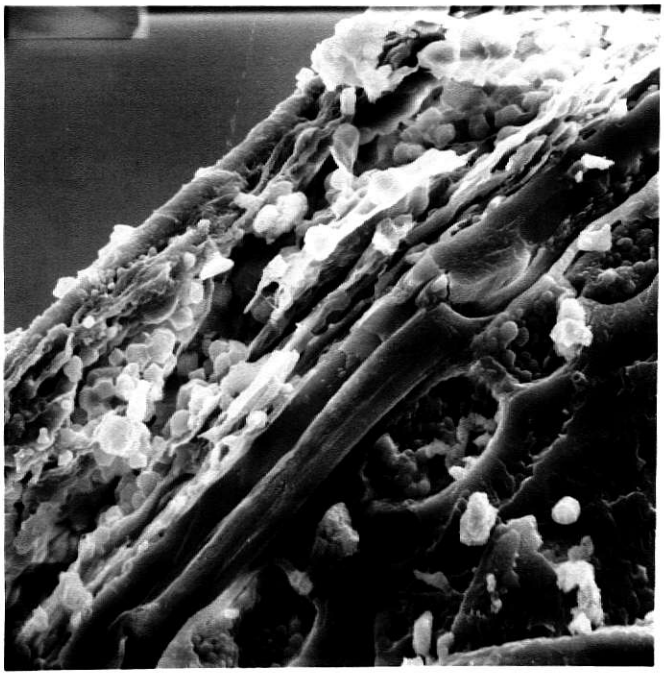


Fig. 5. SEM of the outer edge of grain sorghum showing the testa layer (840x).

Millet Grain Structure.

Average grain weight for millet was 8 mg and the kernel size was 1.5 mm wide, 2 mm long, and 1.5 mm thick. Millet endosperm is shown in Fig. 6. It is similar to sorghum grain endosperm except millets do not have a testa or subcoat layer. The cells and starch granules are smaller than those of sorghum grain. Starch granules ranged from 5 to 12μ. Protein bodies, protein matrix and indentations in the starch granules are seen clearly in Fig. 6 (top). In contrast to sorghum, millet soft endosperm (Fig. 6, bottom) contains no protein bodies.

The starch hilum of both sorghum (Fig. 7, top) and millet (Fig. 7, bottom) are clearly visible. Average size of the sorghum grain hilum appears to be 1μ in diameter and 2.5μ long. For millet the hilum was about 0.5 - 0.75μ in diameter with no evidence of the length.

Autoamylosis of Sorghum Grain.

Cross-sections of the sorghum endosperm (Fig. 4) showed the starch granules both in hard and soft portions of the endosperm to have smooth surfaces and showed no evidence of enzymatic attack. In contrast, enzymatic attack is clearly visible on the surface of sorghum starch from grain soaked overnight in water (Fig. 8). Granules that showed most attack were the sperical ones from the soft endosperm. This indicated that indigenous enzymes of the grain which are located in the soft endosperm are activated and attack the starch granules when the grain is wetted.

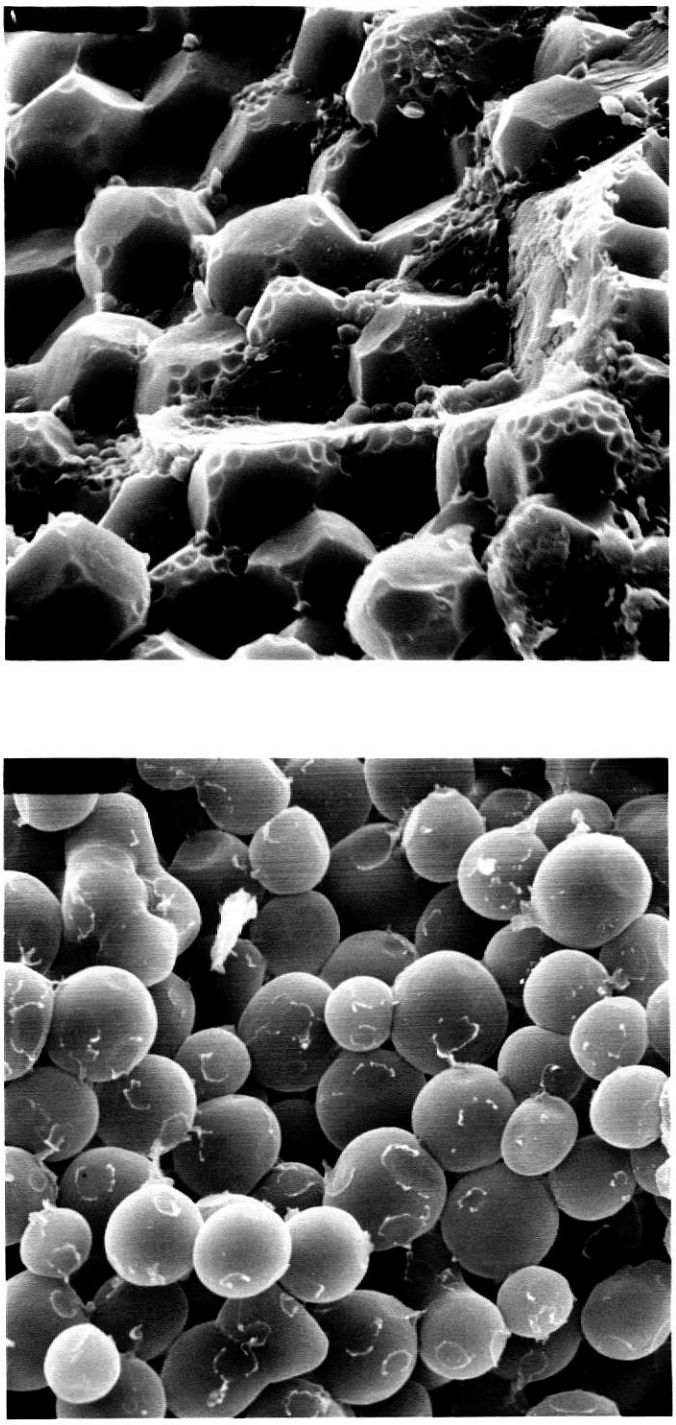


Fig. 6. SEM of millet endosperm. Top, hard endosperm (2000x). Bottom, soft endosperm (1760x).

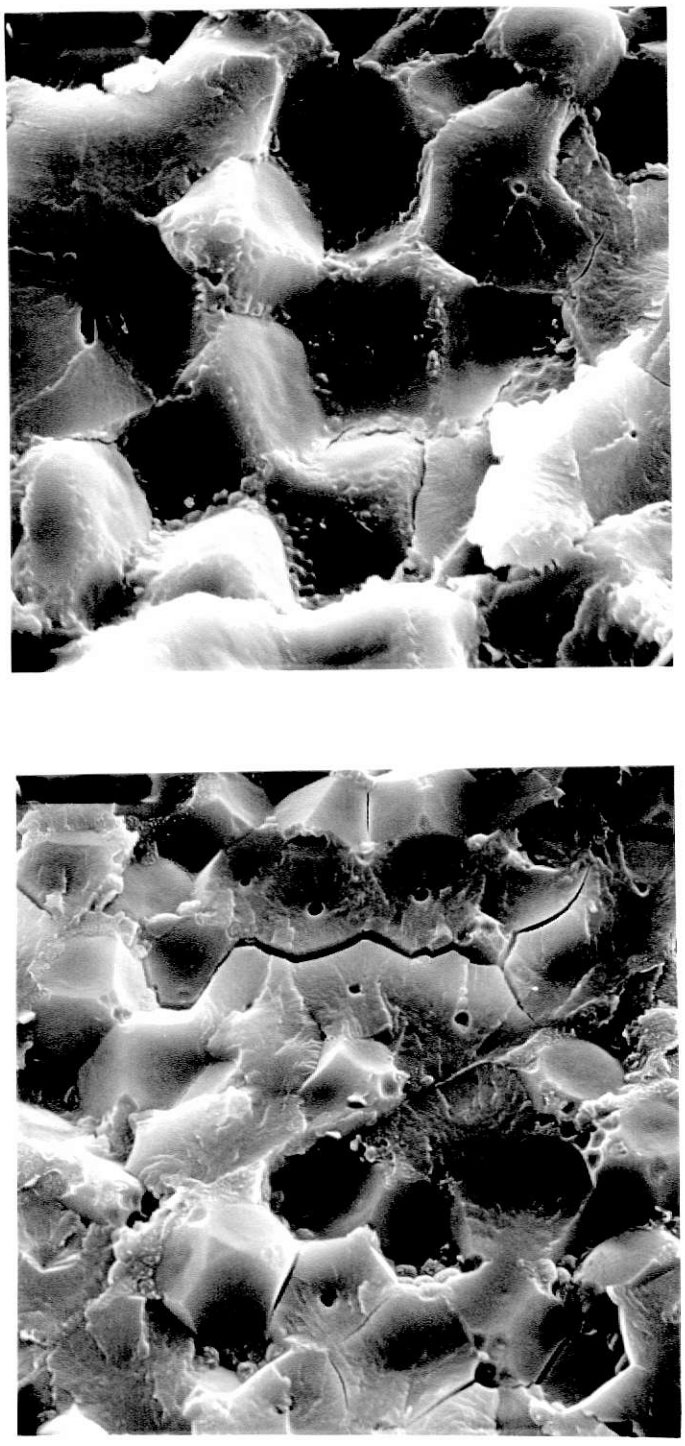


Fig. 7. SEM of hard endosperm portion of sorghum grain (top) and millet (bottom) showing the starch hila, both at (2000x).

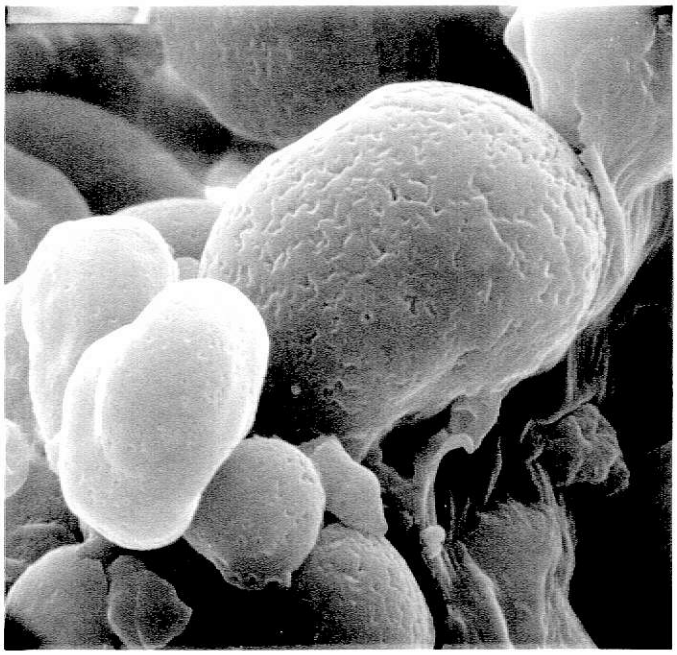


Fig. 8. SEM of sorghum grain soft endosperm which was soaked in water for 16 hours.

Solubility of Sorghum and Millet Protein Bodies.

Reportedly the major portion (30 to 60%) of sorghum grain proteins (prolamines) is soluble in 60°C, 70% ethanol (5). Millet prolamines were reported to be soluble in t-butyl alcohol (9).

The hard endosperm portion of sorghum grain after treatment with 70% ethanol for three hours at 60°C is shown in Fig. 9 (top). The protein bodies (prolamines) were removed leaving a network of matrix protein. Analyses of the meal for nitrogen before and after treatment with alcohol, showed that 24.73% of total protein was dissolved by the alcohol. This value may be due to the relatively short time employed. The similar effect of 60°C, 70% ethanol on millet proteins is shown in Fig. 9 (bottom). Analysis showed that 30.7% of the millet protein was soluble in ethanol. To check the report (9) that millet prolamines were soluble in t-butyl alcohol, millet was treated with t-butyl alcohol overnight at room temperature (Fig. 10). As clearly seen, the protein matrix was removed and the protein bodies remained. Analyses showed that 27.19% of the total millet proteins were soluble in t-butyl alcohol. Thus, there appears to be two different alcohol soluble proteins in millet. Tertiary butyl alcohol did not appear to affect the sorghum grain proteins.

Characterization of Sorghum Grain and Millet Starches.

Sorghum grain and millet starches are shown in Fig. 11. Millet starch granules are 8 - 12μ in diameter, approximately half the size of the sorghum starch granules (20 - 25μ). Within both sorghum and millet grain a variation in size was noted. That variation in size was accompanied by variation in shape, some of the granules being spherical and others

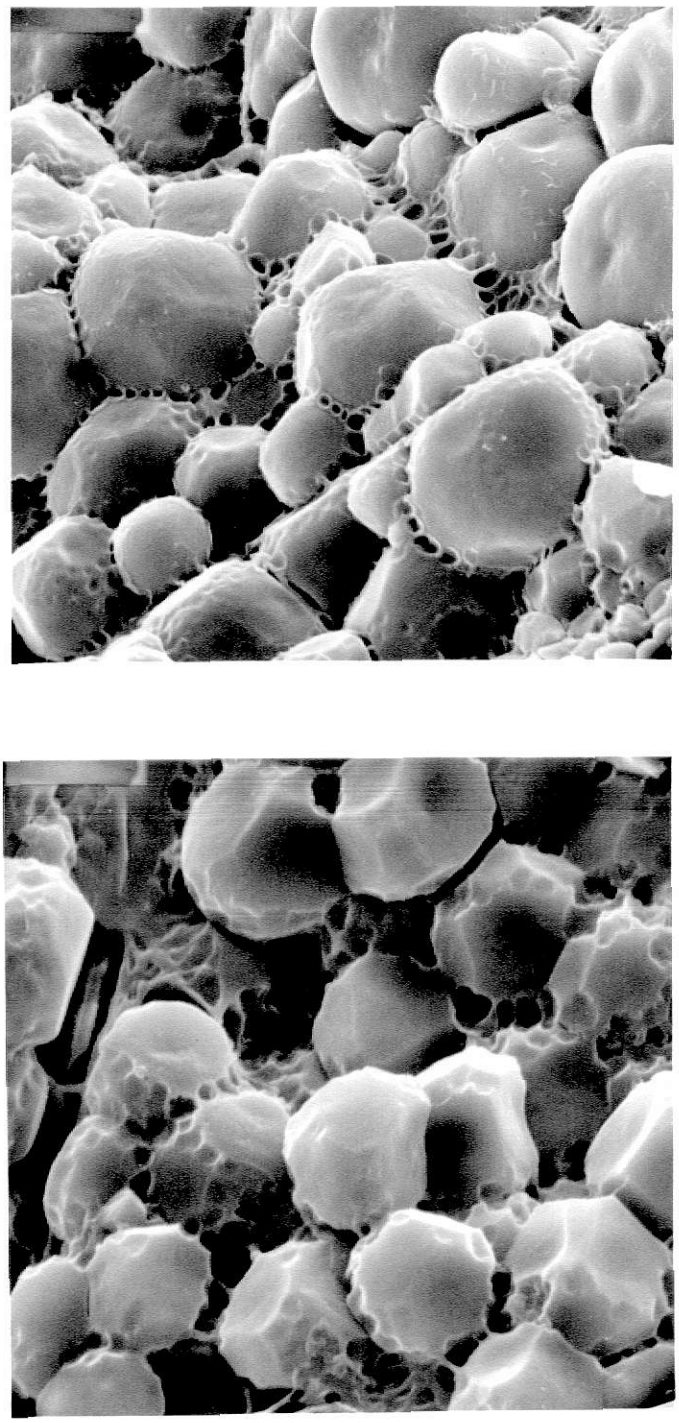


Fig. 9. SEM of sorghum grain (top, 640x) and millet (bottom, 2200x) treated with 60°C, 70% ethanol.

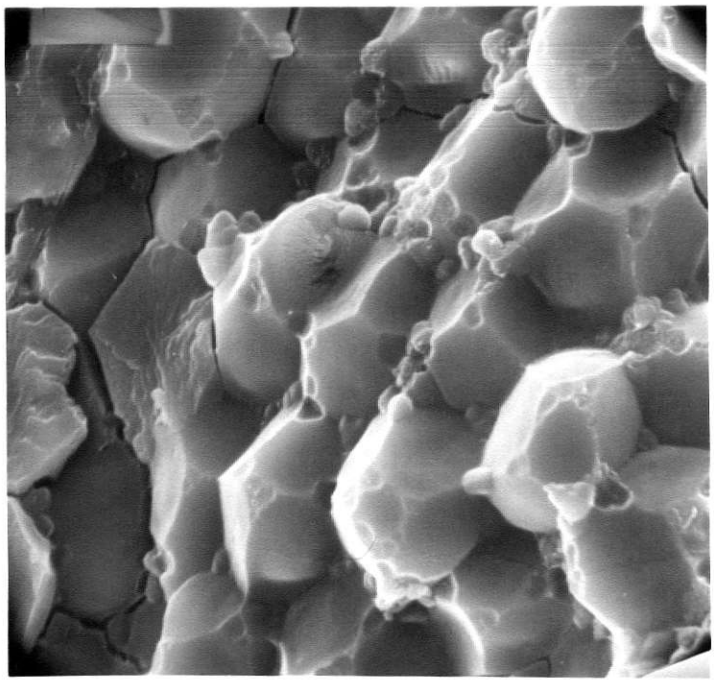


Fig. 10. SEM of millet endosperm treated with t-butyl alcohol (2100x).

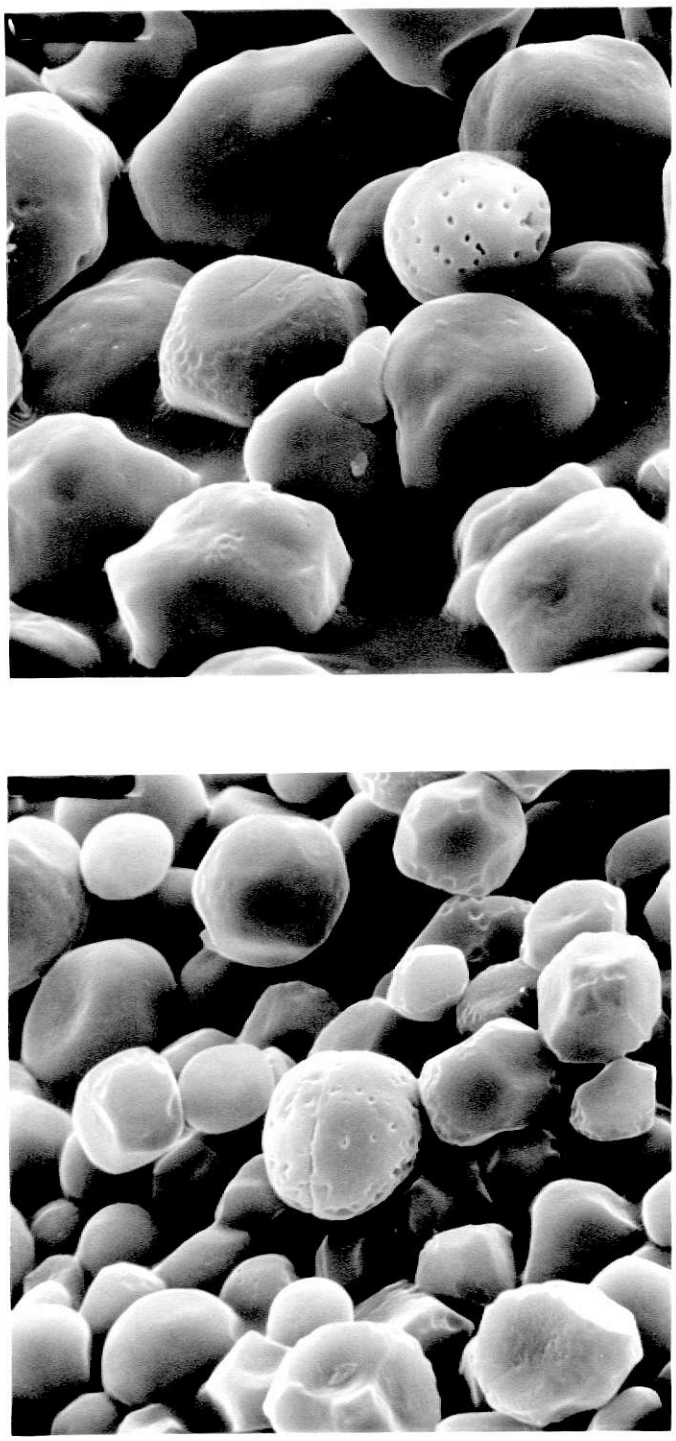


Fig. 11. SEM of isolated grain sorghum (top, 2000x) and millet starch (bottom, 2000x).

being polygonal. Also some granules show indentations of the surface caused by the protein bodies removed during starch isolation.

Both starches showed enzymatic attack on the spherical granules. Those spherical granules are known to come from the soft endosperm portion of the kernel (Fig. 4 and 6). Enzymatic attack was also noted in the kernels soaked in water (Fig. 8) and was concentrated in soft endosperm. The attack apparently occurred during steeping the grain for wet milling. Grain which had not been wetted did not show any attack (Fig. 4 and 6).

A preferential enzymatic attack of spherical granules could be due to one of two reasons. Either the enzymes are concentrated in the soft endosperm of the kernel, or the soft endosperm starch granules are more susceptible to enzymatic attack.

Hot Stage Gelatinization.

Gelatinization temperature of a 1% starch suspension of both sorghum grain and millet were determined using a Kofler hot stage microscope.

Sorghum grain starch undergo gelatinization over a temperature range of 63 - 74°C. Millet starch gelatinization temperature ranged from 51 to 69°C.

Those gelatinization temperatures can be altered markedly by adding certain adjuncts. Some adjuncts accelerate the disruption of the hydrogen bonds to enhance gelatinization (22).

Hydroxides, urea and phosphates lowered the gelatinization temperature of both sorghum and millet starches, and at higher concentrations of these compounds gelatinization occurred at room temperature (Table 1 and 2).

Table 1. Sorghum and Wheat Starches (1% Suspension) Gelatinization Temperature Range and Effect of Different Treatments on Gelatinization Temperature Range.

Treatment	Concentration	Sorghum °C	Wheat °C
Distilled Water		63 - 74	49 - 60
Urea	1 M	49 - 61	40 - 50
Lactic Acid	0.1 N	51 - 70.5	37 - 48
" "	0.5 N	49 - 70.0	36 - 48
" "	1.0 N	48 - 70.0	36 - 48
Sodium Hydroxide	0.025 N	48.5 - 70.0	43 - 59
" "	0.050 N	45 - 67	40 - 56
" "	0.075 N	41 - 60	33 - 46.5
" "	0.100 N	38 - 50	P.R.T. b/
Potassium Hydroxide	0.1 N	41 - 69	"
" "	0.5 N	R.T. a/	"
" "	1.0 N	"	"
Phosphoric Acid	0.25%	58 - 70	37 - 58
" "	0.50%	59 - 71	38 - 58
K_2HPO_4	0.25%	59 - 72	36 - 58
"	0.50%	58.5 - 72	38 - 59
KH_2PO_4	0.25%	59 - 72	36 - 58
"	0.50%	59.5 - 72.5	39 - 59
Sodium Carbonate	0.1 N	65 - 76	56 - 67
" "	0.5 N	65.5 - 81	- -
" "	1.0 N	65 - 82	59 - 70
Sodium Bicarbonate	0.1 N	63 - 75	- -
" "	1.0 N	64 - 80	- -
Potassium Carbonate	0.1 N	65 - 78.5	- -
" "	1.0 N	70 - 93	- -

a/ Gelatinization at room temperature.

b/ Partial gelatinization at room temperature.

Table 2. Gelatinization Temperature Range of Millet, Barley, Triticale Starches (1% Suspension) and the effect of Sodium Hydroxide and Sodium Carbonate on Gelatinization Temperature Range.

Treatment	Concentration	Millet °C	Triticale °C	Barley °C
Distilled Water		51 - 69	43 - 59.5	45 - 60
Sodium Hydroxide	0.025 N	51 - 67	43 - 57	43 - 59
" "	0.050 N	42 - 65	40 - 55	41 - 54.5
" "	0.075 N	P.R.T. a/	30 - 48	35 - 46.5
" "	0.100 N	"	R.T. b/	P.R.T.
Sodium Carbonate	0.100 N	60 - 73	48.5 - 65	50 - 64.5
" "	1.000 N	65 - 78	57.0 - 67.5	55 - 67.5

a/ Partial gelatinization at room temperature.

b/ Gelatinization at room temperature.

Carbonates raised the gelatinization temperature of sorghum grain and millet starches, not only with isolated starch but also in the dough system.

The addition of 0.05, 0.1 or 1.0 N sodium bicarbonate to wheat dough raised the gelatinization temperature. The higher the concentration of sodium bicarbonate the higher was the gelatinization temperature. In contrast, sodium hydroxide at all levels (0.01, 0.05 and 0.1 N) lowered the gelatinization temperature of the wheat dough.

The effect of sodium bicarbonate and sodium hydroxide on sorghum dough similarly raised and lowered gelatinization temperature, respectively.

The other ingredients in the dough such as sugar, nonfat dry milk, and salt had no effect on both sorghum and wheat doughs.

Pasting Properties of Sorghum and Millet Starches.

Amylograph properties of sorghum grain and millet starches and flours are given in Table 3 and Fig. 12. Amylograms were obtained using 40 gm. (14% MB) of isolated starch and 50 gm. (14% MB) of flour in all cases.

The sorghum grain (C-42Y and Bulk) starches showed the highest pasting temperatures 78.5 and 78°C, respectively. The pasting temperature of millet starch was found to be 6 degrees lower (72°C). That agrees with the results of the hot stage microscope gelatinization temperature ranges which gave a maximum of 74°C for sorghum starch and 69°C for millet starch.

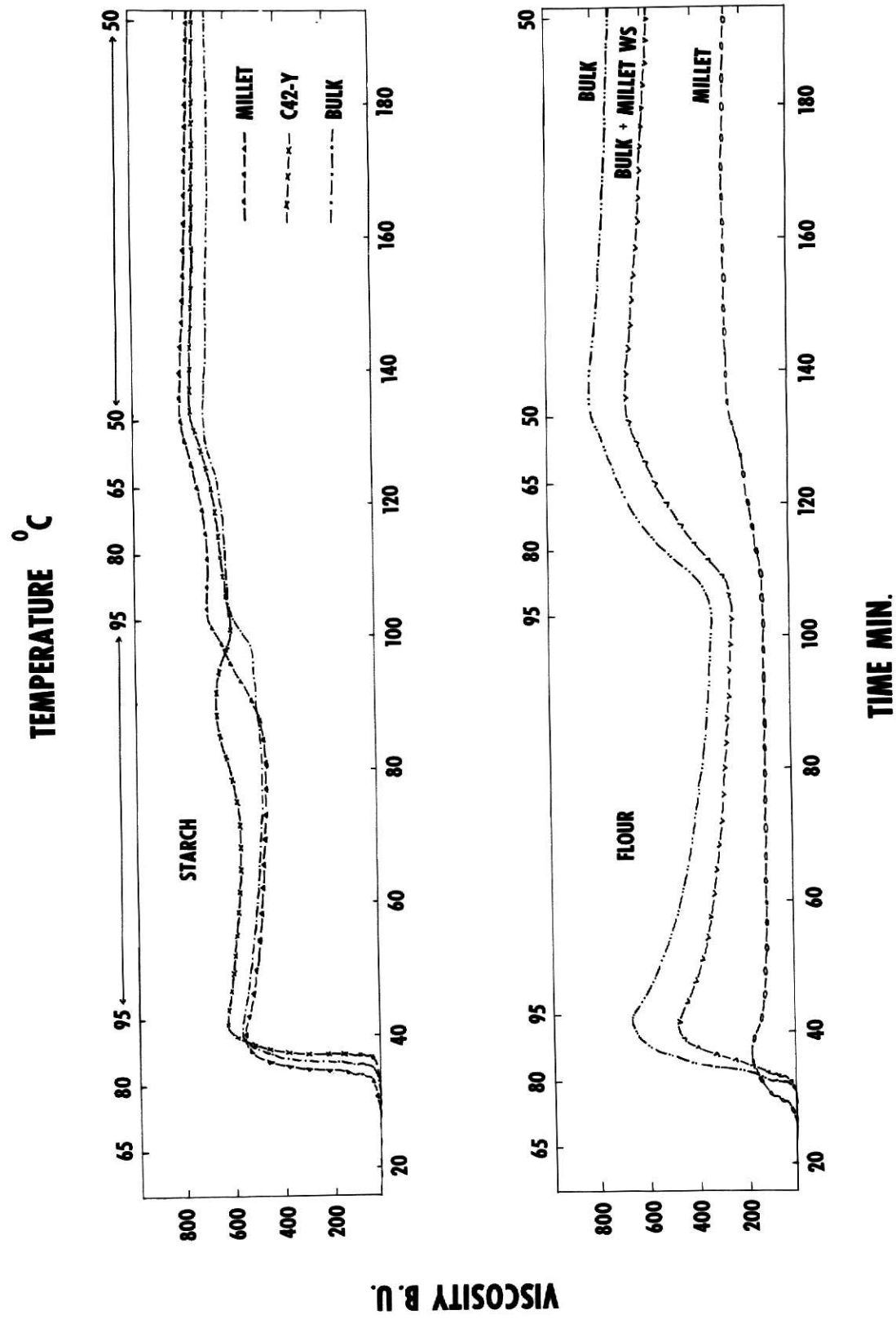
Similar results were obtained with the flours, although the difference was not as large as with starches (Table 3 and Fig. 12).

Table 3. Pasting Properties of Sorghum and Millet Flours and Starches[a/].

Sample	Pasting Temp. °C	Peak Viscosity B.U.	Peak Temp. °C	Viscosity B.U. 1 hr. holding at 95 °C	Cooled to 50 °C	1 hr. hold at 50 °C
Sorghum flour (bulk)	73.5	668	95	324	805	735
Millet flour	70.5	195	90	118	220	215
Sorghum flour + millet WS	72.0	490	95	250	655	580
Sorghum starch (bulk)	78.0	570	95	515	685	675
Sorghum starch (C-42Y)	78.5	635	95	605	738	740
Millet starch	72.0	560	95	640	780	755

a/ Flour sample 50 gm. (14 MB), starches 40 gm. (14% MB).

Fig. 12. Visco-amylograms of sorghum grain and millet starch (40 gm. 14% MB) and flours (50 gm. 14% MB).


TEMPERATURE °C
VISCOSITY B.U.
TIME MIN.
STARCH
MILLET
C42-Y
BULK
FLOUR
BULK
BULK + MILLET WS
MILLET

The sorghum grain starch and flour exhibited a high viscosity (635, 688 B.U.) followed by a pronounced drop in viscosity and a sharp peak for the flour. This behavior reflects the fragility of the swollen granules which first swell and then break down under continuous mechanical stirring.

The millet behaved similarly although it showed a lower viscosity expecially for the flour suspension. That might be due to the presence of α-amylase which would lower the peak viscosity.

All starches and sorghum grain flour showed a peak temperature of 95°C while the millet flour gave a peak temperature of 90°C.

Concentration of the starch or flour in the suspension is one of the major factors for variation in hot paste viscosity. This was minimized by using a constant weight of flour (50 gm.) and a constant weight of starch (40 gm.) throughout the study.

In general, starches and flours lose viscosity during the 1 hr. cooking period at 95°C. That loss in viscosity is due to the progressive fragmentation and solubilization of the swollen granules. The bulk sorghum and millet starches were quite close in their peak viscosity (Table 3), but were different in pasting properties after the 1 hr. holding at 95°C. The sorghum increased 55 B.U. and millet increased 80 B.U. during that cooking period. Millet starch dropped more in viscosity followed by a sharp rise in viscosity in the second half of the 95°C holding period. The C-42Y sorghum starch gave a drop and rise in viscosity similar to that of millet, but it dropped again near the end of the holding period.

All starches increased in viscosity upon cooling from 95 to 50°C (Table 3, Fig. 12). The bulk sorghum starch had the highest set back (170 B.U.), C-42Y sorghum and millet were 133 and 140 B.U., respectively.

Millet starch amylogram was relatively close to those for sorghum starches, however, the millet flour gave a drastically lower peak viscosity and set-back than the sorghum flours. The lower peak viscosity for millet flour, compared with a normal viscosity for millet starch, suggested that the millet flour contained an active amylase system.

Addition of water soluble from millet flour to sorghum flour lowered the peak viscosity. That also indicates the presence of an active water soluble amylase in the millet flour.

Ratios of Amylose and Amylopectin.

Millet starch has been reported to contain 12 - 19% amylose (26), compared to sorghum grain starches which contain 22 - 28% amylose (14).

Millet and bulk sorghum starches were fractionated by sedimentation and precipitation methods and the amylose content was determined by iodine blue value (15, 16, 26). The millet starch contained 17% amylose and bulk sorghum starch 23% amylose. The amylopectin content was 83 and 78%, respectively.

Both values for sorghum and millet were within the range reported in the literature. From this study and earlier reports, it appears that millet starches contained lower percentages of amylose than do sorghum starches.

Chemical and Milling Properties of Sorghum and Millet.

Milling Properties. Sorghum and millet were dry milled using a Quadramat Junior mill (Table 4). A relatively low flour yield was obtained from both grains compared to wheat. Sorghum grain flour yield was only 53%, a higher yield (58%) was obtained from millet, however, the product was gray in color.

Table 4. Yield of Dry Milled Fractions of Sorghum and Millet.

Fractions	Yield	
	Sorghum %	Millet %
Bran	46.88	42.04
High ash flour	14.75	16.57
Low ash flour (+9XX)	33.10	31.11
Low ash flour (-9XX)	6.26	10.26
Total extraction	53.12	57.94

The theoretical yield of both sorghum grain and millet is generally lower than that of wheat due to the variation in grain component percentages. Sorghum grain germ ranged from 7.8 to 12.1% of the total kernel while that of wheat is only 2.5% to 3.6%. The millet germ is 5 to 10% of the total kernel. Although the percentage of bran is higher in wheat the total yield in bran is larger due to the small size of grain sorghum and millet. The 1000 kernel weight of sorghum grain is 20-30 gm., wheat 30-40 gm. and millet is 15-28.

It might be possible to improve the yield of sorghum grain and millet by optimum tempering of the grain, modify the flow sheet, or by changing the milling device altogether.

In later millings a higher extraction for millet (63%) and sorghum grain (60%) along with lighter colored flours were obtained using Buhler experimental mill for millet and a KSU experimental mill for sorghum grain. The improvement in flour yield and product color is probably due to the great flexibility in both the Buhler and experimental mills compared to the fixed flow Quadramat.

The analyses of the fractions from sorghum grain and millet are given in Table 5. The low ash flour (-9XX) for both sorghum grain and millet was low in protein; however, millet contained significantly more protein than the sorghum grain.

The percentage of protein retained in the flour fractions was higher in sorghum grain than millet (55.7% and 44.5%, respectively). This might be due to the distribution of proteins in the kernel.

Amino Acid Analyses. The amino acid analyses of sorghum and millet grain (Table 6) showed the nutritional superiority of the millet grain in supplying essential amino acids.

Table 5. Protein and Moisture Analyses of Sorghum and Millet Fractions.

Fractions	Sorghum		Millet	
	Moisture %	Protein %	Moisture %	Protein %
Bran	11.5	11.5	11.2	16.4
High ash flour	12.2	9.3	12.2	11.3
Low ash flour (+9XX)	12.5	10.0	12.6	9.2
Low ash flour (-9XX)	12.1	5.9	12.4	7.2
Whole grain	10.0	9.6	10.6	12.3

Table 6. Amino Acid Composition (g AA/100 g protein) for Two Sorghums and a Millet[a/].

Amino Acid	Bulk Sorghum	Sorghum C-42Y	Millet
Lysine	2.80	2.54	3.60
Histidine	2.51	2.32	2.60
Ammonia	2.42	2.62	2.54
Arginine	4.30	4.03	5.96
Aspartic Acid	6.54	6.55	8.16
Threonine	3.13	3.04	4.11
Serine	4.32	4.31	4.92
Glutamic Acid	20.68	20.8	19.02
Proline	8.26	8.78	5.92
Glycine	3.22	3.02	3.71
Alanine	8.53	8.58	7.80
Half Cystine	2.17	2.38	2.49
Valine	4.30	4.51	5.13
Methionine	1.57	1.39	1.85
Isoleucine	3.70	3.69	3.88
Leucine	12.82	13.11	9.80
Tyrosine	3.72	3.58	3.51
Phenylalanine	5.01	4.75	4.97

a/ Recovery Kjeldahl protein basis for bulk sorghum 93.44, sorghum C-42Y 101.63 and Millet 100.00.

Millet had higher values for lysine, arginine, aspartic acid, threonine, serine, glycine, valine and methionine, and lower values for glutamic acid, proline, alanine and leucine than did the sorghum grain.

The lysine content of the millet used in this study was 3.6 g AA/100 g protein, a value comparable to that found in high-lysine corn. Other millet samples of varying genetic background have given values as low as 2.1 gm. AA/100 gm. protein, indicating a wide genetic variation in the lysine content of millets.

Amino acid values for the flours from millet were essentially constant (Table 7). The amino acid values for the bran were quite different, being higher in lysine, histidine, arginine, aspartic acid, serine and glycine and lower in leucine and phenylalanine than the flours.

Lipids. A TLC comparison of polar, nonpolar free and bound lipids extracted from sorghum grain, millet, and wheat are given in Fig. 13.

The major component in nonpolar free lipids was triglycerides in all three grains. Smaller amounts of hydrocarbons, steryl esters, fatty acids monoglycerides, diglycerides, sterols and unresolved nonpolar lipids were also present. The bound nonpolar lipids contained the same type of compounds found in the free nonpolar lipid, but the ratios of components were different.

The polar free lipids (Fig. 14) are quite different for wheat than for sorghum and millet. Contrary to reports (52) that millet and wheat contain the same lipids, neither sorghum grain nor millet contained phosphatidyl ethanolamine, digalactosyl diglyceride, or phosphatidyl choline. The bound polar lipids patterns are similar for all three grains.

Table 7. Amino Acid Composition (g AA/100 g protein) of Millet Fractions[a/].

Amino Acid	Fractions			
	Bran	High Ash Flour	Low Ash Flour +9XX	High Ash Flour -9XX
Lysine	4.05	2.60	2.43	2.70
Histidine	2.60	2.26	2.20	2.25
Ammonia	1.66	1.79	1.94	1.97
Arginine	7.01	4.85	4.19	4.48
Aspartic Acid	8.71	7.62	7.62	7.88
Threonine	4.09	3.86	3.92	3.91
Serine	4.94	4.73	4.74	4.61
Glutamic Acid	17.82	20.50	20.85	20.49
Proline	5.55	6.56	6.60	6.47
Glycine	4.12	3.01	2.81	2.93
Alanine	7.76	8.01	8.10	7.81
Half Cystine	2.86	3.25	3.47	2.78
Valine	5.38	5.31	5.05	5.51
Methionine	2.11	2.34	2.53	2.76
Isoleucine	3.98	4.09	4.22	4.21
Leucine	9.06	10.49	10.47	10.44
Tyrosine	3.43	3.44	3.45	3.56
Phenylalanine	4.88	5.30	5.40	5.25

a/ Recovery Kjeldahl protein basis, bran 94.97, high ash flour 101.43, low ash flour +9XX, 100.28, and low ash flour -9XX, 96.65.

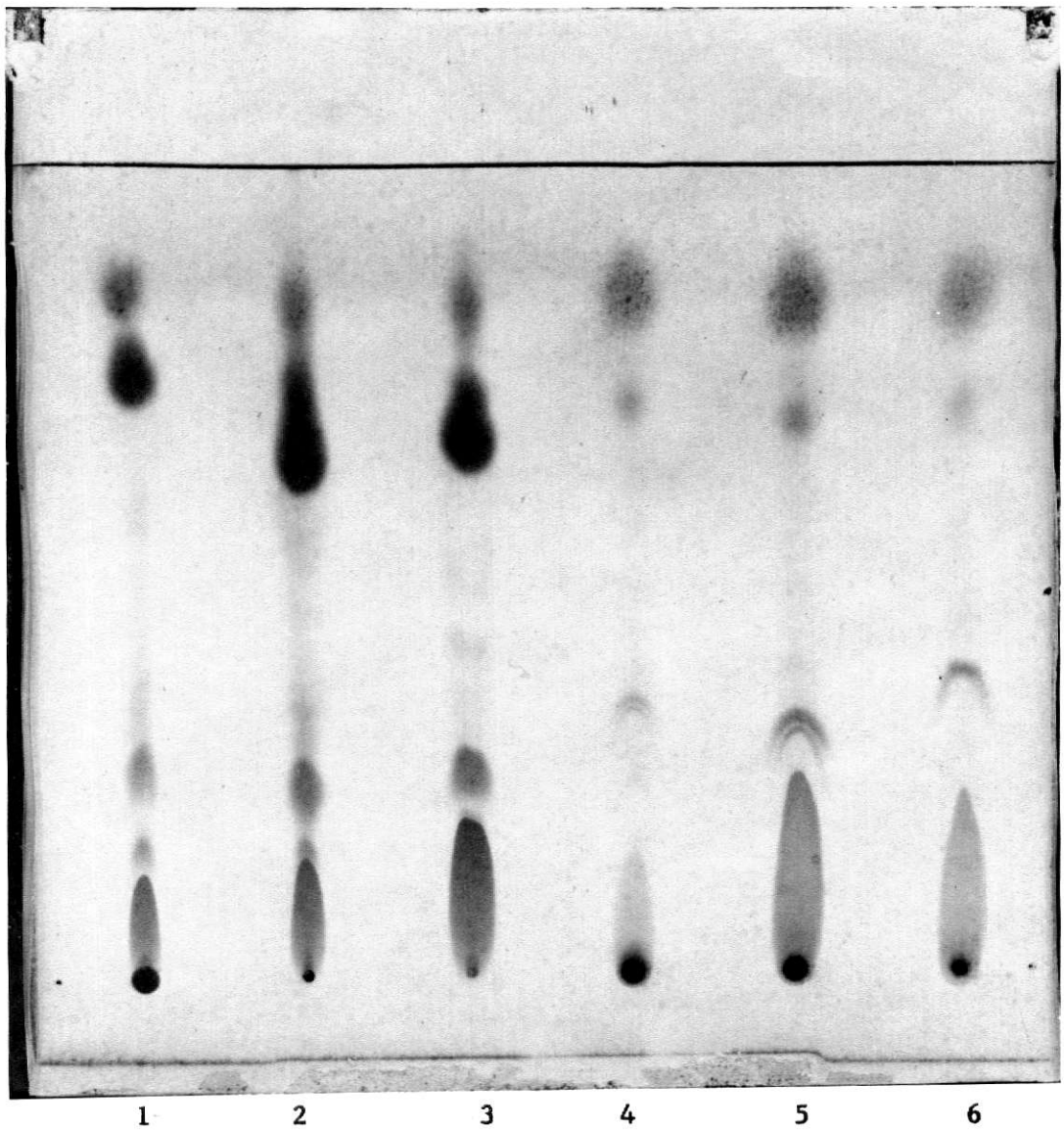


Fig. 13. Thin layer chromatograms of nonpolar free and bound lipids from wheat, sorghum and millet. Pattern 1, free wheat lipids; pattern 2, free sorghum lipids; pattern 3, free millet lipids; pattern 4, bound wheat lipids; pattern 5, bound sorghum lipids; pattern 6, bound millet lipids. The spots are tentatively identified as A, hydrocarbon and steryl esters; B, triglycerides, C, diglycerides; D, free fatty acids; and E, unresolved polar lipids.

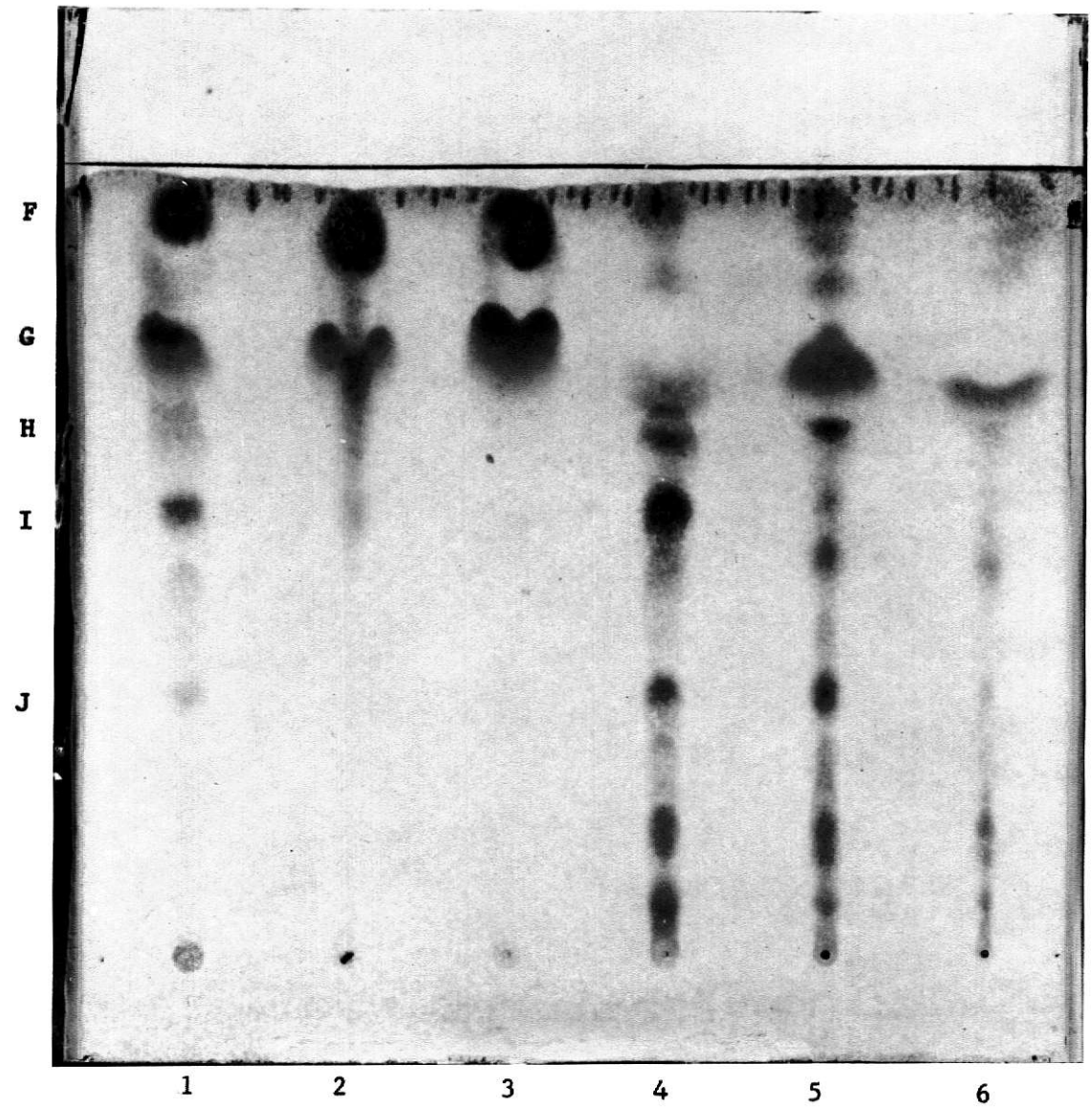


Fig. 14. Thin layer chromatograms of polar free and bound lipids from wheat, sorghum, and millet. Pattern 1, free wheat lipids, pattern 2, sorghum free lipids, pattern 3, millet free lipids, pattern 4, wheat bound lipids; pattern 5, sorghum bound lipids; pattern 6, millet bound lipids. The spots are tentatively identified as F, unresolved nonpolar lipids; G, monogalactosyl diglyceride; H, phosphatidyl ethanolamine; I, digalactosyl diglyceride; J, phosphatidyl choline.

Apparently, the major difference between wheat lipids and those of the other two grains is in the polar free fraction.

The absence of certain polar lipids in sorghum and millet might cause some differences in their flour end uses.

Use of Sorghum Grain and Millet in Baked Products.

Cookies. Using the Finney and Yamazaki cookie test (80), attempts were made to produce sugar snap cookies from sorghum and millet flour. The formula (based on flour weight) contained 60% sugar, 30% shortening, 3% nonfat dry milk, 1.8% sodium bicarbonate, 0.5% ammonium chloride, 0.44% sodium chloride and optimum water.

Both sorghum and millet flours failed to produce acceptable cookies. The cookies gave no spread or top cracks and were tough, hard, gritty with a mealy texture and taste.

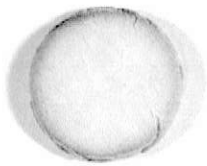
Kissel et al. (85) reported, for wheat flour, that both polar and nonpolar free lipids were important for cookie spread and top grain. Millet and sorghum grain free lipids were shown by TLC to differ from those of wheat.

Consequently, cookies were baked from defatted sorghum and wheat flour. Those cookies gave less spread, were thicker and tougher with no top cracks and a pale color (Table 8 and Fig. 15). Exchanging the lipids (defatted wheat flour + sorghum lipids and defatted sorghum flour + wheat lipids) gave cookies from sorghum flour with improved top-grain and spread (Table 8, Fig. 15). However, the sorghum flour plus wheat flour lipids did not approach the quality of control wheat cookies. Similar results were obtained when wheat lipids were added to the nondefatted sorghum flour.

Table 8. Effect of Certain Treatments on Cookie Diameter.

Treatment	Cookie Diameter		
	Wheat cm	Sorghum cm	Millet cm
Control flour	8.75	6.29	7.00
Defatted flour	6.38	5.88	--
Reconstituted flour	8.80	6.15	--
Defatted flour + exchanged lipids	6.80	6.80	--
Defatted flour + soy oil (0.6%)	--	7.02	--
Control flour + soy oil (0.6%)	--	7.05	7.78
Control flour + malt treatment and soy oil (0.6%)	--	8.70	9.05

Fig. 15. Cookies baked from wheat and sorghum flours which had been defatted, reconstituted, and exchanged.

	WHEAT	SORGHUM
CONTROL		
DEFATTED		
RECONSTITUTED		
EXCHANGED LIPIDS		

That improving effect of wheat lipids on sorghum flour must be due to adding a lipid fraction which was missing in sorghum lipids.

Several commercially available lipids were investigated in an effort to replace the wheat lipids. Unrefined soybean lecithin (0.6%) improved cookies baked from sorghum and millet flours (Table 8, Fig. 16). In fact, adding 0.6% unrefined soybean lecithin gave similar top grain and larger spread than wheat lipids.

Refined lecithin was not as effective as the unrefined soybean lecithin. However, refined lecithin plus monoglycerides in the ratio 3:1 were as effective as the soybean oil.

The use of soybean oil greatly improved the top grain and improved the cookie spread; however, cookies were still gritty, mealy and did not spread comparable to wheat cookies.

Reports (86, 87) had shown that the damaged starch had deleterious effect on the cookie spread. Milling of sorghum and millet to flour fineness gave a high percentage of damaged starch as noted in scanning electron micrographs. In an effort to remove some of that damaged starch, the flours were hydrated for three hours with 2% 60°L malt syrup. After air drying, the resultant flours were baked into cookies using the standard formula and 0.6% soybean oil.

Cookies with a spread and top grain comparable to wheat cookies were obtained (Table 8, Fig. 16). The sorghum cookies color was slightly darker and they were more fragile than the wheat cookies. The grittiness was not as objectionable. Similarly prepared millet cookies gave a larger spread than wheat cookies (9.05 to 8.75 cm.) and had deeper canals in the top grain. In general, the millet cookies were larger, darker and more fragile than the sorghum cookies.

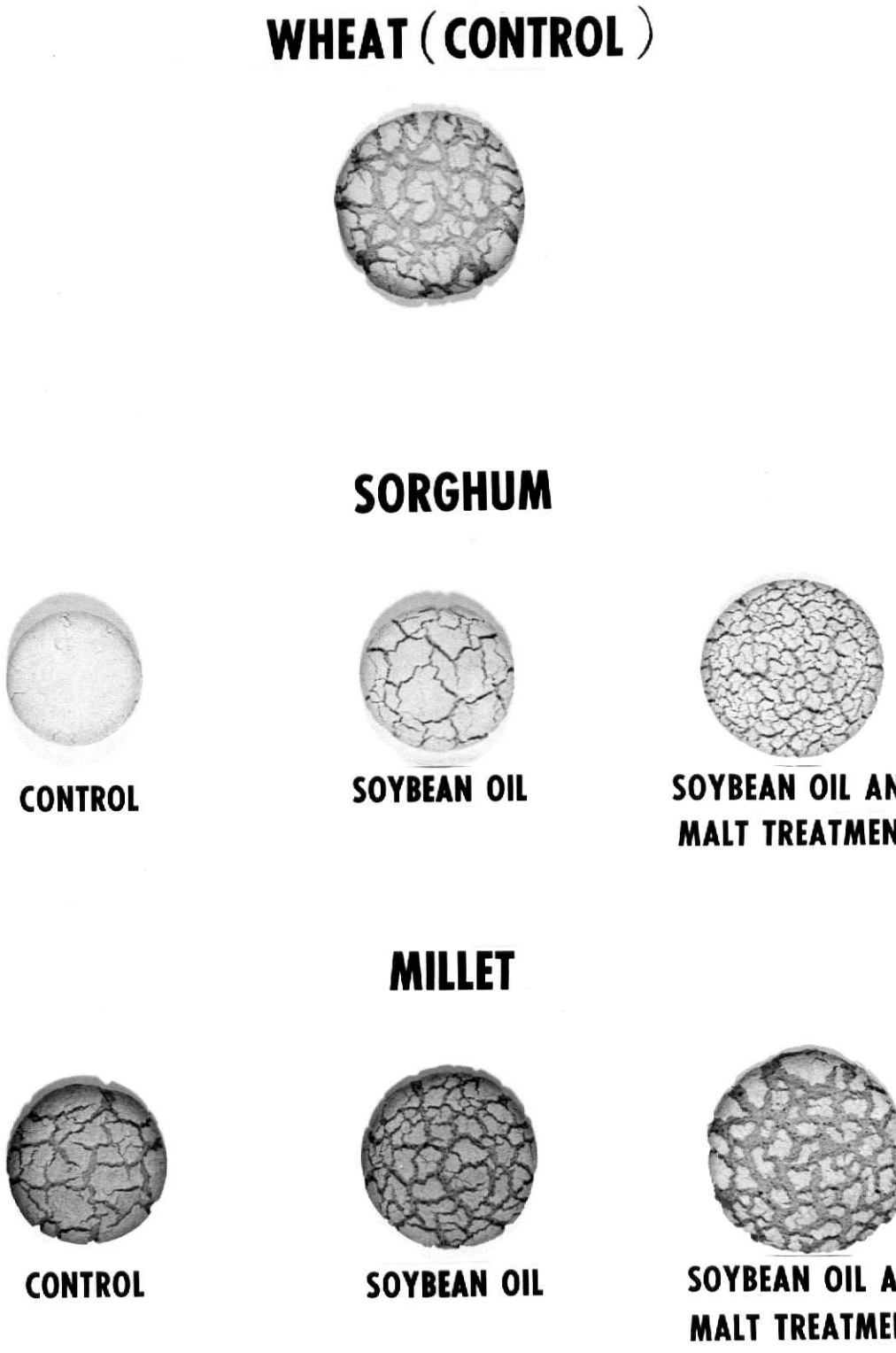


Fig. 16. Cookies baked from sorghum and millet flours, the flour plus 0.6% soybean oil and the flour plus soybean oil plus malt treatment.

In an attempt to reduce the grittiness further, the pH of the cookie dough was increased with sodium carbonate instead of sodium bicarbonate in the creamed ingredients. With both sorghum and millet, cookies were less gritty. In general, millet cookies were less gritty than sorghum cookies. At higher level of sodium carbonate the cookies were much darker.

The increased color of the cookies was probably caused by the increased alkalinity which enhanced the browning reaction.

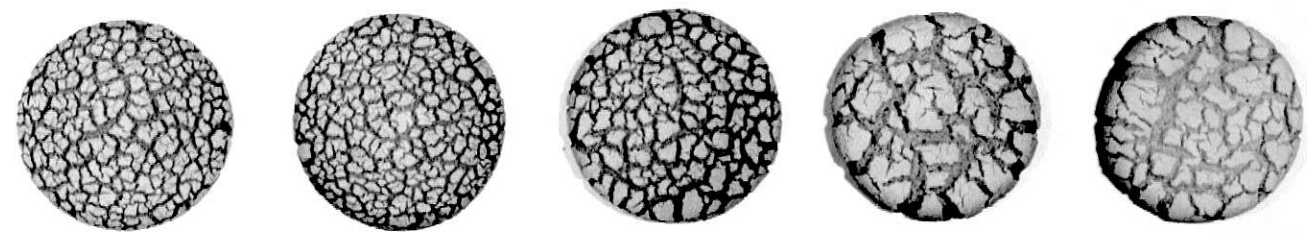
Thus, satisfactory cookies were made from 100% sorghum or millet flour. Three alterations in the procedure were necessary a) hydration of the flour with malt syrup to remove the damaged starch, b) addition of soybean oil to provide the proper lipids for cookie spread and c) replacing part of the sodium bicarbonate with sodium carbonate to reduce the grittiness.

Although satisfactory cookies were made from 100% sorghum or millet flour the cookies were more fragile than wheat cookies. No conditions were found to improve the fragility. Therefore, blends of wheat flour with sorghum flour and wheat flour with millet flour in various ratios, 0:100, 10:90, 20:80, 30:70, 50:50, 70:30, 80:20, 90:10, and 100:0 were investigated. Pictures of the cookies and their diameter are given in Fig. 17 and Table 9.

In blends of wheat flour and sorghum flour, cookies were generally slightly smaller than either 100% wheat flour or 100% sorghum flour. With wheat flour:millet flour blends, the diameters of the cookies were essentially a straight line relationship based on composition of the blend. As noted before, 100% millet flour gave cookies with larger diameter than 100% wheat flour. Difference in color and top grain varied with the composition of the blend.

Fig. 17. Cookies baked with blends of wheat and sorghum flour and wheat and millet flour.

SORGHUM	%	100	80	50	20	0
WHEAT	%	0	20	50	80	100



MILLET	%	100	80	50	20	0
WHEAT	%	0	20	50	80	100

Table 9. Effect of Blends of Sorghum Grain and Millet Flour with Wheat Flour on Cookie Diameter.

% of Wheat Flour in the Blend	Cookie Diameter	
	Sorghum cm	Millet cm
0%	8.75	9.00
10%	8.60	9.05
20%	8.62	8.93
30%	8.63	8.90
50%	8.55	8.88
70%	8.33	8.70
80%	8.55	8.80
90%	8.40	8.60
100%	8.73	8.76

Sorghum and millet flour treated with malt and contain 0.6% soybean oil based on sorghum and millet flour weight.

Cookie containing over 50% wheat flour baked with $NaHCO_3$, less than 50% wheat flour baked with Na_2CO_3.

Thus, there exists the possibility of producing sorghum and millet cookies containing small amounts of wheat flour to improve the fragility.

Bread. Wheat flour to be used for bread is routinely supplemented with malted wheat or barley flour. That improves loaf volume, texture and overall appearance of the loaf. This is generally considered to be due to the action of α-amylase on starch.

As noted earlier, millet flour gave a low pasting curve on visco-amylograph and it was suspected to contain significant α-amylase activity.

The relationship between the enzymatic activity of millet flour and malted wheat flour was determined by adding each to a constant flour weight and determining the hot paste viscosity in a visco-amylograph (Fig. 18 and 19). It was found that 10% millet was equivalent to 0.15% malted wheat flour. That relationship suggests that millet flour might be useful in bread baking.

The results of the baking tests (Tables 10, 11, and 12) have been expressed in terms of loaf volume because of the importance of this parameter in bread baking. The loaf volume is highly correlated over a relatively wide range with consumer acceptance, technological versatility, rheological properties, and other important breadmaking characteristics.

Addition of 10% millet flour to the regular baking formula increased the loaf volume slightly. This increase in loaf volume was accompanied by an improvement in crumb texture.

When wheat flour was baked without malt or sugar in the formula a poor loaf with small volume (400 cc.), compact grain, and pale crust was obtained. Addition of 10% millet to the above formula (no malt or sugar)

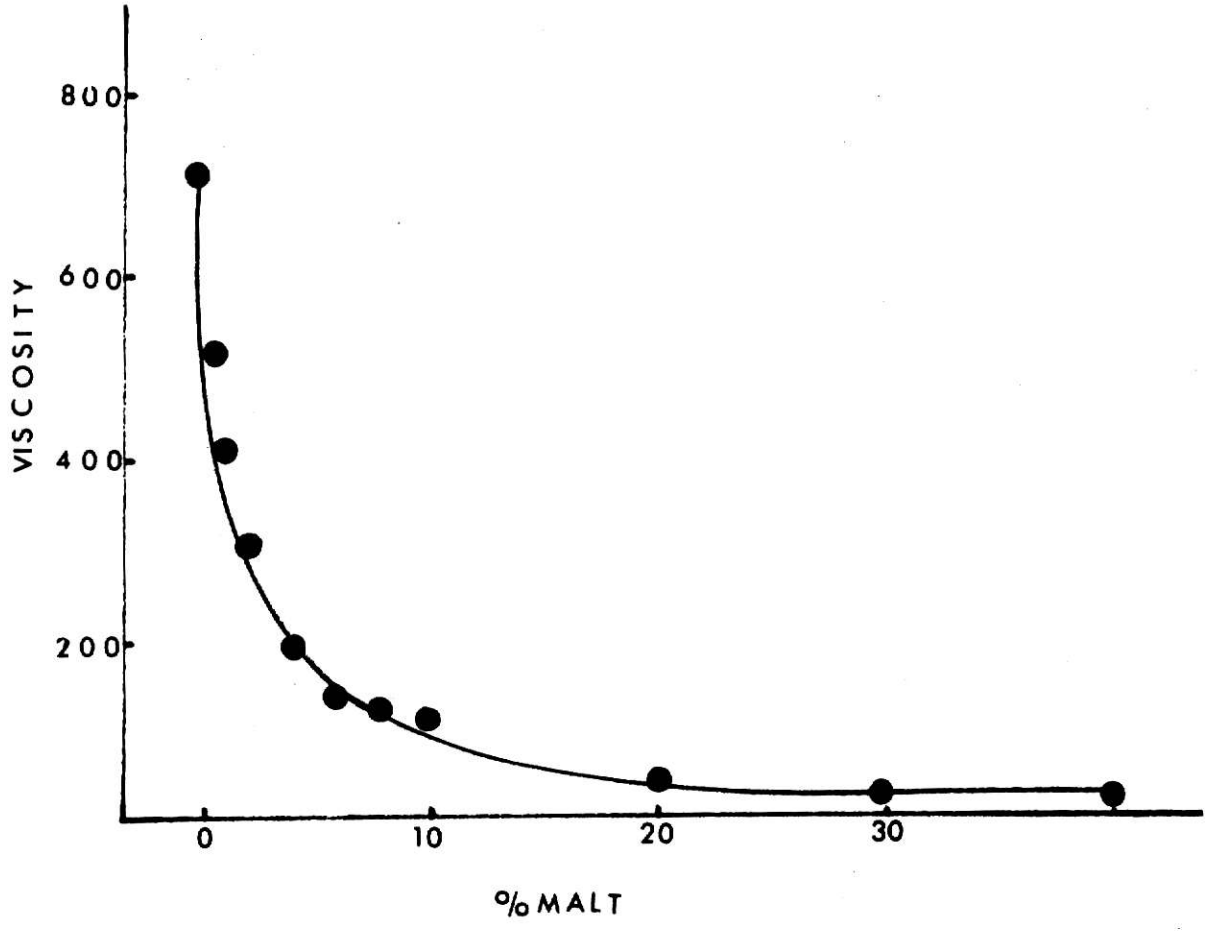


Fig. 18. Effect of malted wheat flour on wheat flour (60 gm, 14% MB) hot paste viscosity (% of malt based on wheat flour weight).

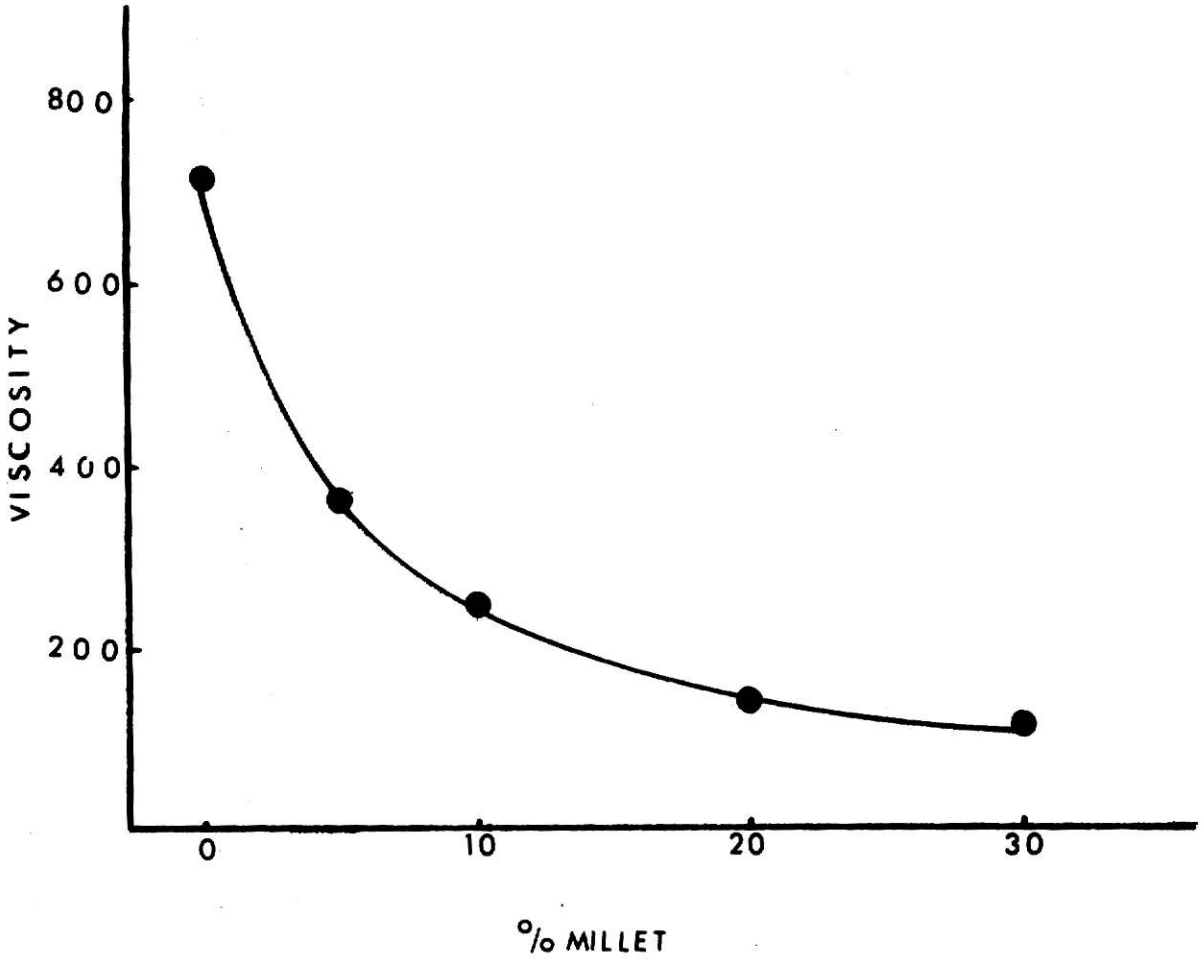


Fig. 19. Effect of millet flour on wheat flour (60 gm, 14% MB) hot paste viscosity (% of millet based on wheat flour weight).

Table 10. Loaves Baked from 100 gm. of Wheat Flour (14 MB) plus Indicated Levels of Sorghum and Millet Flour.

Treatment	Loaf Volume	
	No Sugar or Malt cc	6% Sugar no Malt cc
Wheat Control	400	855
5% Millet	850	905
10% "	925	890
15% "	905	880
20% "	-	830
5% Sorghum	400	820
10% "	400	820
15% "	400	822.5
20% "	400	822.5

Table 11. Loaves Baked from 100 gm. of Wheat Flour, 10% Millet Flour and Different Levels of Malt.

% Malt Syrup $60^{o}L$	Loaf Volume	
	Wheat Control cc	10% Millet cc
0	400	887
0.5	882	960
0.85	927	972
1.0	937	945

Table 12. Effect of Sodium Stearyl-2 Lactylate and Soybean Oil on Loaf Volume of Loaves Containing 15% Sorghum or Millet Flour.

Treatment	Loaf Volume	
	Sorghum cc	Millet cc
0.5% Sodium stearyl-2 lactylate	860	858
0.5% Soybean oil	858	845
Sodium stearyl-2 lactylate plus soybean oil	880	860

gave a loaf volume (925 cc.) significantly better than the same wheat flour baked with the regular formula including malt and sugar (Table 10, Fig. 20). Addition of increasing amount of millet flour up to 10% of the wheat flour in the baking formula increased loaf volume, thereafter, the loaf volume remained essentially constant through 15% and then decreased slowly. Addition of 0.5 sodium stearyl lactylate or 0.5% soybean oil to doughs containing 15% millet did not increase the loaf volume, but slightly improved the handling of the dough and smoothness of the crust (Table 12). The improving action of millet flour without malt or sugar indicated that the millet contained an active α-amylase which could replace both malt and sugar.

Addition of sorghum flour to the regular baking formula (5, 10, 15, or 20%) had a deleterious effect on loaf volume (Table 10). There was no difference between the addition of 5% or 20% sorghum flour, all levels gave almost the same loaf volume. Addition of 10% sorghum flour to a formula containing no malt or sugar gave a poor loaf volume (400 cc.). Addition of SSL combined with soybean oil, 0.5% each, appreciably increased loaf volume (820 to 880 cc.) together with an improvement in color and texture of the crust (Table 12). The effect of SSL and soybean oil on sorghum grain flour, but not on millet flour, showed the diversity of surfactants effect on different flour sources and this could be a function of these chemical diversities.

Fig. 20. Loaves of bread (left) regular formula, (middle) 10% millet flour no sugar or malt, (right) no millet flour, no sugar, no malt.

SUMMARY

Sorghum grain and millet endosperm is composed of soft and hard portions. The hard portion had tightly packed starch granules while in the soft portion, the starch granules were loosely packed. Certain sorghum grain varieties contained a testa or subcoat layer but none was found in the millet.

Approximately 25% of the sorghum grain protein is soluble in 60°C, 70% ethanol. Millet contained two alcohol soluble proteins, one soluble in 60°C, 70% ethanol (30.73% of the total protein) and the other in tertiary butyi alcohol (24.14% of total protein).

There was evidence of enzymatic activity on starch in both sorghum and millet grain upon soaking the grain in water.

Sorghum starch granules vary in size and shape. They are about twice as large as millet starches. Sorghum and millet starches had comparable pasting properties such as peak viscosity, but varied in the 1 hr. holding period at 95°C and cooling cycle. Sorghum starch contained 23% amylose and millet contained 17% amylose.

Sorghum, millet and wheat contained essentially the same nonpolar lipids and bound polar lipids, except that the concentration of individual lipids varied. The free polar lipids of both sorghum and millet were different from those of wheat, particularly in the phospholipids.

Amino acid analyses showed the nutritional superiority of millet in providing essential amino acids compared to other cereal grains. Millet had a lysine content as high as 3.6 g AA/100 g of protein.

Sorghum and millet flour produced acceptable cookies after treatment including hydration of the flour with 2% malt syrup, addition of 0.6% soybean oil, and raising the pH of the cookie dough by replacing part of

the sodium bicarbonate with sodium carbonate. Addition of small percentages of wheat flour to the treated sorghum or millet flour produced cookies with less fragility and lighter color.

Addition of 10% millet flour to wheat flour replaced the sugar and malt in regular bread formula, and acceptable bread was made with up to 20% millet flour. Addition of sodium stearyl-2 lactylate and soybean oil to dough containing sorghum flour improved the loaf volume and crust color.

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CHEMICAL CHARACTERIZATION OF SORGHUM AND MILLET GRAIN AND THEIR USE IN BAKED PRODUCTS

by

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Sorghum and millet grain endosperm is composed of soft and hard portions. The hard portion had tightly packed starch granules, while, in the soft portion, the starch granules are loosely packed. Certain sorghum varieties contained a testa or subcoat layer, but none was found in the millet.

Approximately 25% of the sorghum grain protein is soluble in 60°C, 70% ethanol. Millet contained two alcohol soluble proteins, one soluble in 60°C, 70% ethanol (30.73% of the total protein) and the other in tertiary butyl alcohol (27.14% of total protein).

There was evidence of enzymatic activity on starch in both sorghum grain and millet upon soaking the grain in water.

Sorghum starch granules vary in size and shape. They are about twice as large as millet starches. Sorghum and millet starches had comparable pasting properties such as peak viscosity, but varied in the 1 hr. holding period at 95°C and cooling cycle. Sorghum grain starch contained 23% amylose and millet contained 17% amylose.

Sorghum, millet and wheat contained essentially the same nonpolar lipids and polar bound lipids, except that the concentration of individual lipids varied. The free polar lipids of both sorghum and millet were different from those of wheat, particularly in the phospholipids.

Amino acid analyses showed the nutritional superiority of millet in providing essential amino acids compared to other cereal grains. Millet had a lysine content as high as 3.6 g AA/100 g of protein.

Sorghum and millet flour produced acceptable cookies after treatment including hydration of the flour with 2% malt syrup, addition of 0.6%

soybean oil, and raising the pH of the cookie dough by replacing part of the sodium bicarbonate with sodium carbonate. Addition of small percentages of wheat flour to the treated sorghum or millet flour produced cookies with less fragility and lighter color.

Addition of 10% millet flour to wheat flour replaced the sugar and malt in regular bread formula, and acceptable bread was made with up to 20% millet flour. Addition of sodium stearyl-lactylate and soybean oil to dough containing sorghum flour improved the loaf volume and crust color.