DRY MILLING OF GRAIN SORGHUM FOR GRITS ON ROLLER MILLS

by

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INTRODUCTION

Many diverse plant forms are included in the species Sorghum bicolor (LINN.) (73) such as the sweet sorghums, sudan grass, broom corn, and the grain sorghums (44, 77). Grain sorghum is cultivated specifically for the grain and is found throughout the world though it be known by many names. Its popular name in the United States is 'milo' (77) while in India it is called 'jowar' and in Sudan 'durra' (69, 79). Sorghum is a tropical plant, a native of Africa and India (25, 44). It grows mainly in regions where the climate is too hot and dry for other cereals to be produced successfully (11). The major producing countries are the United States, India, Red China, Ethiopia, South Africa, Nigeria, Argentina and Mexico (57). The average world production for the last five years was about 51 million metric tons (22). About 75% of this production is consumed by humans (25, 39). In parts of Africa, Asia and Latin America it forms a staple part of the diet (30). It constitutes more than 70% of the total calories and furnishes much of the protein in the diet (73). However, most sorghum produced in the U. S. is used for livestock feed, with only a small quantity used for industrial and food purposes (30, 62).

Although the use of sorghum for human food is widespread and the potential for other uses is great the technology for milling sorghum is far from adequate. Most of the grain is milled traditionally either by grinding the whole grain in stone mills or by coarse grinding in a wooden mortar and pestle made of heavy wood (42, 46). Research towards the development of improved methods for milling sorghum started during

World War II (25). Attempts have been made to develop suitable processes for milling sorghum. But until now no one of these attempts has succeeded to provide a standard commercial process. More research has to be conducted towards the development of a technique or a process for milling sorghum since the demand for sorghum as human food and other uses will increase as the population of the world increases.

OBJECTIVES OF THE STUDY

The purpose of this study was to investigate the suitability of a simple system of roller mills and sifters aided by gravity separators for milling sorghums into refined endosperm fractions with low fat and ash. The system can be used as a foundation for a commercial sorghum dry milling process to produce grits. If desired, grits can be ground into flour.

The study also included the rate of water penetration into the sorghum kernel during the tempering process. The structure of the endosperm of the sorghum used was examined by a scanning electron microscope.

LITERATURE REVIEW

USES OF GRAIN SORGHUM

Nearly all grain sorghum grown in the U.S. is used as livestock feed; less than 1% is involved in milling operations (30). However, worldwide grain sorghum is the third most important food grain after wheat and rice. As a food grain, sorghum is used to make a flat unleavened bread which is a staple food in many of the developing countries (5). It is sometimes boiled with meats or cooked to make a porridge. Grain sorghum is also fermented into a drink (25) and into industrial ethyl alcohol. During World War II grain sorghum was used as an adjunct in the brewing industry (76). Hahn (25) reported that the use of sorghum grits in brewing offer four advantages: short boiling time; fast run-off; more usable extract; and a very nutritious wort.

There is a great potential for using sorghum flour in bread making and other baked products. Rao and Shurpalekar (54) reported that up to 10% of milo flour (80% extraction) could be blended with wheat flour for bread making without any adverse effect. They added that a biscuit preparation based on 80:20 blend of wheat flour and sorghum flour compared well with biscuits based only on wheat flour. Rooney et al. (62) formulated yeast leavened pan bread, cakes and cookies containing sorghum flour. Casier (17) reported that it is possible to obtain bread from the pure flour of sorghum using 3-4% rye pentosan. He found that the best results were obtained when using sorghum flour of 53% extraction.

In contrast Badi et al. (7) reported that addition of sorghum flour (5-20%) to the standard baking formula deleteriously affected the loaf volume. Badi and Hoseney (8) also found that cookies made from sorghum flour (63.4% extraction) had essentially no spread and no top cracks. They added that the cookies were tough, hard, gritty and mealy in texture and taste. However Badi et al. (5) found that sorghum can be used to make snack foods similar to pretzels and corn chips. Okovio (46) reported that wheat flour could be mixed with 5-15% of sorghum flour for making "Sambusa" which is a spiced pie whose crust is made from unleavened wheat dough.

Grain sorghum has been used by the wet milling industry. It is an attractive raw material for the production of starch due to its lower cost (25). Grain sorghum starch has found application in many industries employing starch products such as the paper and textile industries and in oil well drilling and the refining of aluminum ore (76).

STRUCTURE OF GRAIN SORGHUM

Botanically the sorghum seed is a caryopsis which is a dry fruit with a single seed enclosed in a dry outer covering fused to the seed coat (57). The seed is a flattened sphere approximately 4.0 mm long by 3.5 mm wide and 2.5 mm thick (39). The grains from irrigated land are generally larger than those of a dry land crop (76). The kernel weight varies from 8 to 50 gms per 1000 kernels with an average of 28 gms (58). It ranges in color from white to yellow, red, brown and black (44, 62).

The general structure of a grain sorghum kernel is similar to that found in all other cereals (44). The mature seed consists of three main parts (Fig. 1): the outer covering (pericarp); the germ or embryo; and the storage tissue (endosperm) (39, 57, 58, 73). The percentage of endosperm, germ and bran (pericarp and aleurone layer) are given in the

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Fig. 1: Longitudinal section showing the structure of grain sorghum (57)

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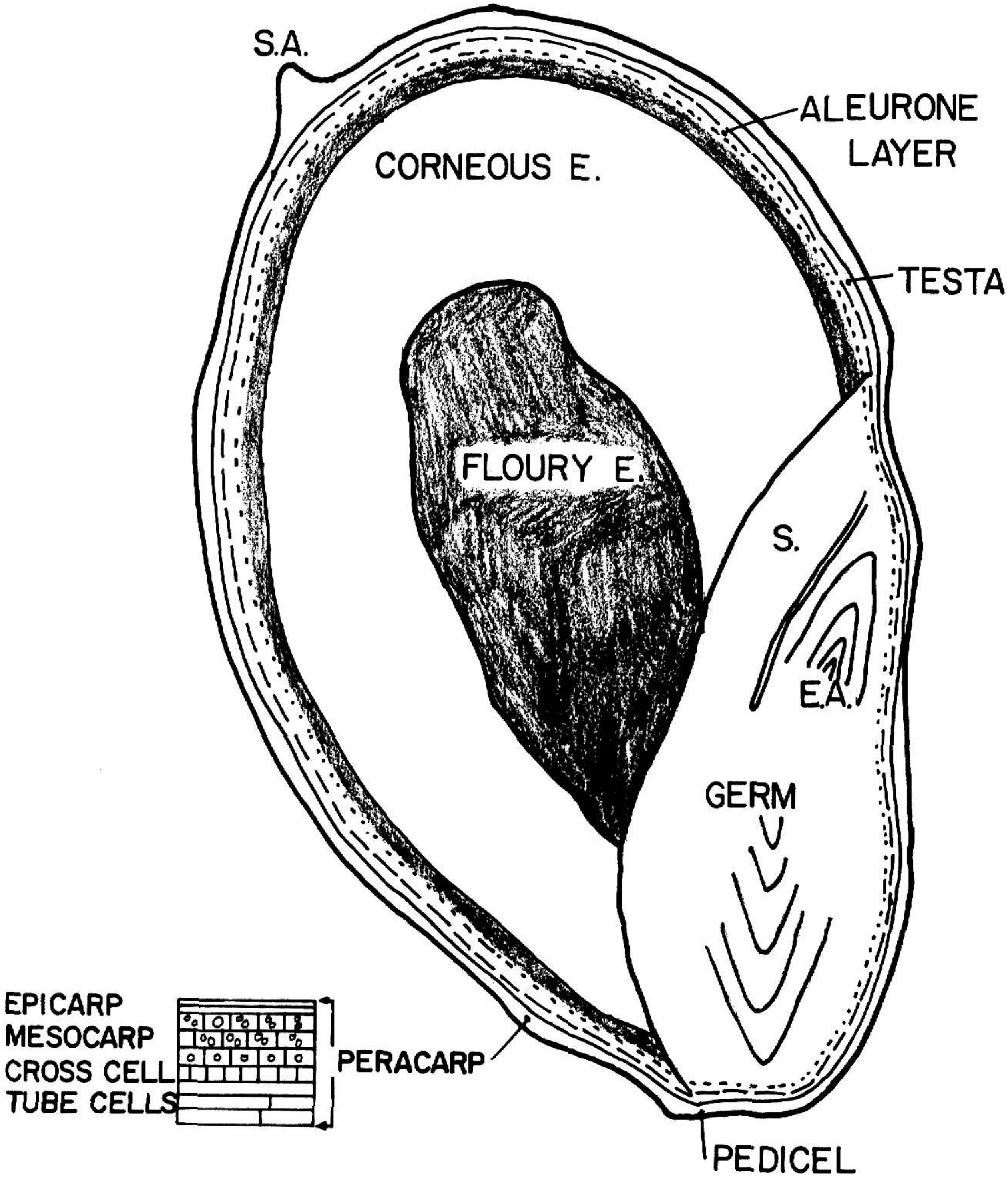
FIG. 1


S.A.
ALEURONE LAYER
CORNEOUS E.
TESTA
FLOURY E.
S.
E.A.
GERM
EPICARP
MESOCARP
CROSS CELL
TUBE CELLS
PERACARP
PEDICEL

following table (31):

TABLE 1. Distribution of Kernel Weight among Endosperm, Bran and Germ.

	Range %Wt.	Mean %Wt.
Endosperm	80.0 - 84.6	82.3
Bran	7.3 - 9.3	7.9
Germ	7.8 - 12.1	9.8

The pericarp is composed of three layers (58). The epicarp (outside layer) which contains pigments and wax. The mesocarp (middle layer) contains small starch granules (30, 77). The endocarp (inner layer) is composed of cross cells and tube cells. Just beneath the pericarp some sorghum kernels have a highly pigmented layer called the testa or subcoat (30, 61).

The germ contains high oil content. It is firmly embedded in the kernel and is difficult to remove during dry or wet-milling (58, 72).

The endosperm consists of an aleurone layer and peripheral, corneous and floury regions (58, 61, 72, 73). The aleurone is a single cell layer rich in oil and protein on the surface of the endosperm (58, 72). It contains minerals, water soluble vitamins, and autolytic enzymes (61). The peripheral endosperm beneath the aleurone layer consists of the first two to six endosperm cells. These cells are small and blocky, containing undersized starch granules embedded in a dense proteinaceous matrix (61). The corneous (horny) endosperm is characterized by a tightly packed structure with no air spaces (30). It contains starch granules which are very angular or polyhedral in shape with depressions where protein bodies were trapped between expanding starch granules (30. 61).

The floury endosperm has a loosely packed endosperm cell (30, 57, 61). It is mainly spherical starch granules with intergranular air spaces. Because of this fact the floury endosperm can more easily be broken into small particles during processing than the corneous endosperm (57).

CHEMICAL COMPOSITION

The chemical composition of grain sorghum is comparable to that of other cereal grains particularly corn (73, 76). Sorghum and corn have about the same composition with sorghum containing slightly less oil and a little more protein.

No major differences were found in general composition between a large number of sorghum selections (73). However, the composition of sorghum from different sources may vary because of many factors, including genetic and climatic factors as well as soil conditions and crop management practices (72). Data by Hubbard et al. (31) showing the range and average composition of whole grain and hand dissected fractions is tabulated in Table 2.

STARCH

Starch is the major component of grain sorghum; other carbohydrates are present in small amounts (39). Starch granules of sorghum are very similar to those of corn and have the same properties (25, 39, 58). However, sorghum starch granules are slightly larger than those of corn (72). The starch granules are roughly spherical or polyhedral (38, 61). They are approximately the same size ranging from 4-25u with the majority being 15-20u (41). Most of the starches contain 20-30% amylose

TABLE 2

CHEMICAL COMPOSITION OF GRAIN SORGHUM[1]
(MOISTURE-FREE BASIS)

	Whole kernel		Ash		Protein		Starch		Fat	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Whole grain	-	-	1.57 - 1.68	1.65	11.5 - 13.2	12.3	72.3 - 75.1	73.8	3.2 - 3.9	3.6
Endosperm	80.0 - 84.6	82.3	0.3 - 0.44	0.37	11.2 - 13.0	12.3	81.3 - 83.2	82.5	0.4 - 0.8	0.6
Germ	7.8 - 12.1	9.8	-	10.36	18 - 19.2	18.9	-	13.4	26.9 - 30.6	28.1
Bran	7.3 - 9.3	7.9	-	2.02	5.2 - 7.6	6.7	-	34.6	3.7 - 6.0	4.9

[1] Data from Hubbard et al. (31)

and 70-80% amylopectin (58). The starch component of the waxy grain approaches 100% amylopectin (38, 41, 61).

PROTEINS

Grain sorghum seems to be variable in protein content due to the climate, soil fertility, cultural practices and variety grown (58, 71, 77). Kafirin (prolamine) and glutelin are the principal proteins of sorghum endosperm. Albumin and globulin together account for less than 12% of the total endosperm protein (71).

Sorghum proteins, like those of other grains, are generally low in the essential amino acids lysine, tryptophan, and threonine (32, 72). In turn, sorghum proteins contain large quantities of leucine, glutamic acid, proline and aspartic acid (57).

Increasing the protein content of sorghum tends to cause a decrease in the percentage of lysine (58, 71). Virupaksha and Sastry (71) reported that for each 1% increase in protein there is a decrease of 0.041% lysine. The increase in protein is attributed mainly to an increase in kafirin which is low in lysine (57, 71).

LIPIDS

The lipids of sorghum influence the flavor and storage characteristics of the grain and the fractions (72). Sorghum contains approximately 3-4% ether extract, part of which are waxes. The oil is concentrated in the germ, pericarp and the aleurone layer with 70% of the total oil in the germ (60, 73). Germ oil is more unsaturated than that from the pericarp and endosperm and contains lesser amounts of free fatty acids (9, 58, 60). Thin-layer chromatography shows that the free and bound lipids extracted from different varieties have similar components (60). The characteristics and fatty-acid composition of sorghum oil is nearly the same as that of corn oil (9, 58, 60).

PIGMENTS

The pigments of sorghum can be divided into two broad categories: the carotenoids and the phenolic compounds (tannins) (58).

Carotenoids are yellow pigments found in the endosperm of some grains (7). The major carotenoids in sorghum are lutein, zeoxanthin and B-Carotene (60). These pigments are important in feed grains due to their pro-vitamin A activity and to the yellow color they impart to the skin and eggs of poultry (13).

Protection of the seed head from weathering after pollination increases the carotenoids present in the grain (13).

Phenolic compounds (tannins) are found in the pericarp but are absent in the germ and endosperm (58). They cause bitterness, low palatability, low digestibility and diminish the nutritional quality of the grain (52, 58).

Jambunathan and Mertz (32) reported that results obtained from feeding rats a tannin-rich sorghum which had been dehulled with sodium hydroxide indicated that the dehulling improves the nutritional quality of the grain. However, the presence of tannins makes the grain "bird-resistant" and decreases the susceptibility of the grain to molding and preharvest germination (52).

THE PROCESS OF TEMPERING

Prior to grinding on roller mills grain is 'tempered' to improve the subsequent separation of endosperm and branny materials. Tempering involves the addition of water followed by a rest period which fosters the best physical state for milling (18, 24). Briggs (15) stated that the aim of tempering wheat was a toughening of the bran to allow a cleaner separation of bran and endosperm. Moreover, the endosperm should become more friable so that middling particles fall apart easily.

If the grain is too dry the endosperm will not break up readily on the rolls while the bran will pulverize too readily. On the other hand, if the grain is too damp endosperm particles adhere to the bran (24).

Cleve (18) stated that the difficulty of finding the best conditioning treatment lies in bringing the outer layer of the endosperm into the correct condition because this layer lies at the junction of the tough and the friable parts of the grain.

The phenomena underlying the effects of tempering are not completely understood but the addition of moisture to grain has been found to cause the germ to swell and to pull away from the endosperm (73).

The chief factors effecting proper conditioning of the grain prior to milling are the correct amount and distribution of water within the kernel (14, 45). The latter in turn are determined by the amount of water added, the water's temperature, and the time allowed for the water's distribution inside the kernel (36). Each of these parameters has its own significance which may be enhanced through interaction with the other two. No one moisture content is ideal for all millings; the three parameters must be optimized for best results in each situation (24).

Wu (78) reported that the most important factors in tempering sorghum are the time and moisture and that the grain temperature has the least effect.

Perten (50) studied the influence of tempering on decortication of sorghum. He found that the tempering decreases the throughput, increases the amount of broken kernels, and increases the ash and fat contents of the flour. Perten's results agree with the findings of Rao and Shurpalekar (54) that as the conditioning moisture level increases the degree of polish decreases and the percentage of broken kernels slightly increases.

Stewart (67) investigated the effect of moisture on the grinding characteristics of sorghum using an impact grinder. He concluded that decreasing the moisture content makes the grain harder and more brittle while increasing moisture content makes it tougher.

Rao and Shurpalekar (54) used a Buhler laboratory mill to study the effect of conditioning on the yield of sorghum flour. They found that the yield obtained from unconditioned sorghum is higher than that from conditioned grain. However, the color grade of flour ground from conditioned sorghum is better.

WATER PENETRATION IN WHEAT AND SORGHUM

The rate of water penetration into the grain is very important for processing (36). It affects the time needed for tempering, the distribution of water inside the kernel and must be considered in the mixing of different grain lots (10, 21).

WHEAT

Fraser and Haley (23) found that the variety, time, temperature and size of the kernel are all factors which affect the amount and rate of absorption of water by wheat. They added that scouring of the grain before moisture addition increases water absorption and that the percentage of protein has a very minor effect.

In contrast, Butcher and Stenvert (16) stated that the concentration and distribution of protein are significant in affecting the rate of moisture penetration into the grain. Protein is well known for its ability to bind water and in this way may be responsible for retarding the movement of moisture into the grain.

The texture of the endosperm affects the rate of water penetration (36). Vitreous grain has a lower rate of water absorption than a mealy grain. This agrees with the findings of Hinton (28) and Stenvert and Kingswood (65) that the permeability of the endosperm is not affected by the class of wheat (hard or soft) but by whether the kernel is vitreous or mealy in character. The physical hardness of the grain is not related to the rate of penetration of the moisture into the kernel (16).

Farrell (21) reported that the rate of water absorption by hard and soft red winter wheat is slower than that found in white wheat. He also found that wheats of different crop years vary in the rate of water absorption.

Baker (10) stated that wet wheat takes up water more readily than dry wheat. Briggs (15) reported that cold water penetrates the outer coverings of hard wheat very slowly and that heating the kernel results in a more rapid absorption of water and shorter conditioning time. A possible explanation of this concept was furnished by Cleve (18) who reported that the slow penetration of water through the outer layers is due to the presence of air in the capillaries through which water penetrates.

Hinton (28) reported that the testa is the layer offering greatest resistance to water entry. This agrees with the tests which showed that water penetrates most slowly through the pigment layer situated near the aleurone layer (36). Jones (34) found that the rate of absorption of water through the bran is the same as that through the germ. However, Stenvert and Kingswood (66) stated that there is a rapid entry of water at the region where the germ meets the bran on the dorsal side of the grain.

Sullivan (68) reported that it is possible to cut the tempering time from overnight to two or three hours by using a surface active agent.

SORGHUM

Little has been written about the uptake of water by grain sorghum.

Fan et al. (20) studied the effect of temperature and time on the diffusion of water into the grain by measuring the increase in kernel weight. Their results showed that at the beginning of steeping the rate of weight increase was quite rapid for all temperatures, but decreased gradually with increased time. They also indicated that the diffusivities of water in the grain of corn and sorghum are of the same order of magnitude as those in wheat.

Weinecke et al. (75) studied the effect of grain texture on the absorption of water. They found that hard sorghum took longer to absorb moisture than did soft sorghum.

Mustafa (43) reported that waxy sorghum varieties absorbed more water during steeping than non-waxy varieties.

Watson et al. (74) reported that a maximum moisture content of 42-45% was reached in the first 8 to 10 hours of steeping.

Sanders (63) found that increased cell wall thickening and seed coat development slowed down the passage of water through the pericarp.

DRY MILLING OF SORGHUM

As with other types of cereal milling, the purpose of dry milling sorghum is to make the most complete separation of endosperm, bran and germ.

Isolated endosperm fractions have greater economic value: removal of pericarp lowers the fiber and ash; elimination of germ and aleurone reduces oil content and ensures longer stability of the milled endosperm (73).

Many attempts have been made to develop suitable processes for milling sorghum.

Hahn (26) reviewed the dry milling methods that have been applied to sorghum. Roller milling, pearling or decortication, degermination and fine grinding and air classification have been used. Hahn concluded that dehulling is quite effective for sorghum seed but noted that the grain must be cleaned and classified according to kernel size before being fed to the pearler.

Peplinski et al. (49) reported that fine grinding and air classification improved commercial sorghum flours and grits for industrial uses by removing protein, ash and fat and reducing diastatic activity.

Weinecke and Montgomery (75) developed an experimental unit for peeling and degerming sorghum grains. A combination of splitting and brushing actions were applied to the grain. The actions remove the hull and germ and reduce the endosperm size. The hull and germ were separated from the grits by aspiration and flotation in a sodium nitrate solution, respectively.

Anderson (1) used a Buhler automatic laboratory mill (type MLU202) to study the effect of varying moisture on the milling characteristics of sorghum. He found that milling at low temper moisture results in flours with slightly higher fat. The rate of extraction remain in the range of 51 to 53% regardless of tempering conditions. Flour milled at 19.6% has the lowest fat. The bran increased with increases in moisture and varied in fat content. He also reported that peeling of the grain before milling produced more flour with low fat and ash.

Anderson et al. (2) used a number of procedures employing different equipment for preparing refined endosperm fractions. The equipment included a barley pearler, rice huller, Alpine Kolloplex pin mill, brush degerminator, solid rotor degerminator and Buhler laboratory mill. They found that the brush machine gave a low fat endosperm at up to 75% extraction, while the impaction at 900 r.p.m. gave the poorest results. Impaction with 1500 r.p.m. yielded endosperm fractions essentially the same in fat content as when the grain was dehulled and then impacted. Roller milling gave endosperm with high fat content. They also reported that using gravity table for grit-germ separation gave results comparable to flotation in sodium nitrate solution.

Shoup et al. (64) studied the use of an experimental sorghum grain peeler as a means of preparing the grain for conventional milling by roller mills. They reported that the peeled grain contained a large percentage of the whole grain with the germ intact. They also found that the Miag Multomat mill produced products with a wide range of protein contents. They attributed the increase in protein content of a product to the large amount of corneous endosperm present.

Viraktamath et al. (69) tried three abrasive devices used in conventional grain milling machinery for continuous large scale pearling of sorghum. The devices included a rice huller, an improved horizontal Gota machine and a vertical inverted truncated cone used for polishing rice. They reported that the cone polisher of rice satisfactorily removed husk and bran from moistened sorghum.

Anderson and Burbridge (3) outlined an integrated approach for dry milling sorghum. The process consisted of an abrasive rice mill which removed 18% of the kernel as bran, followed by an aspirator. The debranned kernels were tempered and degerminated in an impact mill. Stocks from the degerminator were dried, and sized on a 14w, 20w and 34w screens. The +14w and +20 fractions were passed through aspirators followed by gravity tables to remove the germ. A yield of 73% grits with low fat and ash was obtained.

Deman et al. (19) evaluated the performance of the Palyi compact milling system. The system is based on the use of abrasive discs and air separators. They found that the system is a satisfactory method for dehulling of sorghum and millet grains of various sources. They also reported that the dehulling of sorghum and millet could be carried out without tempering the grains.

Reichert and Youngs (55, 56) compared commercial attrition and abrasive mills with a laboratory barley pearler in the dehulling of pigmented Nigerian sorghums and millets. They found that the laboratory pearler was more efficient, removing most of the color with less loss of material. Using the pearler they reported that millet was harder than sorghum and less likely to crack. They also reported that the three mechanical dehullers decreased the quantity of oil and ash markedly, and protein to a lesser degree.

Wyss (70) proposed a modern grinding plant consisting of cleaning, storage, de-hulling, and grinding steps. He noted that grinding with rolls allowed for flexibility in obtaining different flour qualities in various granulations.

Rooney et al. (59) used stepwise abrasive grinding to remove approximately 45% of the kernel. They indicated that it is theoretically possible to obtain appreciable quantities of fractions with improved protein content and quality.

Maxon et al. (40) and Kapasi-Kakama (35) studied the milling properties of different varieties of sorghum grains using an abrasive mill. They concluded that the proportion of corneous to floury endosperm in the kernel influences milling yields and grits composition. Varieties with corneous endosperm produce higher yields of grits with low ash and fat content. Kapasi-Kakama also found that the color and thickness of the pericarp, the presence of pigmented testa, the weathering, and the size and shape of the kernel are characteristics which influence pearling of the grain.

Anderson (4) using an integrated process (3) for milling high lysine grain sorghum found that the grain produced less grits with high fat and ash than normal sorghum hybrid.

Mustafa et al. (42) reported that grain samples with larger kernel size have a shorter decortication time.

Perten (50) studied the difference in milling characteristics of wheat, sorghum and millet. He found that sorghum and millet flours (-10xx) have higher ash and fat contents than the coarse fractions (+10xx) unlike wheat flour.

MATERIALS AND METHODS

GRAIN SAMPLE

The sorghum used in this study was commercially grown in Kansas during the 1978 crop year. It was of the type which is normally used by the feed industry. The grain was cleaned on the Carter Dockage Tester, scoured with an experimental scourer, and further cleaned with a Kice aspirator. After cleaning the test weight of the grain was 59.8 pounds per bushel and the 1000 kernel weight was 24.9 grams. The chemical analysis of the grain may be summarized (values except moisture content are on a 14% moisture basis):

Moisture content	12.4%
Protein content (N X 6.25)	9.10%
Fat content	3.29%
Ash content	1.49%

SCANNING ELECTRON MICROSCOPY OF SORGHUM KERNELS

Sorghum kernels were freeze dried and fractured along a longitudinal axis with a razor blade. Half kernels were mounted on aluminum stubs and coated with gold-palladium prior to being viewed and photographed on an ETEC scanning electron microscope at an accelerating voltage of 20 kv.

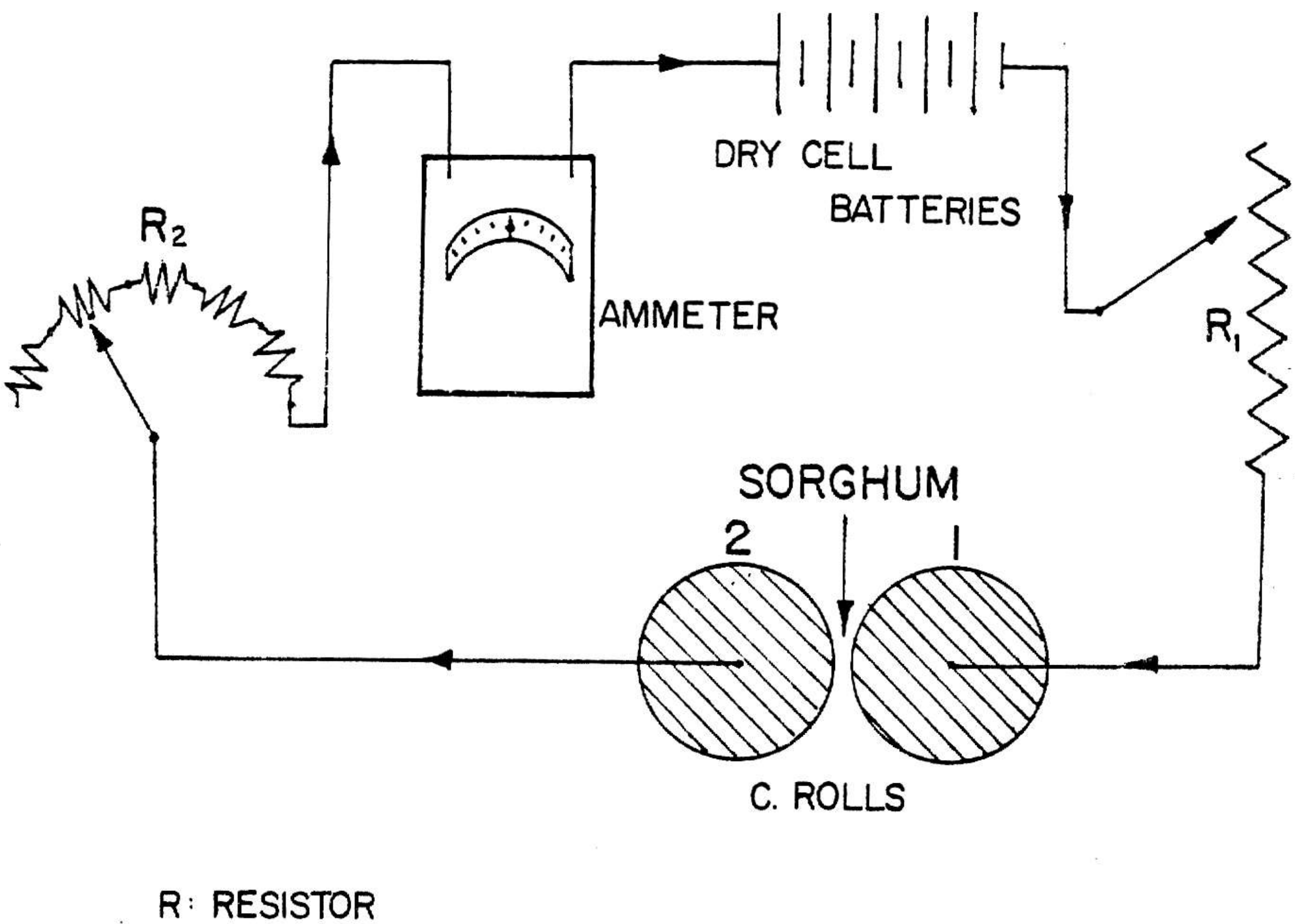
PENETRATION OF WATER INTO THE SORGHUM KERNEL

Water penetration was studied by two different methods. In the first method a Tag-Heppenstall electrical conductance moisture tester was used. This moisture measuring device exploits the relationship between a

Fig. 2. Circuit schematic diagram of the electrical conductance moisture meter.

FIG. 2

THE ELECTRIC MOISTURE METER



R: RESISTOR

grain sample's moisture content and its resistance to electrical current (21). The tester consists of a pair of corrugated rolls, a set of dry cell batteries, a variable resistor and an ammeter (Fig. 2). When the sorghum passes between the rolls it closes the circuit from roll 1 to roll 2. By measuring the current (I) which has passed through the grain going between the rolls, the resistance (R) of the sorghum is determined by Ohm's Law $I = E/R$. The voltage (E) is held constant. The resistance is inversely proportional to the moisture content.

Sorghum samples of 3000 gms each were moistened to different moisture levels (15, 16, 17, or 18%) with the amount of water required to bring them to the desired level. The grain and water were mixed in a rotating steel drum for a period of time that allowed complete absorption of the water on the surface. Then each sample was kept in a closed can. A small sample from each can was passed through the moisture meter at various times after the initial introduction of the water to the grain. Values for moisture content were recorded.

In the second method the rate and pattern of moisture uptake was followed by an autoradiographic technique. Thirty sound kernels were placed in two glass vials and 0.2 ml of tritiated water (50 mci/ml) was added to each vial. The vials were shaken and then allowed to sit at 25°C for 1 or 3 hours. After the designated time period sorghum kernels were washed with distilled water, cut with a razor blade, mounted in pith-wood, rewashed, blotted dry on filter paper, and then frozen in liquid nitrogen. Half-kernels were taped to pre-frozen strips of NMB film and allowed to expose for twenty four hours at -78°C. Following the exposure period, the kernels were removed from the film and the film was developed for three minutes in D-19, placed in stop bath for two minutes, fixed for eight minutes and washed in tap water for thirty minutes.

DRY MILLING MACHINERY

The milling system used in this study consisted of the following machines:

A. Two pairs of rolls 6 x 6 ins. with variable speed for the slow rolls of each pair (Fig. 3a). The function of the rolls is to tear open the kernels and break the stock into small particles.

B. A Gyro-Laboratory Sifter (Fig. 3b) which uses a gyrating action for sifting. It has a throw of 2.1 ins. and revolves at a speed of 225 rpm. Its function is to arrange the stock from the breaks according to particle size.

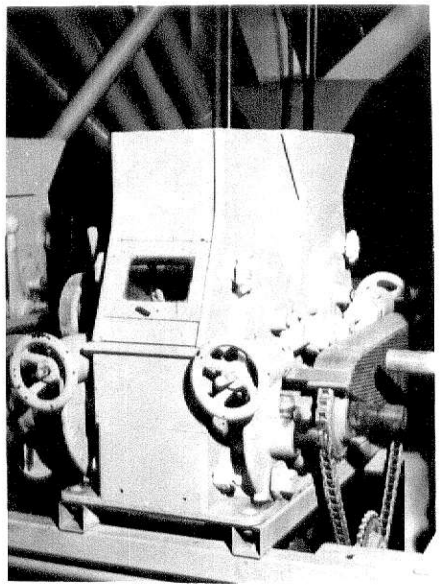
C. The gravity separator (Fig. 3c) makes separations according to particle size, shape, and density. In this study the particle shape and size were controlled by sifting and the separations achieved by the gravity separator were based on density alone.

The separation is made by passing the material over a porous 'deck' which is sloped in two directions, vibrating in a straight-line reciprocating motion, and through which air is discharged upwards into the material stream. The air stratifies the material according to the terminal velocity of each particle. Heavy endosperm sinks to the bottom and is conveyed to the high side and bran particles being light in weight flow to the low side.

Fig. 3. Machinery used in dry milling of grain sorghum: a. experimental roll stand; b. Gyro-laboratory sifter; and c. gravity separator.

FIG. 3

a:



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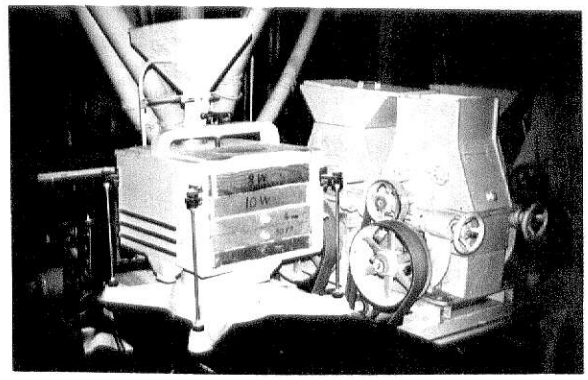

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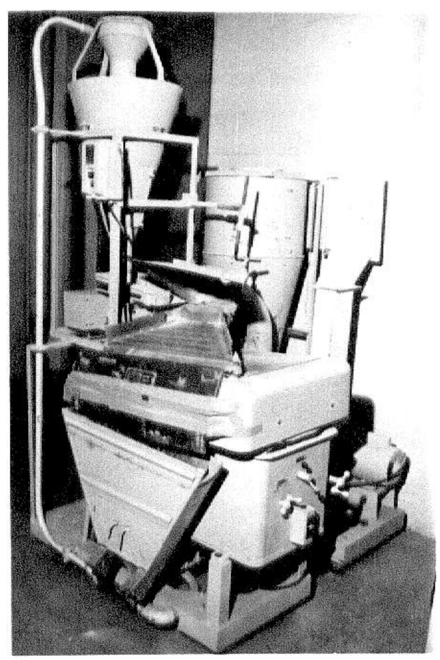


DRY MILLING SYSTEM

Initially a simple milling system consisting of three breaks and three sifters followed by three gravity tables was used. A sample of 3000 gms tempered to 17% moisture and held for four hours was run through the system. To study the effect of using a pre-break instead of a normal break another sample tempered to the same conditions was run through the same system except this time the first break was replaced by a pre-break (Fig. 4a). The pre-break rolls had a fine corrugation and a differential of 1:1.3. In preliminary tests it was found that the refined grits from the first gravity separator (+10W) had a high fat and ash content in both samples. However, the sample milled on the system with the pre-break was lower in fat and in ash.

The initial milling system was modified by the elimination of the first of the gravity separators and by the addition of two more breaks to grind the grits going to the first gravity separator (Fig. 4b).

The modified system was used to study the effect of different tempering conditions on the behavior of the grain during milling. Different samples were tempered to four levels of moisture and held for three different periods prior to milling. The different moisture levels and holding times are tabulated below.

% Moisture	Time (hrs)
16	2, 4 and 8
17	2, 4 and 8
18	2, 4 and 8
19	2, 4 and 8

Twelve combinations of temper moisture level and holding time were tested. In each case the samples were milled with a constant roll and feed setting. The percentage of total products of the fractions obtained from each sample was determined. Each fraction was analyzed for moisture, fat and ash.

Fig. 4a. Flow diagram for production of sorghum grits employing pre-break grinding, two break grinding and three gravity separators.

FIG. 4a

PRODUCTION OF SORGHUM GRITS

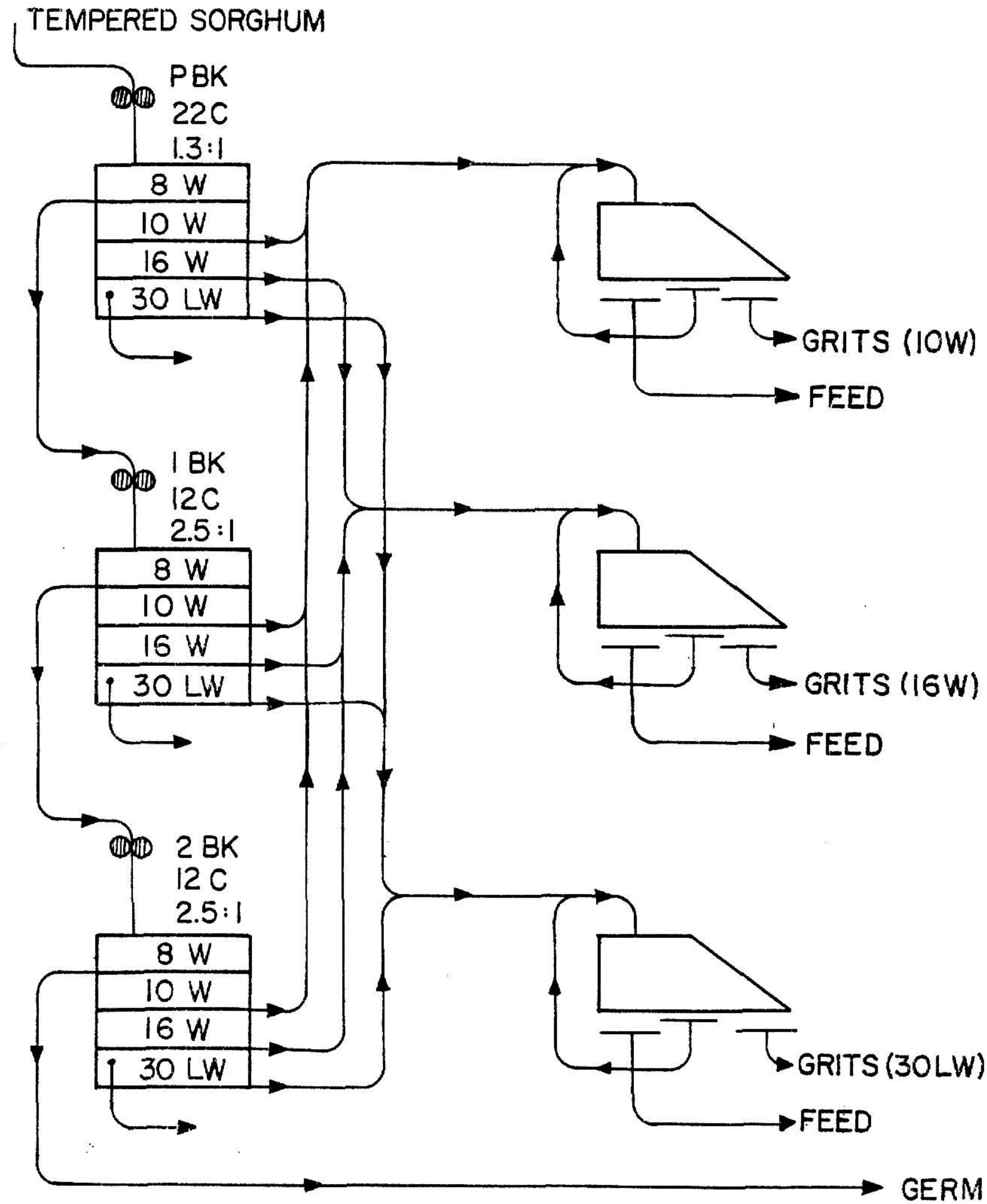


Fig. 4b. Flow diagram for the production of sorghum grits using a pre-break grinding, four break grindings and two gravity separators.

PRODUCTION OF SORGHUM GRITS

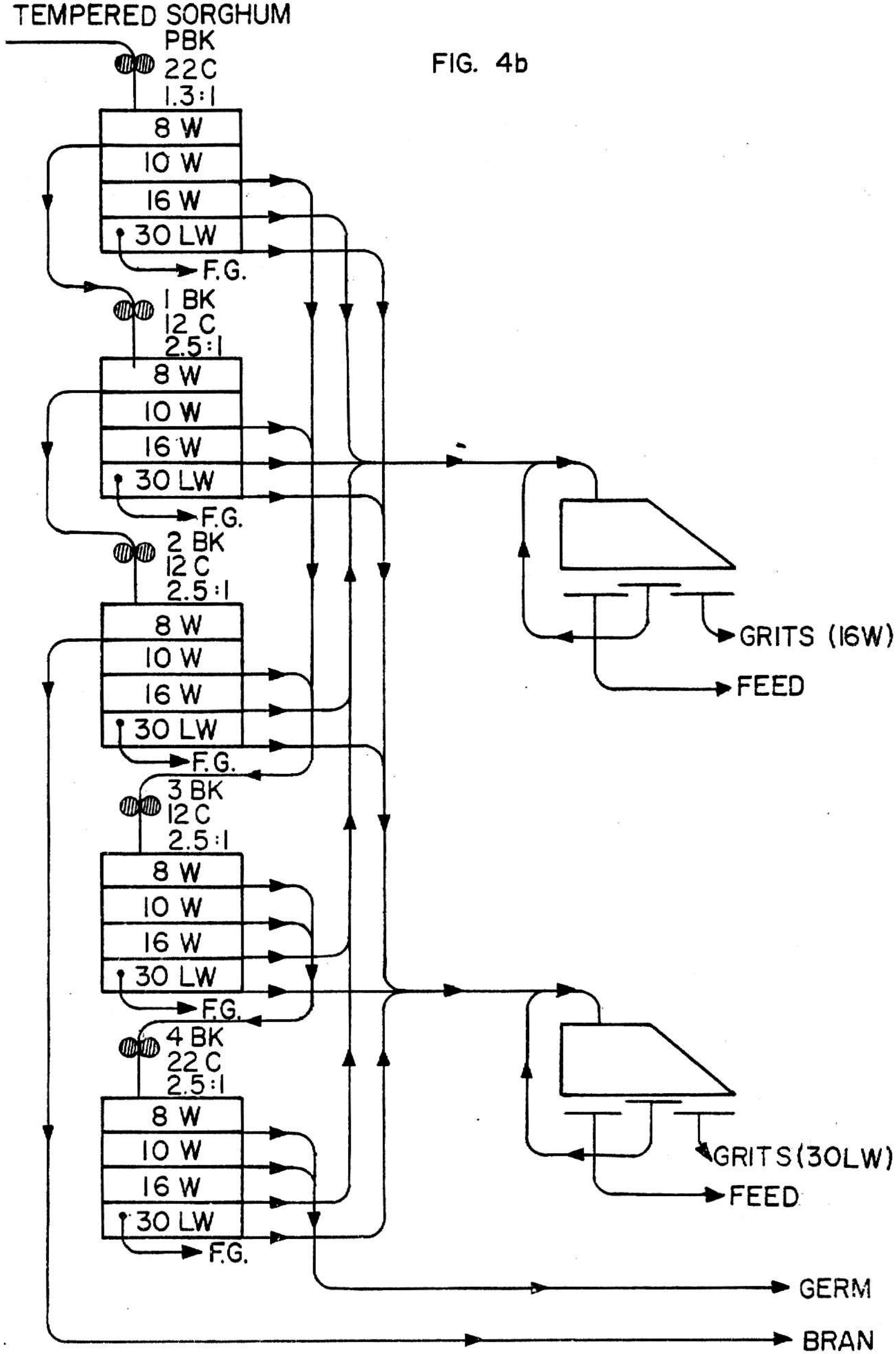


FIG. 4b

RESULTS AND DISCUSSION

SCANNING ELECTRON MICROSCOPY OF SORGHUM KERNELS

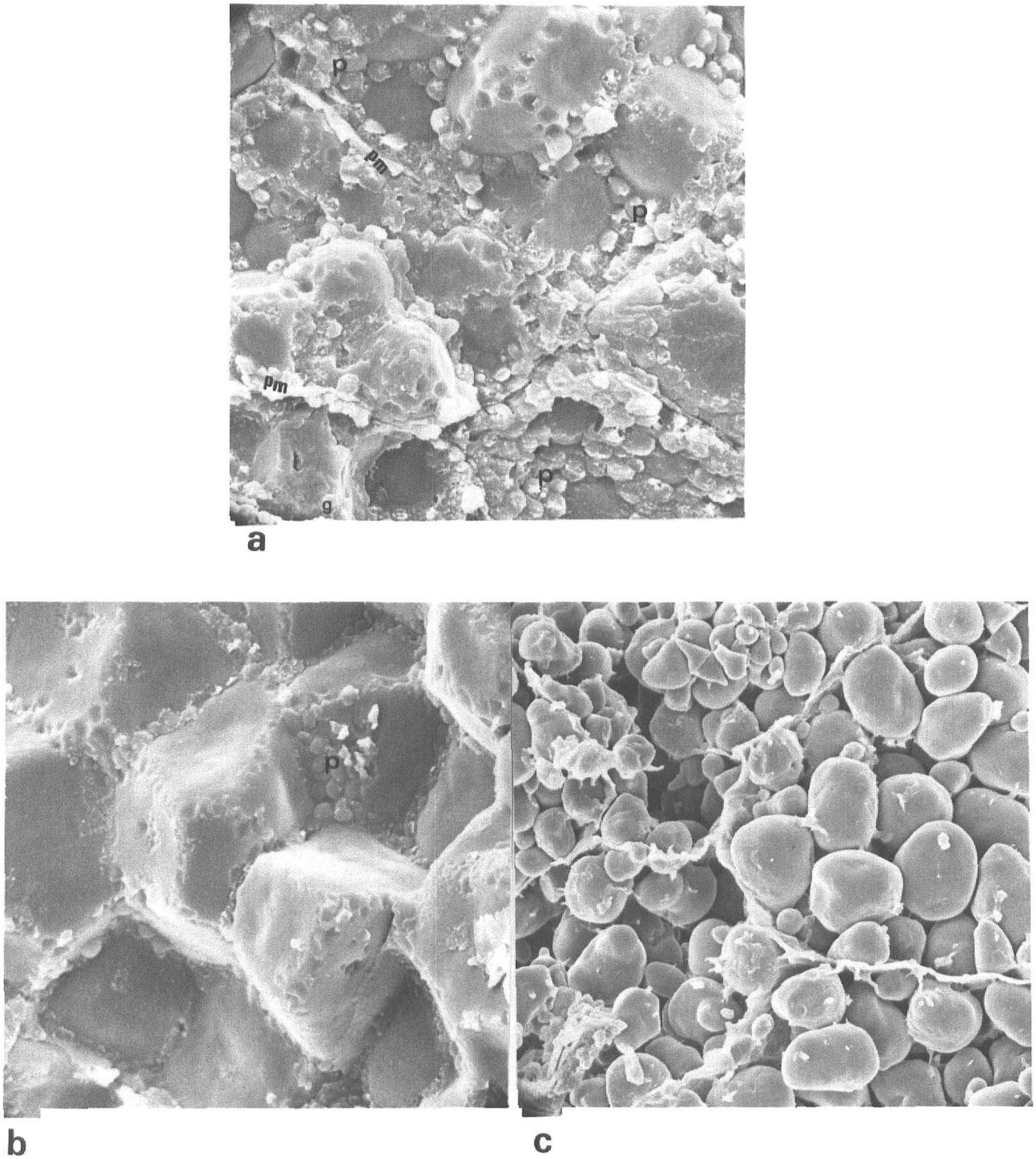
The scanning electron micrographs of the sorghum endosperm (not including the aleurone layer) at different regions are shown in Fig. 5. Sorghum endosperm has peripheral, corneous, and floury endosperm. The peripheral endosperm (Fig. 5a) which lies immediately inside the aleurone layer contained starch granules and numerous protein bodies embedded in a dense protein matrix. This agrees with the findings of Rooney and Sullins (61) and Hoseney et al. (30). The protein matrix is comprised of glutelin and prolamine proteins while the protein bodies are primarily prolamines (61). The corneous endosperm (Fig. 5b) located beneath the peripheral endosperm contained polyhedral starch granules with depressions where protein bodies were trapped. Hoseney et al. (30) attributed the angularity of the starch granules to the loss of water during maturation of the grain. During this process the otherwise round starch granules are forced into the polygonal shape. In turn, the relatively small protein bodies are forced to the interfacial edges of the starch granules where they are concentrated and make indentations at the edges of the polygonal-shaped starch granules. The corneous endosperm contained fewer protein bodies than did the peripheral endosperm. The floury endosperm (Fig. 5c) contained spherical starch granules with many intergranular air spaces.

PENETRATION OF WATER INTO THE SORGHUM KERNEL

The results of the electrical conductance moisture tests on grain sorghum tempered to various levels are given in Tables 3 and 4. Data from

Fig. 5. Scanning electron micrographs of grain sorghum endosperm (3000X): a. peripheral endosperm; b. corneous endosperm; and c. floury endosperm.

FIG. 15



these tables were plotted to present the rate of water penetration into the sorghum kernel (Fig. 6a and Fig. 6b).

At first nearly all of the added water was on or near the surface of the kernels and the reading indicated a much higher moisture percentage than that to which the kernels were tempered. With additional time the moisture on the surface was absorbed into the kernels. The rate of penetration was very fast at the beginning and after three hours most of the water had been absorbed into the kernel. The last of the added water was absorbed very slowly. This was true for both samples with different initial moisture contents.

Although sorghum kernels are comparatively hard the rate of water penetration into the kernel is very rapid. The apparent kernel hardness does not prevent the fast penetration of water into the kernel. This may be due to the flattened spherical shape and small size of the kernel. It may also be due to the presence of the floury endosperm which contains a lot of intergranular air spaces. An investigation of the relationship between kernel hardness and the rate and pattern of moisture absorption is warranted.

Butcher and Stenvert (16) stated that the protein content and distribution in wheat kernels are significant in affecting the rate of moisture penetration. This may be also true for sorghum.

Figure 7 shows the extent of water penetration into individual kernels using tritiated water for a duration of either one or three hours. The darkened areas are those to which water penetrated during these periods. After one hour the water was confined to the outside layers of the kernel whereas after three hours water was distributed throughout the

TABLE 3

RATE OF WATER PENETRATION INTO GRAIN SORGHUM
(1978) (12.5% M)

Moisture indicated by the Moisture Meter

Tempering Level (%)	Period of Tempering (hrs)										
	1/4	1/2	1	1-1/2	2	3	4	5	6	7	8
15	20.0	19.2	17.8	16.8	16.4	15.9	15.7	15.6	15.6	15.6	15.5
16	21.2	20.6	19.1	18.1	17.5	16.8	16.6	16.5	16.5	16.3	16.3
17	21.3	21.3	20.8	19.9	19.0	18.1	17.7	17.5	17.4	17.3	17.3
18	23.8	23.0	21.6	20.8	19.8	19.0	18.6	18.5	18.3	18.2	18.0

TABLE 4

RATE OF WATER PENETRATION INTO GRAIN SORGHUM
(1979) (10.87% M)

Moisture indicated by the Moisture Meter

Tempering Level (%)	Periods of Tempering (hrs)										
	1/4	1/2	1	1-1/2	2	3	4	5	6	7	8
13	21.0	19.5	17.5	16.1	15.2	14.2	14.0	13.7	13.6	13.6	13.5
14	21.6	21.3	19.8	18.4	17.2	15.8	15.3	15.0	14.9	14.8	14.7
15	-	-	21.4	20.2	19.1	17.5	16.7	16.2	15.9	15.8	15.8
	1-1/4	1-1/2	1-3/4	2-1/4	2-3/4	3-1/4	4-1/4	5-1/5	6-1/4	7-1/4	8-1/4
16	21.4	20.9	20.4	19.5	18.8	18.2	17.4	17.0	16.7	16.6	16.6
17	-	21.5	21.4	20.8	20.0	19.5	18.7	18.2	17.8	17.6	17.5
18	-	-	-	21.5	21.3	21.1	20.6	19.8	19.3	18.9	18.8

FIG. 6a

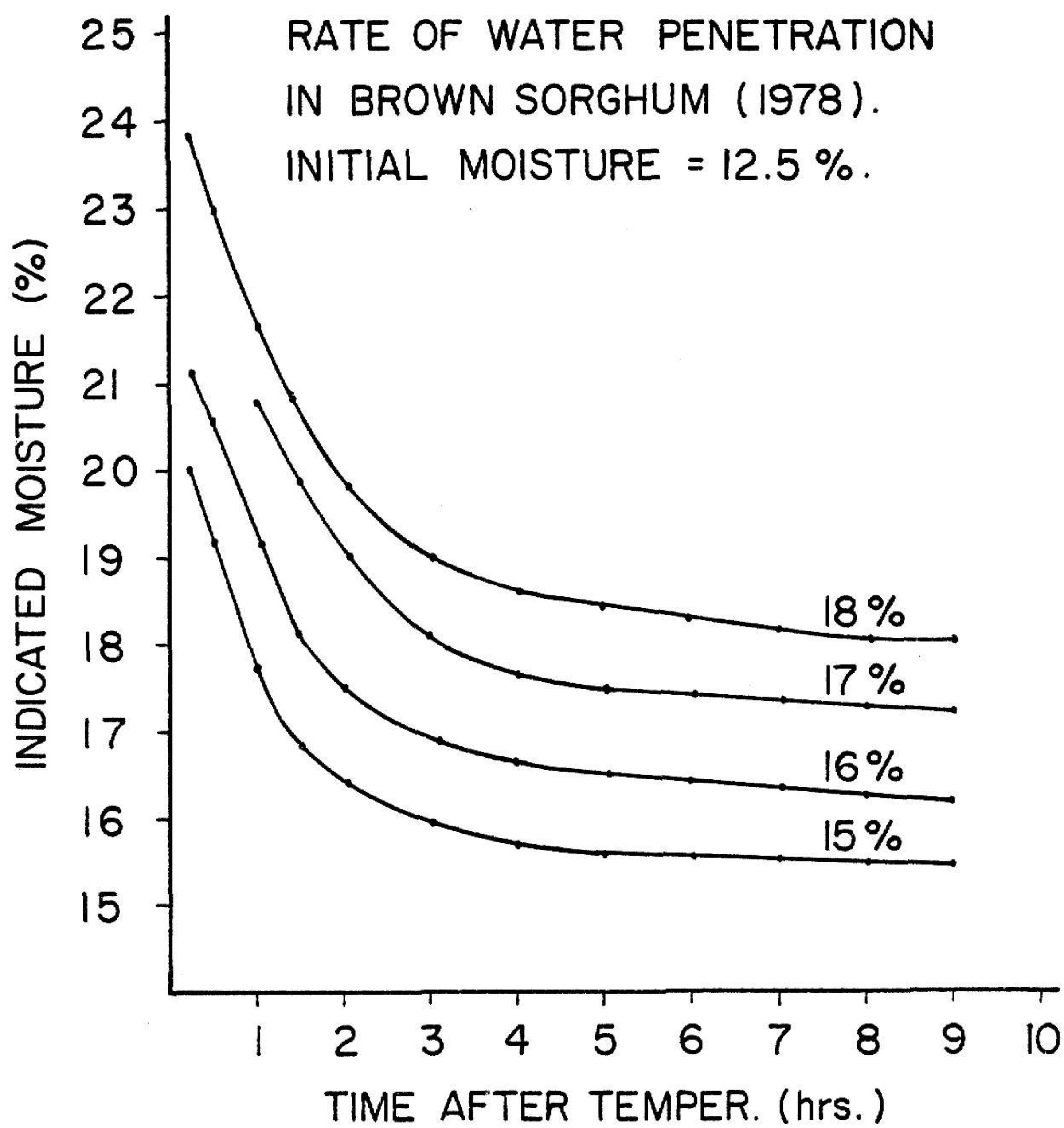

RATE OF WATER PENETRATION
IN BROWN SORGHUM (1978).
INITIAL MOISTURE = 12.5 %.
INDICATED MOISTURE (%)
25
24
23
22
21
20
19
18
17
16
15
18 %
17 %
16 %
15 %
1
2
3
4
5
6
7
8
9
10
TIME AFTER TEMPER. (hrs.)

FIG. 6b

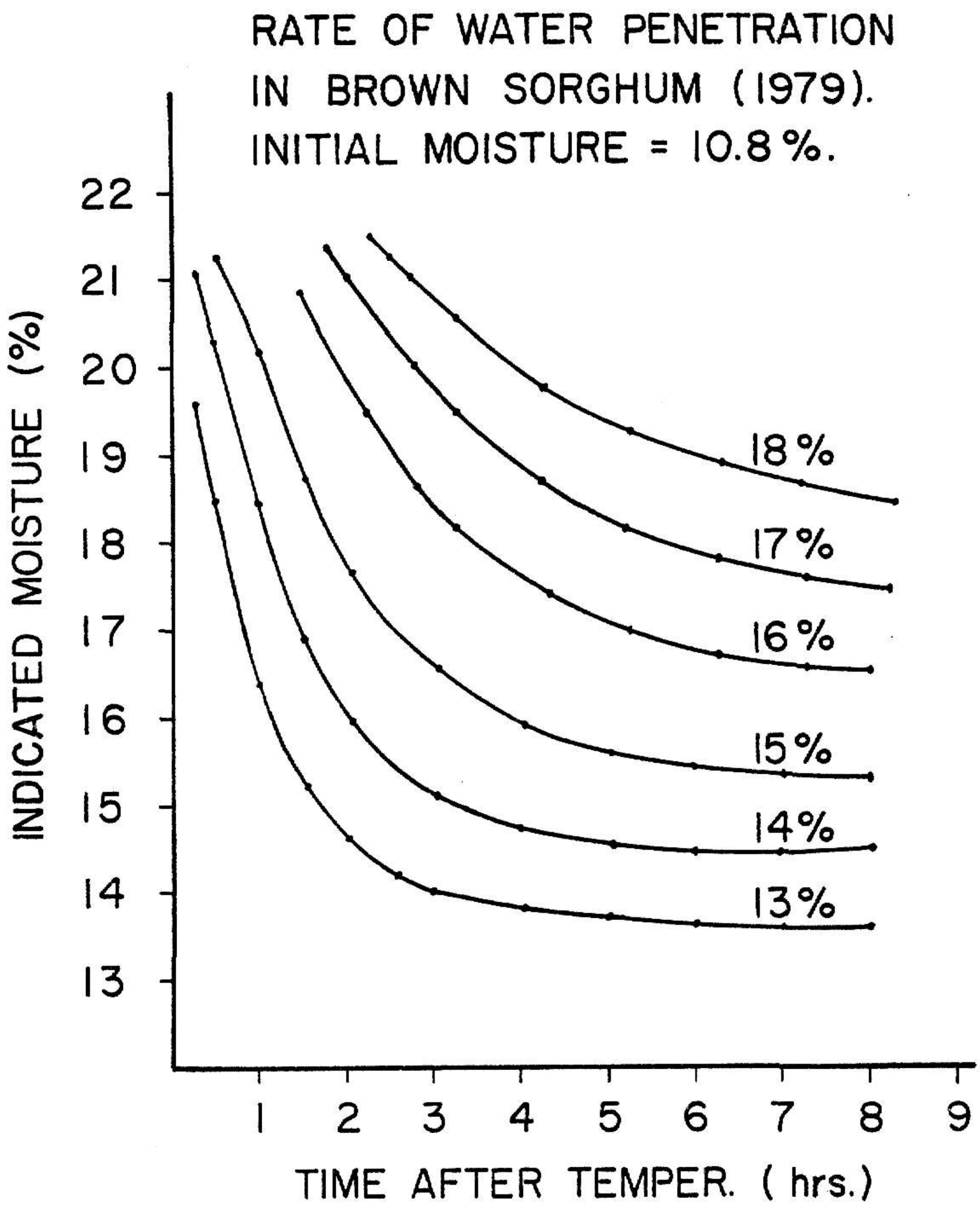
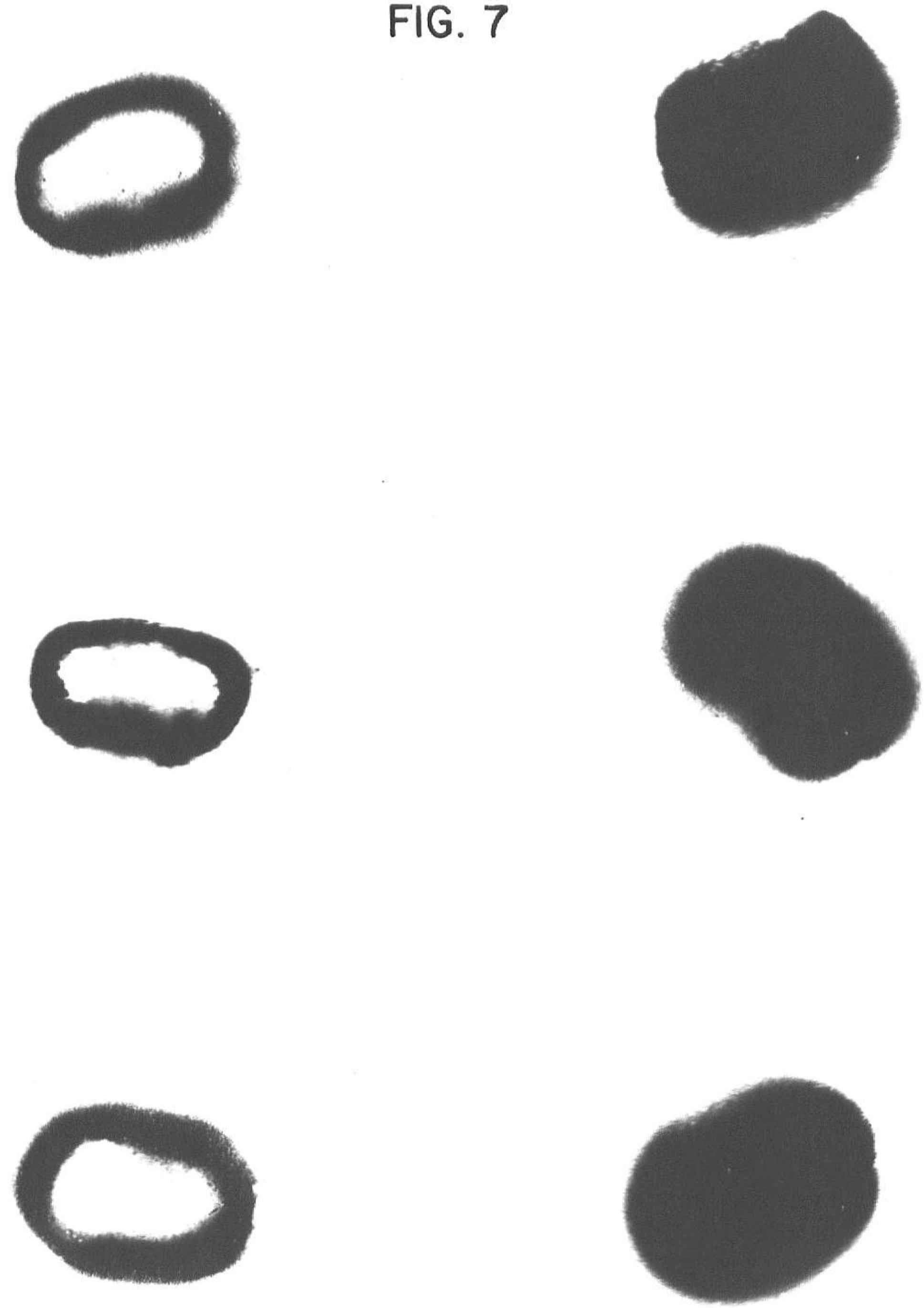

RATE OF WATER PENETRATION
IN BROWN SORGHUM (1979).
INITIAL MOISTURE = 10.8%.
INDICATED MOISTURE (%)
22
21
20
19
18
17
16
15
14
13
18%
17%
16%
15%
14%
13%
1
2
3
4
5
6
7
8
9
TIME AFTER TEMPER. (hrs.)

Fig. 7. Autoradiogram of water penetration into grain sorghum kernel after one and three hours soaking.

FIG. 7



one hr. three hrs.

kernel. These results concur with the electrical moisture tester data cited above. Water appeared to enter the kernel without preference for any region of the kernel's surface.

DRY MILLING SYSTEM

The results of using a simple milling system of three grinding steps (Fig. 4a) are given in Table 5. The results compare the system where three breaks were used with that where a pre-break was used instead of the first break. Cumulative fat content was plotted as a function of total products (Fig. 8). The system with a pre-break gave a total product of grits (-8W + 30LW) with lower fat than the system without a pre-break. This may have been because the pre-break tended to open the grain rather than to crush it and therefore produced less bran powder. The pre-break also appeared to make the endosperm release more readily in the subsequent breaks. However with and without the pre-break refined coarse grits (+10W) with high fat content were produced. When the modified system (Fig. 4b) was used a small fraction with high fat content was separated (+10W) leaving the refined grits (-8W + 30LW) with low fat content (Table 6). The foregoing suggests that the overs of the 10 wire contain the germ. The sorghum germ being small remained intact with the endosperm in the overs of the 10 wire. Several authors have noted that the germ is firmly embedded in the kernel and is difficult to remove during both dry and wet milling (58, 72).

TEMPERING CONDITIONS

The effect of different tempering conditions on the behavior of the grain during milling was studied by comparing the total yield, fat,

TABLE 5

THE EFFECT OF A PRE-BREAK ON GRINDING OF GRAIN SORGHUM

	3 BKS			PBK and 2 BKS		
	T.P	FAT	ASH	T.P	FAT	ASH
+ 10W	34.1	2.13	0.92	28.0	2.15	0.94
+ 16W	21.8	1.30	0.48	22.9	1.09	0.48
+ 30LW	10.2	2.76	1.18	11.9	2.50	1.00
-30LW	8.9	1.87	0.81	11.1	1.77	0.81
Bran	4.6	8.06	3.56	4.6	7.89	3.47

TABLE 6

THE EFFECT OF A SYSTEM WITH PRE-BREAK AND
4 BREAK ON GRINDING GRAIN SORGHUM

	T.P	FAT	ASH
+16W	36.5	1.59	0.69
+30LW	17.1	1.19	0.48
-30LW	17.0	1.86	0.77
Bran	4.4	8.30	3.82
Germ	7.6	14.30	5.87

Fig. 8. Cumulative fat for grits obtained from milling systems employing three breaks or a pre-break and two breaks. (Cumulative fat at each level of product yield is calculated according to the formula:

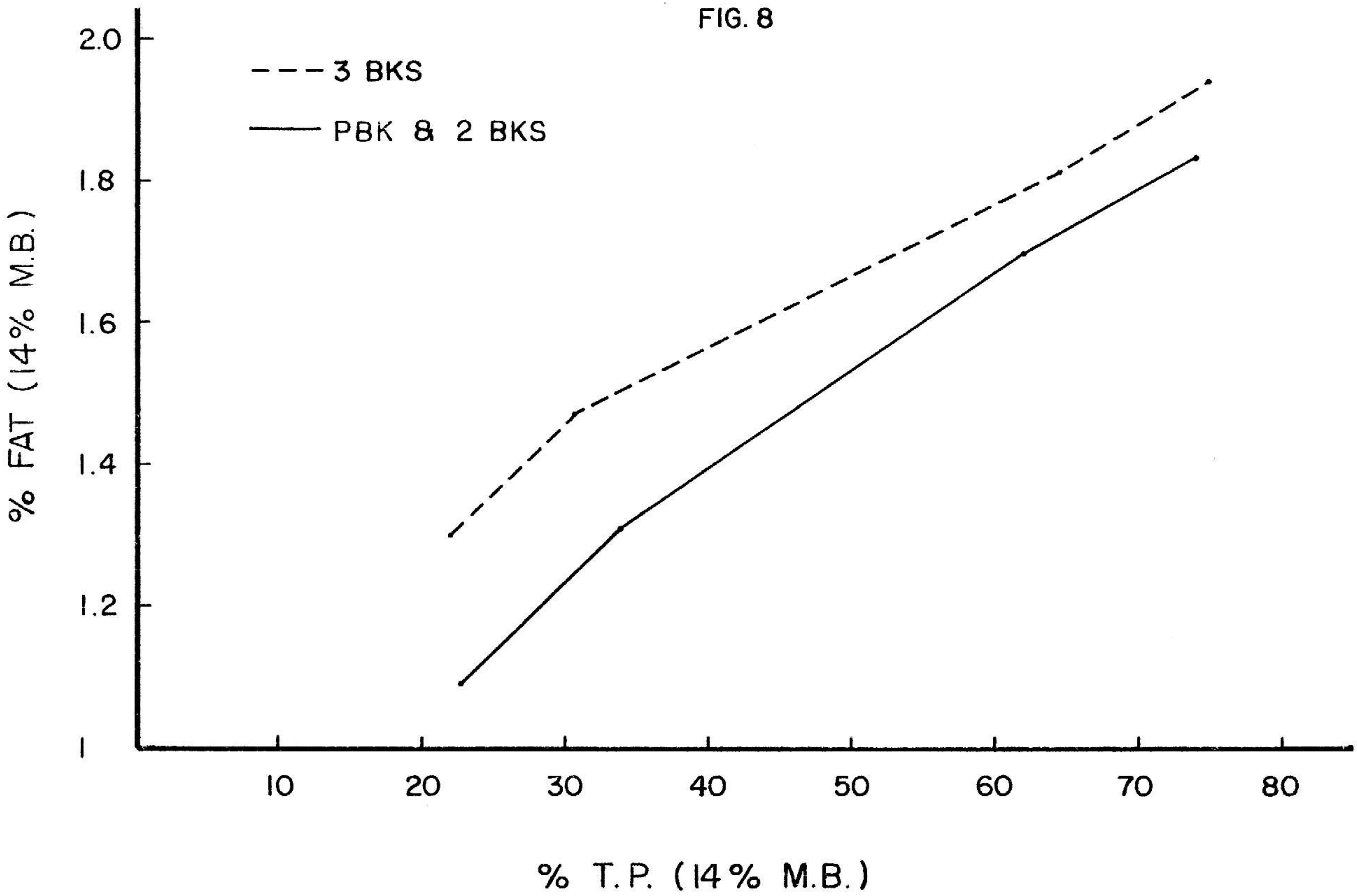
$$\frac{\Sigma Q X F}{\Sigma Q}$$

where

Q is the percentage of total product of each fraction

F is the percentage of fat present in each fraction.)

FIG. 8



3 BKS
PBK & 2 BKS
2.0
1.8
1.6
1.4
1.2
1
10
20
30
40
50
60
70
80
% FAT (14% M.B.)
% T.P. (14% M.B.)

and ash of each fraction produced by each set of tempering conditions. For each sample, four fractions were obtained following grinding and sifting (Fig. 4b). These included bran, germ, fines (-30LW) and grits (-10W + 30LW).

The results of each fraction at different combination of tempering conditions are given in Tables 7, 8, 9, and 10 and are plotted in Figs. 9, 10, 11, and 12, respectively.

The effect of the interaction between moisture and time on total product yield (T.P.), fat, and ash was tested using Tukey's test (47) and the characteristic root test (33). Both tests failed to show a significant interaction between moisture and time on total product yield (T.P.), fat, and ash. Furthermore, the main effects of moisture and time on each fraction was studied using the analysis of variance (ANOVA). The F-values and the significance of the main effects are shown in Table 11.

THE EFFECT OF TEMPERING CONDITIONS ON BRAN SEPARATION

The amount of bran produced (T.P.) increased as the moisture content increased (Table 9 and Fig. 9). Fat and ash were affected to a lesser degree by moisture except at 19% moisture where both fat and ash decreased markedly.

The observed increase in bran suggests that the increase in moisture toughens the bran: additional bran passed through the grinding rolls without being broken into small particles. However, at high moisture levels (19%) some endosperm apparently remained attached to the bran, as evidenced by the decrease in fat and ash content of the bran.

The increase in tempering time caused a decrease in the total production of bran (Table 7 and Fig. 9) but it had no significant effect on either the ash or the fat content of the bran (Table 11). As the holding time increased moisture penetrates the kernel leaving the bran with less water; thus the bran becomes less tough and would break more readily into particles which pass through the 8W sieve.

The above results indicate that the effect of moisture on sorghum bran is the same as that on wheat bran. Moderate amounts of moisture make the bran tough and easy to separate while excessive moisture makes it difficult to separate from the endosperm material (24).

THE EFFECT OF TEMPERING CONDITIONS ON GERM SEPARATION

The level of tempering moisture had a significant effect on the total production, fat and ash content of the germ (Table 11). As the moisture level increased the quantity of germ produced increased (Fig. 10 and Table 8). However, at 19% moisture and two hours tempering there was a decrease in the quantity of germ produced. This may have been due to the fact that some germ remained attached to the bran. The quantity of bran produced was much more than what would have been expected (Table 7).

The fat and ash contents of the germ decreased as the tempering moisture level increased. This may have been due to additional endosperm material remaining attached to the germ.

The tempering time had no significant effect on the total product or on the fat and ash contents of the germ (Table 11).

THE EFFECT OF TEMPERING CONDITIONS ON FINES (-30LW) PRODUCTION

The temper moisture level had a significant effect on the total production of fines (Table 11). As the moisture level increased the quantity of fines produced increased (Table 9 and Fig. 11).

The fines produced by the pre-break, first and second break grindings were white in color and smooth to the touch in comparison to the yellow and grainy fines of the third and fourth breaks. This suggests that the fines from the earlier breaks were derived mainly from the floury endosperm which is white in color. It is possible that the intergranular air spaces known to be present allow the floury endosperm to pulverize readily upon grinding. As the tempering moisture level increased the corneous endosperm became soft and more easily broken into fines. The increase in fines was due to corneous endosperm and not bran since the fat and ash decreased as the fines increased (Table 9 and Fig. 11).

The amount of fines produced at four hours tempering time was less than that produced at two and eight hours (Fig. 11). The decrease in fat and ash with increased tempering time indicates that the increase in fines at two hours is due to certain outer layers having been reduced to fines while the increase at eight hours is due to the reduction of some corneous endosperm into fines.

At high tempering moisture (19%) the total production of fines increased with time and there was a drop in the fat and ash contents.

THE EFFECT OF TEMPERING CONDITIONS ON GRITS (-10W + 30LW) PRODUCTION

Both tempering moisture and holding time had a significant effect on the total product yield, fat, and ash of the grits (Table 11).

The increase in moisture caused a decrease in the total product yield of grits (Table 10 and Fig. 12). This may, in part, have been because the grits are corneous endosperm which is rendered more friable by moisture and therefore reduced more easily to fines. It may also be due to high moisture levels causing some outer layers of the endosperm to remain attached to the bran.

The increase in tempering time caused an increase in grits yield. The increase may have been due to reduction of some outer layers. Additional bran may have been included with the grits since there was an increase in the fat and ash contents of the grits.

REFINEMENT OF GRITS ON THE GRAVITY SEPARATOR

Tables 12 and 13 show the results of refining the coarse and medium grits, respectively, with a gravity separator.

The gravity separator operates at a high efficiency to separate refined grits from bran. An average of 81% of the material obtained from the separator was separated into refined grits with low fat and ash. The remaining 19% of the material was separated as bran containing high fat and ash.

The percentage of total refined grits recovered (Table 14) was affected by different tempering conditions. The total production of main grits (-10W + 30W) for several tempering conditions appear for each moisture level (Figs. 13, 14, 15, and 16). Cumulative fat data was plotted for each tempering time. Based on the data presented the best tempering time for each moisture level was determined and appear below:

% Moisture	Optimum Time (hrs)
16	4
17	8
18	4
19	2

The cumulative fat data for the four moisture levels are shown in Figure 17. The tempering conditions which gave the maximum amount of low fat grits was found to be 17% moisture with 8 hours holding time.

The suction in the gravity separator helped in removing bran particles and therefore aided in the production of low fat grits (Table 15). However, at high tempering moistures the gravity separator removed excessive amounts of product. This may have been due to a downward shift in the average particle size distribution at the highest tempering level.

TABLE 7

THE EFFECT OF DIFFERENT TEMPERING CONDITIONS ON BRAN SEPARATION

	Moisture (%)				
TIME (hrs)	16	17	18	19	14% M.B.
	5.40	6.70	9.80	15.00	T.P.
2	8.27	8.16	8.20	7.93	FAT
	3.94	4.08	4.15	3.81	ASH
	3.80	5.50	9.40	10.30	T.P.
4	8.36	8.20	7.97	7.58	FAT
	4.04	3.96	3.79	3.69	ASH
	2.30	5.00	7.50	10.00	T.P.
8	8.50	8.20	8.55	7.77	FAT
	4.25	3.96	4.08	3.94	ASH

TABLE 8

THE EFFECT OF DIFFERENT TEMPERING CONDITIONS ON GERM SEPARATION

	Moisture (%)				
TIME (hrs)	16	17	18	19	14% M.B.
	5.80	7.50	7.60	6.19	T.P.
2	14.01	12.72	12.72	12.73	FAT
	6.62	5.89	5.80	5.50	ASH
	5.80	6.9	7.40	8.70	T.P.
4	14.69	13.62	13.12	12.33	FAT
	6.52	6.00	5.81	5.72	ASH
	5.30	6.90	7.70	7.50	T.P.
8	14.77	14.52	13.00	12.76	FAT
	6.45	6.37	5.97	5.80	ASH

TABLE 9

THE EFFECT OF DIFFERENT TEMPERING CONDITIONS ON FINES SEPARATION (-30LW)

	Moisture (%)				
TIME (hrs)	16	17	18	19	14% M.B.
	12.80	13.50	14.00	14.20	T.P.
2	1.84	1.65	1.56	1.36	FAT
	0.76	0.69	0.62	0.61	ASH
	12.20	12.90	13.90	15.30	T.P.
4	1.64	1.54	1.45	1.26	FAT
	0.75	0.69	0.59	0.57	ASH
	13.00	13.90	14.20	16.40	T.P.
8	1.65	1.35	1.35	1.13	FAT
	0.73	0.60	0.57	0.54	ASH

TABLE 10

THE EFFECT OF DIFFERENT TEMPERING CONDITIONS ON GRITS SEPARATION (-10W + 30LW)

	Moisture (%)				
TIME (hrs)	16	17	18	19	14% M.B.
	76.00	72.30	68.60	64.60	T.P.
2	2.37	2.17	1.90	1.73	FAT
	1.05	0.94	0.82	0.76	ASH
	78.20	74.70	69.30	65.70	T.P.
4	2.45	2.28	2.00	1.89	FAT
	1.11	1.03	0.90	0.81	ASH
	79.40	74.20	70.60	66.10	T.P.
8	2.65	2.28	2.07	2.07	FAT
	1.25	1.04	0.91	0.86	ASH

Fig. 9. The effect of several tempering conditions on bran separation.

Fig. 10. The effect of several tempering conditions on germ separation.

FIG. 9 : BRAN

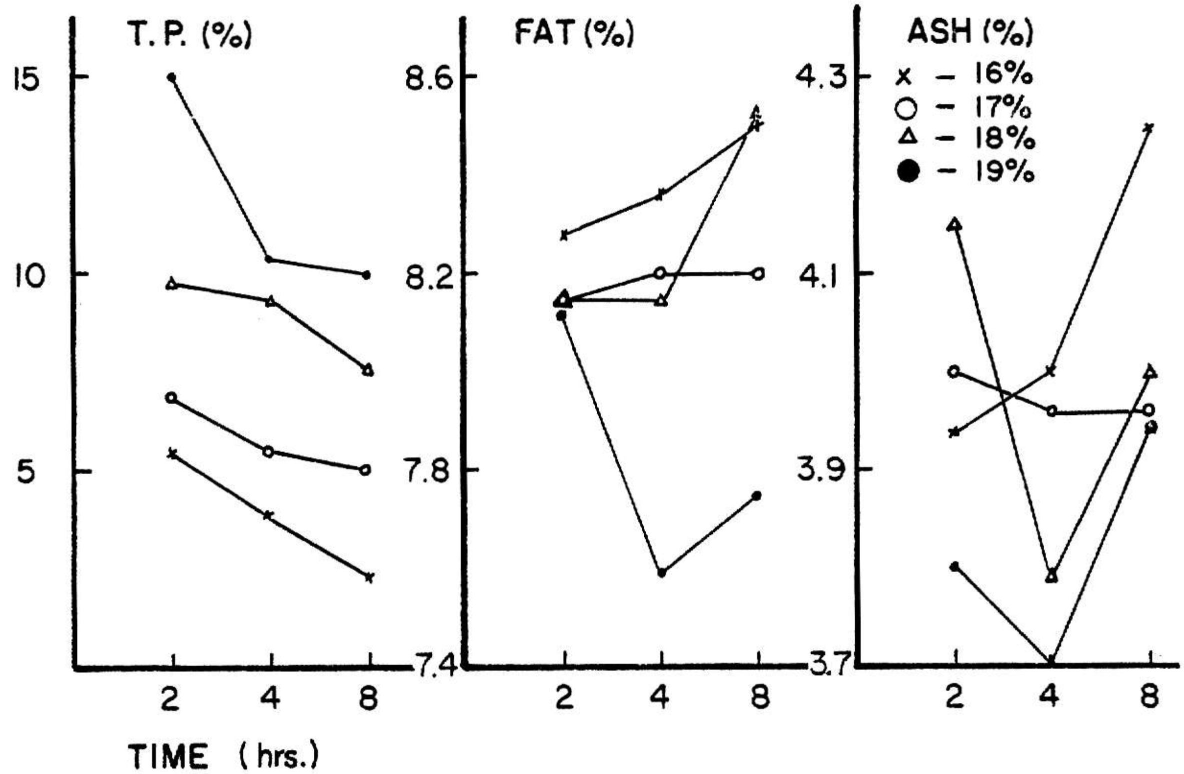


FIG. 10 : GERM

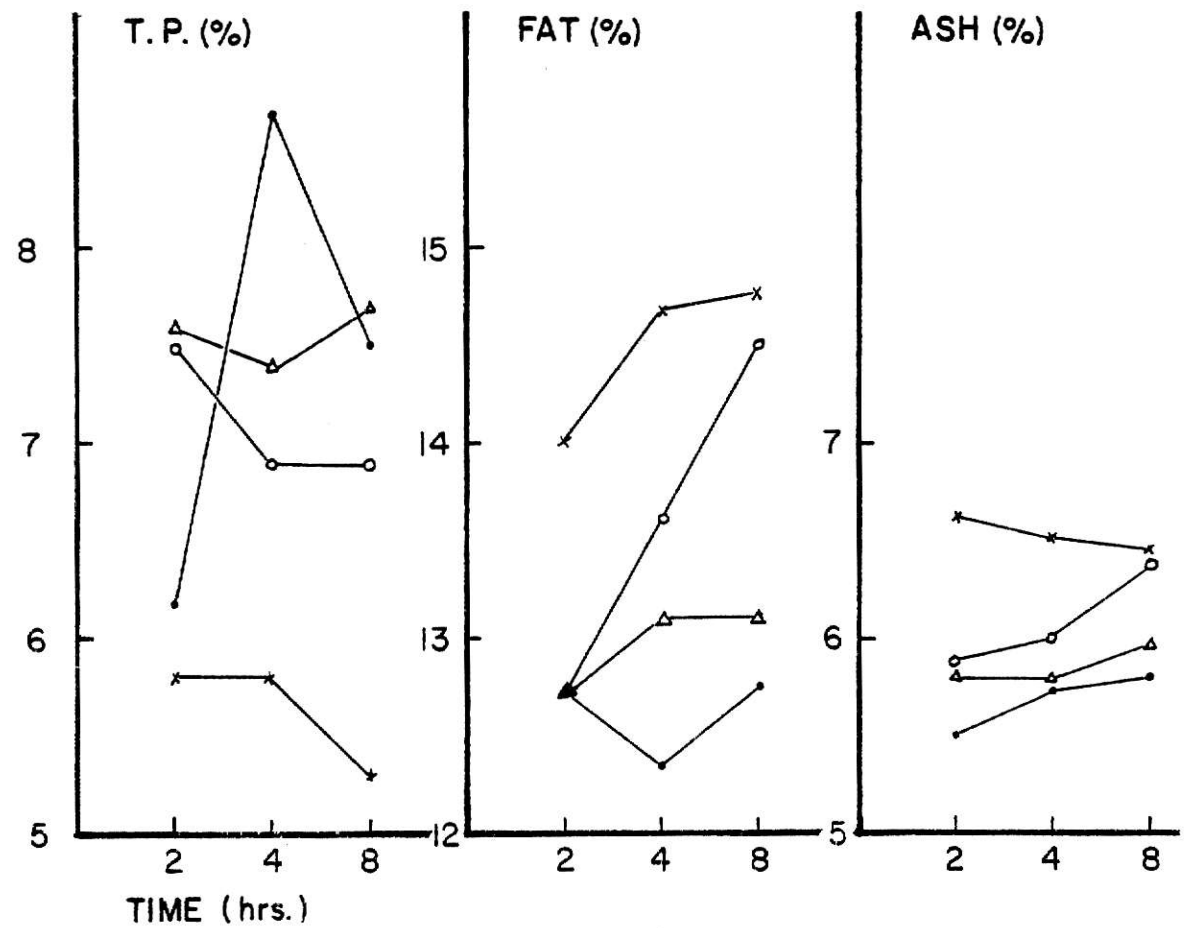


Fig. 11. The effect of several tempering conditions on fines (-30LW) production.

Fig. 12. The effect of several tempering conditions on grits (-10W + 30LW) production.

FIG. 11: FINES (-30 LW)

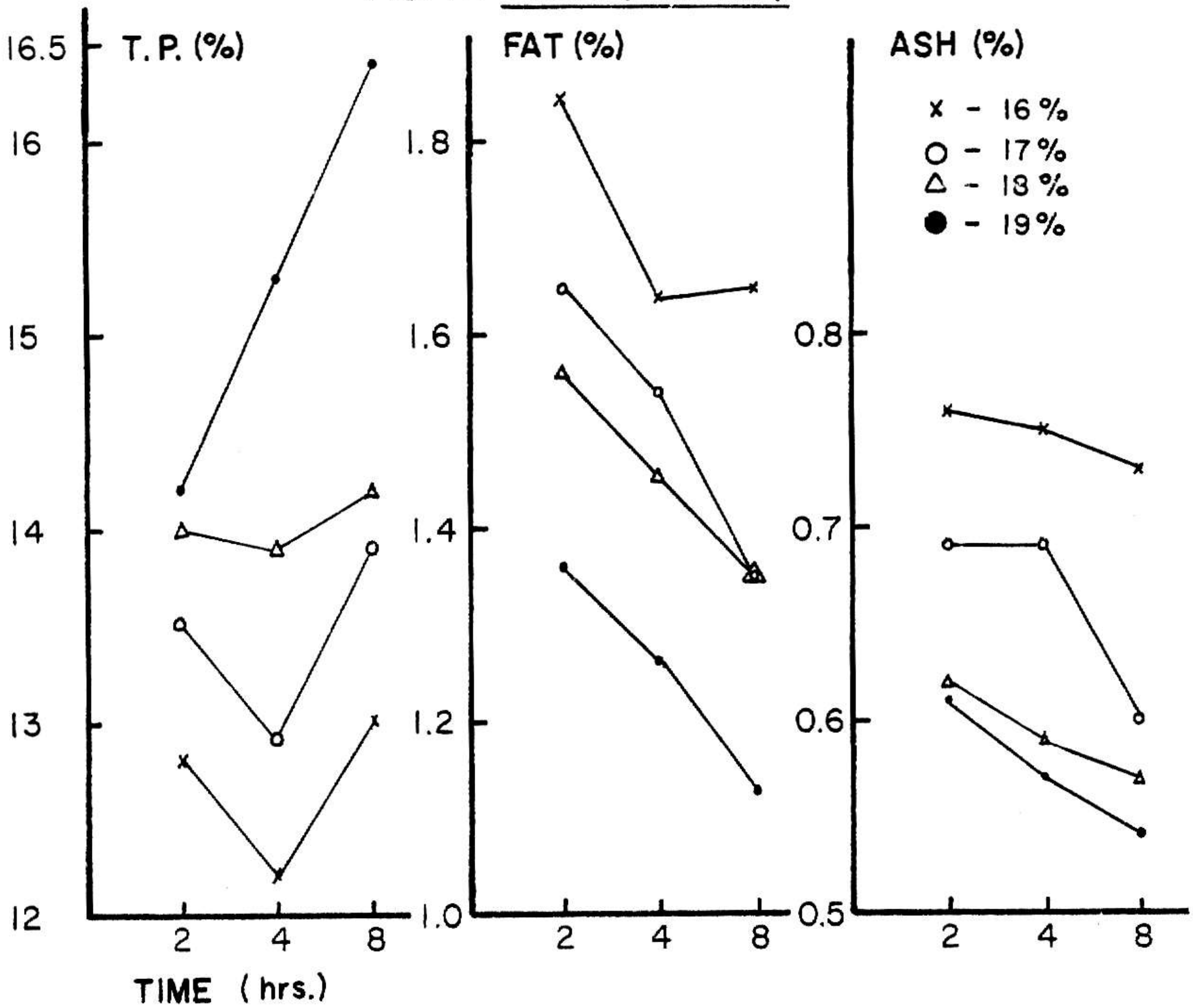


FIG. 12: GRITS (-10 + 30 LW)

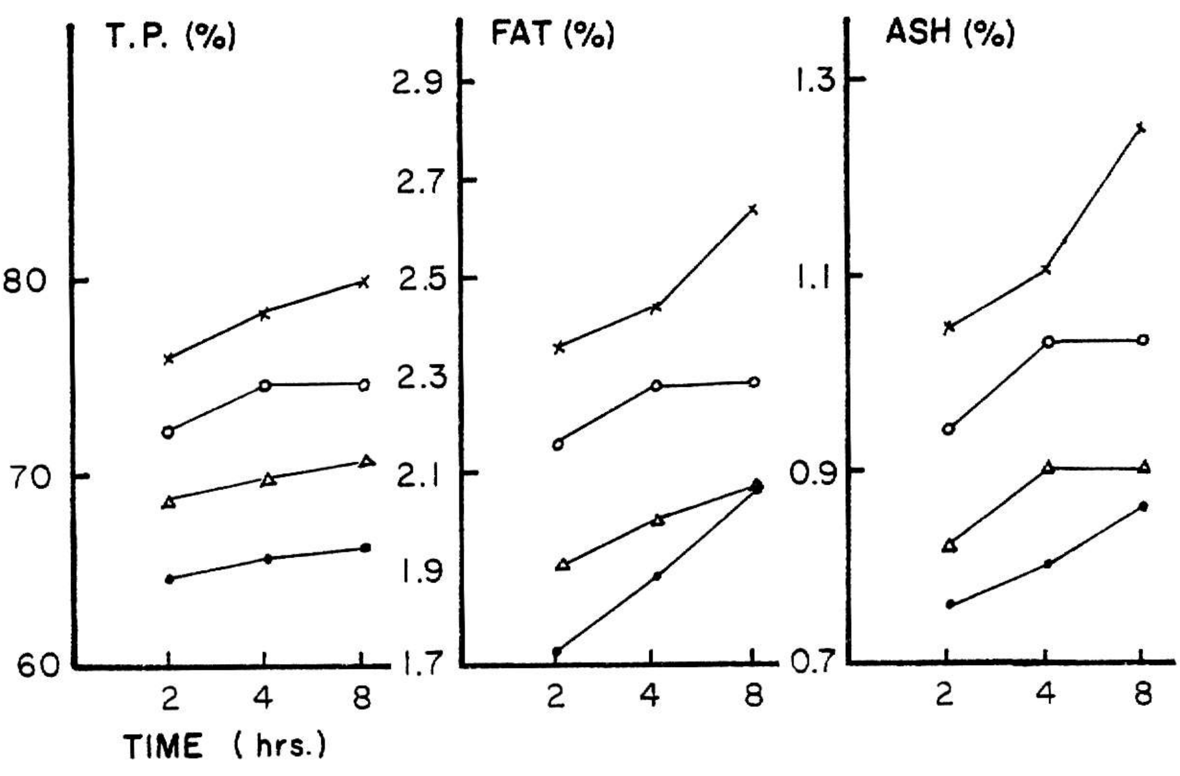


TABLE 11

F-VALUE AND SIGNIFICANCE OF THE MAIN EFFECTS (5% LEVEL)[1] OF MOISTURE AND TIME ON TOTAL PRODUCT, ASH AND FAT OF BRAN, GERM, FINES AND GRITS

		Moisture		Time	
		F-value	Significance	F-value	Significance
	T.P.	34.48	X	9.12	X
Bran	ASH	2.52	none	2.41	none
	FAT	8.15	X	1.99	none
	T.P.	4.55	X	0.39	none
Germ	ASH	19.22	X	1.89	none
	FAT	11.12	X	2.69	none
	T.P.	12.99	X	2.81	none
Fines	ASH	51.62	X	10.50	X
	FAT	56.06	X	28.29	X
	T.P.	248.42	X	14.97	X
Grits	ASH	55.27	X	13.36	X
	FAT	61.48	X	14.55	X

X - significant.

1 - 1% level has the same significance of the main effects except for bran (fat) which is not significant at this level.

TABLE 12

PERFORMANCE OF GRAVITY SEPARATOR IN SEPARATING COARSE GRITS (-10W, +16W)

Moisture (%)	TIME hrs	High Side (%) System Yield[1] (%)	T.P.[2] (%)	ASH (%)	FAT (%)	Low Side (%) System Yield (%)	T.P. (%)	ASH (%)	FAT (%)
	2	82	42.6	0.70	1.77	18	9.5	2.32	5.31
16	4	81	44.2	0.79	1.77	19	10.2	2.40	5.77
	8	83	44.6	0.78	1.78	17	9.4	2.30	5.28
	2	81	36.2	0.67	1.57	19	8.6	1.77	3.93
17	4	76	33.7	0.59	1.39	24	10.4	1.76	3.91
	8	80	40.2	0.68	1.49	20	9.9	2.04	4.65
	2	81	32.4	0.62	1.49	19	7.6	1.77	3.93
18	4	76	33.7	0.59	1.39	24	10.4	1.76	3.91
	8	82	36.8	0.76	1.89	18	8.2	1.86	4.11
	2	87	31.2	0.65	1.49	13	5.9	1.67	3.64
19	4	85	33.7	0.63	1.57	15	6.1	1.67	3.72
	8	80	32.9	0.69	1.59	20	8.4	1.77	4.03

[1]Percentage of total product obtained from gravity separator.

[2]Percentage of product of the overall system.

TABLE 13

PERFORMANCE OF A GRAVITY SEPARATOR IN SEPARATING MEDIUM GRITS (-16W + 30LW)

		High Side (%)				Low Side (%)			
Moisture (%)	TIME hrs	System Yield[1] (%)	T.P.[2] (%)	ASH (%)	FAT (%)	System Yield (%)	T.P. (%)	ASH (%)	FAT (%)
	2	76	15.1	0.46	1.27	24	4.8	1.37	2.54
16	4	84	16.2	0.45	0.98	16	3.2	1.66	3.32
	8	78	14.6	0.43	1.00	22	4.1	1.37	2.94
	2	88	20.1	0.46	1.08	12	2.7	1.27	2.74
17	4	80	15.2	0.41	0.83	20	3.8	1.17	2.54
	8	87	15.8	0.45	1.00	13	2.4	1.28	2.76
	2	80	15.9	0.36	0.96	20	4.1	0.93	1.89
18	4	90	17.5	0.43	0.99	10	2.1	1.18	2.36
	8	80	12.7	0.40	0.89	20	3.1	1.08	2.16
	2	84	16.1	0.40	0.80	16	3.1	0.99	2.17
19	4	84	15.3	0.40	1.00	16	2.8	0.96	2.31
	8	81	14.3	0.39	0.89	19	3.3	0.96	1.95

[1]Percentage of total product obtained from gravity separator.

[2]Percentage of product of the overall system.

TABLE 14

REFINED MAIN GRITS FROM GRAVITY SEPARATOR
(-10W + 30LW)

	Moisture (%)				
TIME (hrs)	16	17	18	19	14% M.B.
	57.70	56.30	48.30	47.30	T.P.
2	1.64	1.38	1.32	1.25	FAT
	0.64	0.60	0.47	0.56	ASH
	60.4	53.00	51.20	49.00	T.P.
4	1.56	1.36	1.25	1.39	FAT
	0.78	0.58	0.54	0.56	ASH
	59.20	56.00	49.50	47.20	T.P.
8	1.57	1.35	1.63	1.38	FAT
	0.69	0.58	0.67	0.60	ASH

Fig. 13. Cumulative fat content of grits from sorghum tempered to 16% moisture and held for two, four or eight hours.

Fig. 14. Cumulative fat content of grits from sorghum tempered to 17% moisture and held for two, four or eight hours.

FIG. 13: CUMULATIVE FAT

16% M

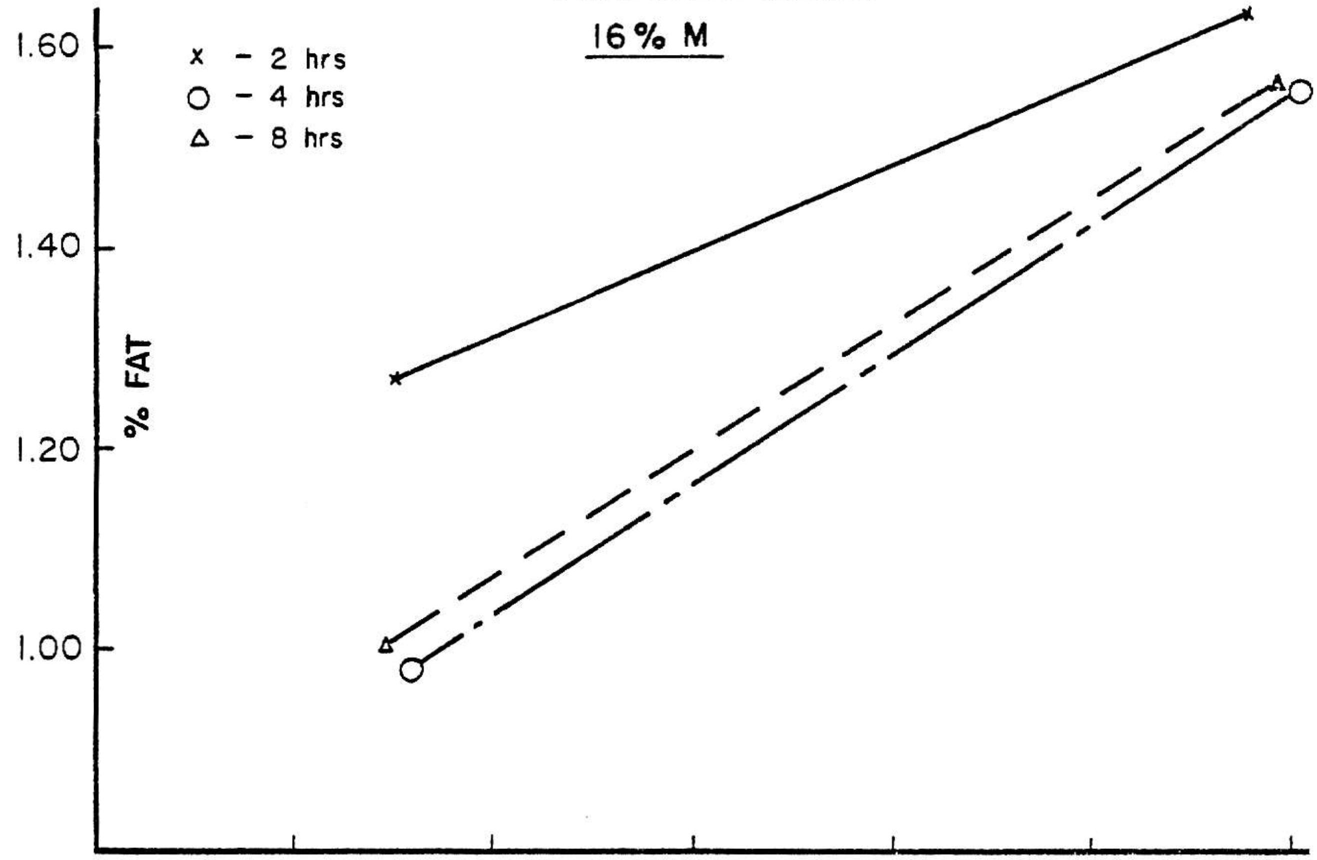


FIG. 14 17% M

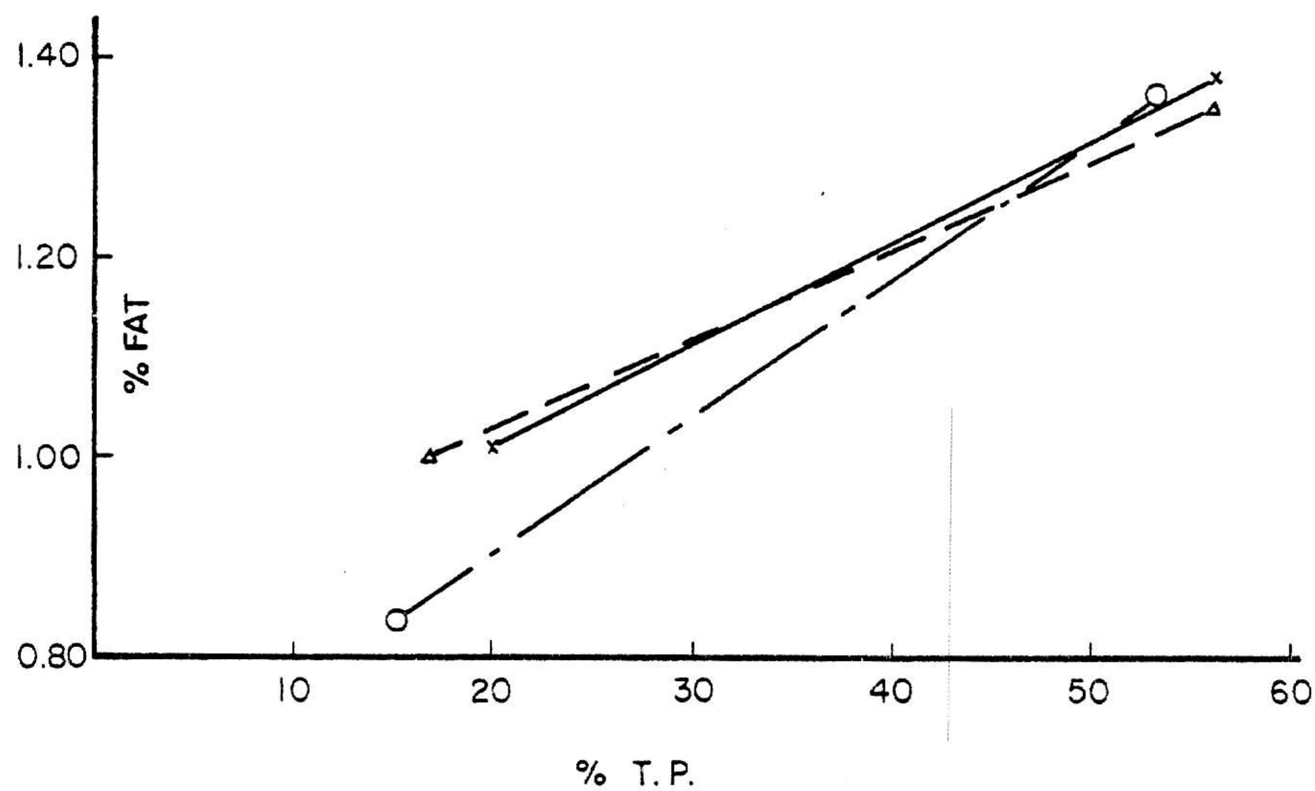


Fig. 15. Cumulative fat content of grits from sorghum tempered to 18% moisture and held for two, four or eight hours.

Fig. 16. Cumulative fat content of grits from sorghum tempered to 19% moisture and held for two, four or eight hours.

FIG. 15: CUMULATIVE FAT
18% M

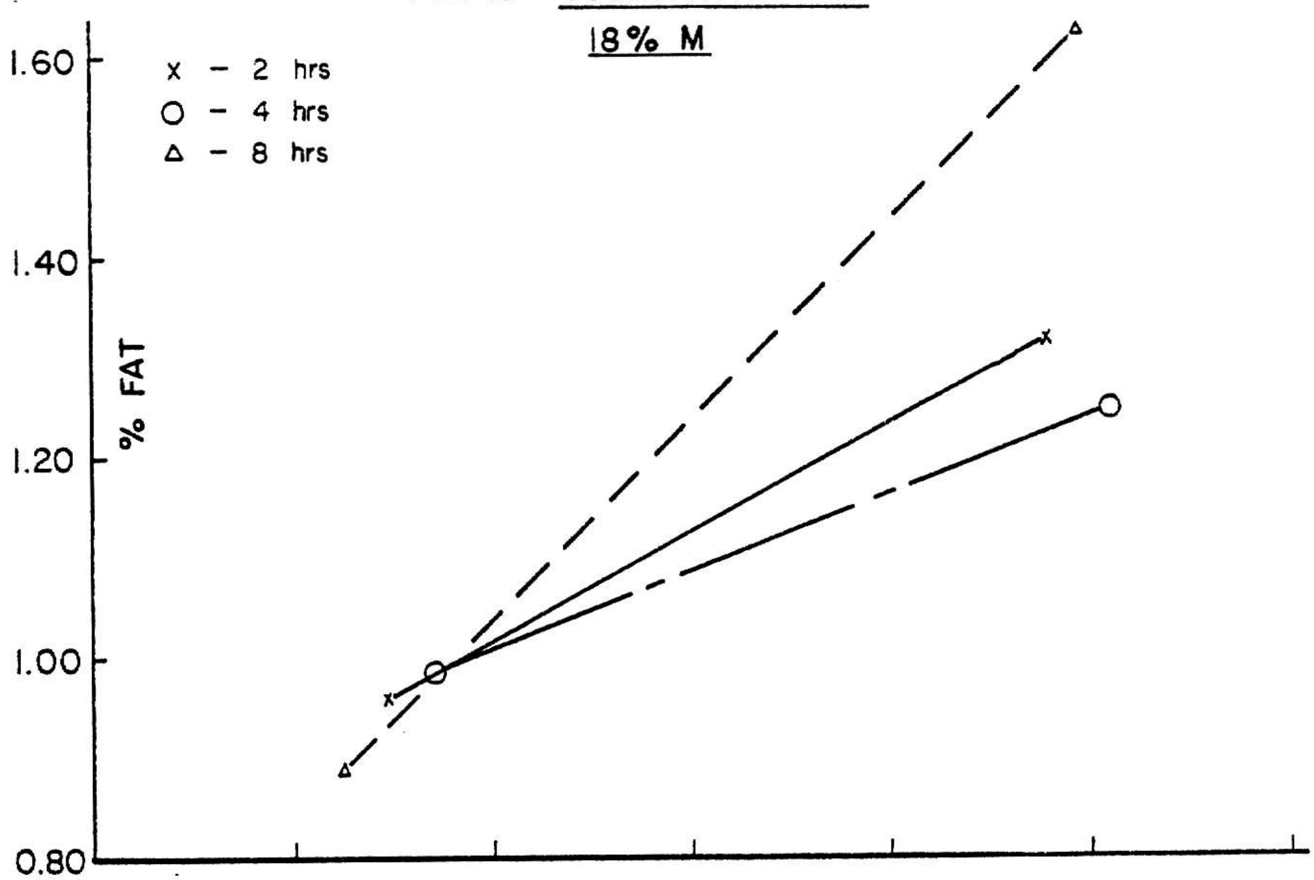


FIG. 16: 19% M

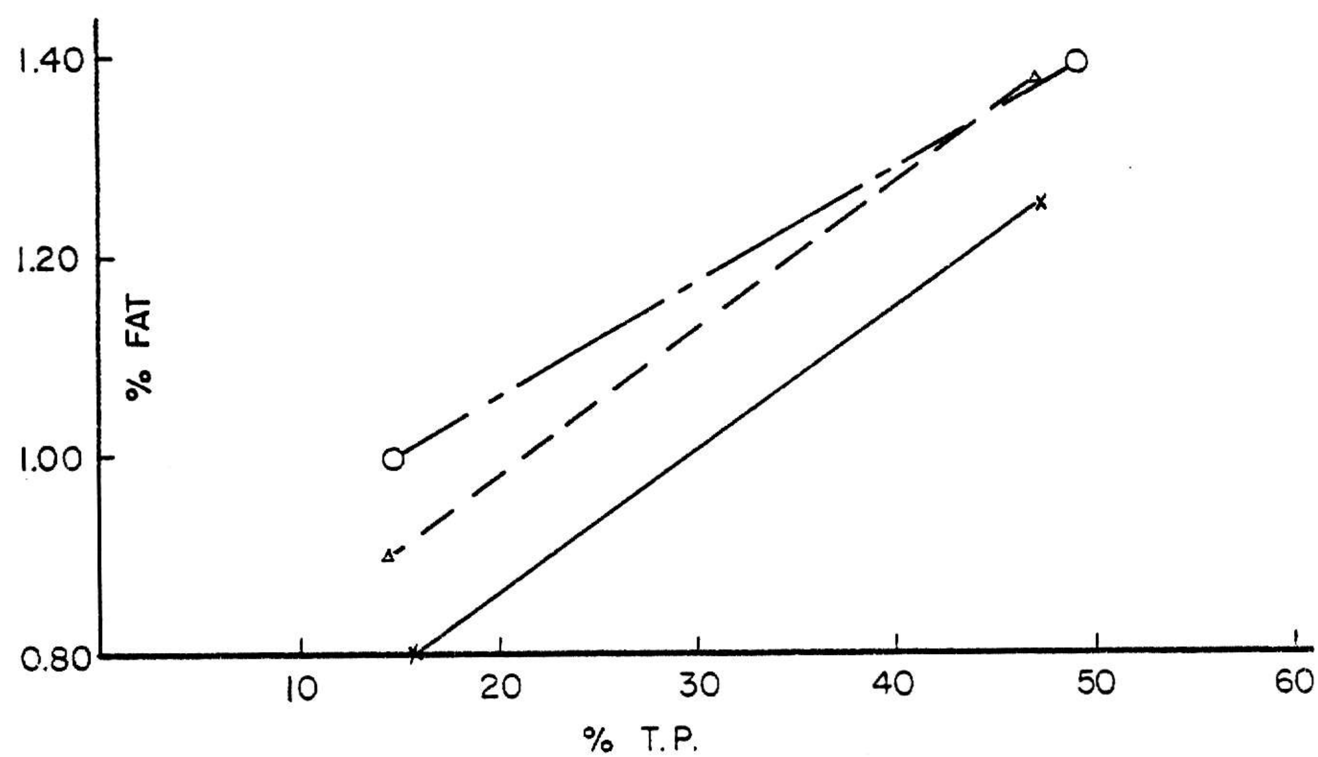


Fig. 17. Cumulative fat content of grits from sorghum tempered to 16, 17, 18, and 19% moisture for optimum holding times.

FIG. 17 : CUMULATIVE FAT

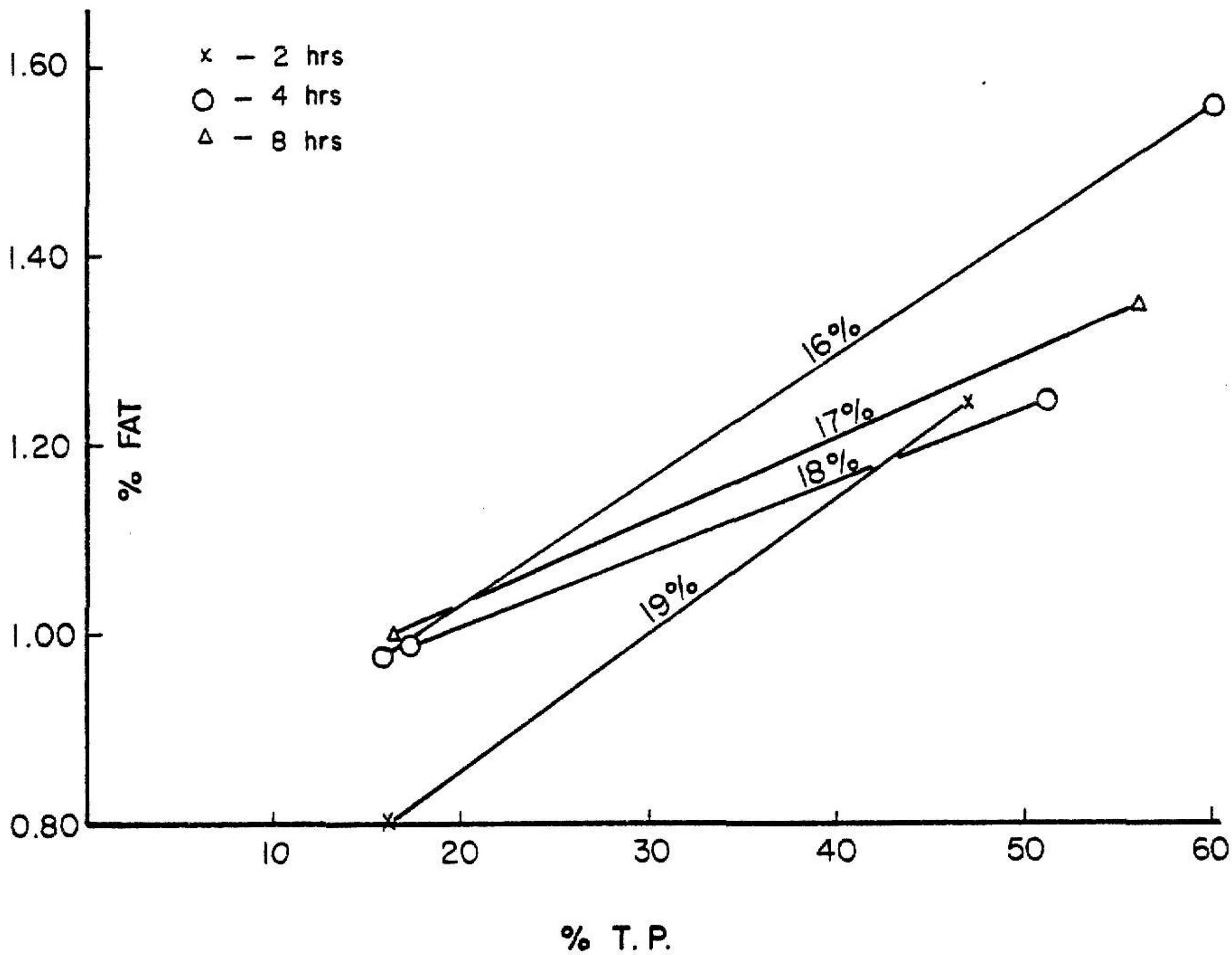


TABLE 15

THE PERCENTAGE OF THE TOTAL PRODUCT YIELD REMOVED BY THE SUCTION OF THE GRAVITY SEPARATOR DURING GRITS REFINING

MOISTURE (%)	TIME (hrs)	T.P. (%)	FAT (%)	ASH (%)
	2	4.01	-	-
16	4	4.49	3.86	1.83
	8	6.72	3.87	1.74
	2	4.64	3.54	1.63
17	4	5.82	3.09	1.45
	8	5.87	3.10	1.45
	2	8.52	2.53	1.17
18	4	5.65	3.12	1.46
	8	9.79	2.35	1.08
	2	8.26	2.54	1.17
19	4	7.77	2.54	1.17
	8	7.23	2.43	1.26

CONCLUSIONS

Grain sorghum is an important food grain in many parts of the world. The structure of the kernel is critical in the processing of the grain. The endosperm of the grain is composed of the aleurone layer and the peripheral, corneous, and floury regions of the endosperm. The peripheral endosperm contains starch granules which are embedded in a protein matrix along with numerous protein bodies. The corneous endosperm contains starch granules with superficial depressions caused by entrapped protein bodies. The floury endosperm consists of spherical starch granules separated by air spaces. The penetration of water into the grain during tempering is very rapid. After three hours tempering time water is distributed throughout the kernel. This may be due to the shape and the size of the kernels and to the presence of the floury endosperm.

Dry milling of the grain with a system employing a pre-break produced grits with lower fat and ash contents than those produced when a pre-break was not used. During dry milling with roller mills the oil-rich germ remains with the material remaining over the 10 wire sieve. The tempering conditions employed affect the behavior of the grain during milling. An increase in temper moisture level causes an increase in bran and fines (-30LW) yield and reduces the quantity of grits produced. Thus tempering water affects the dry milling performance of grain sorghum as it does that of wheat.

The gravity separator was found to be effective in the separation of grits from bran. The yield of refined grits separated by the gravity separator varied with tempering conditions. It toughens the bran and renders the endosperm soft and friable. The optimum tempering treatment for the production of grits with maximum yield and low fat content was found to be 17 per cent moisture and 8 hours tempering time. The suction of the gravity separator was found to be helpful in removing bran particles during the refining of grits.

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DRY MILLING OF GRAIN SORGHUM
FOR GRITS ON ROLLER MILLS

by

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AN ABSTRACT OF A MASTER'S THESIS

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Grain sorghum is an important crop in Africa, Asia and other parts of the world where the climate is too hot and dry for other cereals to be grown. About 75% of the world production is consumed as human food, most of which is milled traditionally by grinding the whole grain in a stone mill. In this study a simple milling system was developed for milling sorghum into refined grits. Sorghum was ground in roller mills and sifted in gyratory sifters followed by gravity separators for refining. The results showed that the system was suitable for producing grits with low fat and ash content and that the gravity separator was effective in separating bran from grits. The tempering conditions were found to have an effect on the behavior of the grain during milling. The best tempering treatment for production of grits with maximum yield and low fat and ash content was found to be 17% moisture and 8 hours tempering time.

The rate of water penetration into the sorghum kernel was studied using an electrical conductance moisture tester and an autoradiographic technique. Both methods indicated that the rate of water penetration during tempering is very rapid. After three hours tempering time water was distributed throughout the kernel. Water appeared to enter the kernel without preference for any region of the kernel's surface.