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THIRD ANNUAL REPORT

October 1979 — September 1980

IMPROVEMENT OF PEARL MILLET

Contract: AID/ta-C-1458
Project: 931-1040
Project Office: DS/AGR/FCP

KSU
KANSAS STATE UNIVERSITY
MANHATTAN, KANSAS 66506

IMPROVEMENT OF PEARL MILLET

CONTRACT: AID/ta-C-1458
PROJECT: 931-1040

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Third annual report for the period October 1979 through September 1980 submitted to the Agency for International Development by Kansas State University, Manhattan, Kansas 66506.

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ANNUAL REPORT

October 1979 - September 1980

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I. Executive Summary

This section contains titles or abstracts of research results in support of the four research objectives of the contract. We have included the research of all three years in this section. There are brief narratives of other project activities. More detailed information is provided in other sections of the report for year 3, 1979-1980. For more detailed information of the research for years 1 and 2, the annual reports for 1977-78 and 78-79 contain this information.

Research Results

(Year 1 1 October 1977 - 30 September 1978)

Objective 1. "Accelerate improvement in pearl millet yield by creating widely adapted high yielding populations and synthetic varieties and investigate possibilities of creating inbred lines and hybrids for use in developing countries."

Pearl Millet Breeding

[*Pennisetum americanum* (L.) K. Schum.]

W. D. Stegmeier

Pearl millet breeding and research was started in 1971 at the Fort Hays Branch Experiment Station. The work has progressed through the initial screening of materials available from the Southern Regional Plant Introduction Station, Experiment, Georgia and the World Pearl Millet Collection to the present stages of development of several populations, composites, and dwarf, early-maturing hybrids and inbred lines. In order to obtain breeding populations from the introduced materials, it was necessary to make extensive use of varieties from Ghana and Uganda to obtain earliness and increased seed size and forage inbreds from Georgia to provide dwarfness and the A_1B_1 and A_2B_2 cytoplasmic male-sterility and fertility maintainer systems. Therefore, the germplasm base of the breeding population is restricted and crossing and backcrossing to both the original and new introductions will be necessary to obtain additional variability. Hays Millet Population (HMP) 550 and HMP1700 have been advanced, respectively, to the Cycle 2 progeny testing phase and the Cycle 1 recombination generation. Development of lines to be used as parents of grain type F_1 hybrids continues to show promise. Several dwarf millet hybrids with maturity requirements similar to the sorghum checks produced yields, plant heights, and lodging scores comparable to hybrid grain sorghum.

Yield and Heterosis Studies of Pearl Millet
[*Pennisetum americanum* (L.) K. Schum.]

J. C. Palmer, H. A. Praeger, Jr. and W. G. Stegmeier

Pearl millet [*Pennisetum americanum* (L.) K. Schum.] often is characterized by low yields, excessive height, and small seed size. In the first experiment, selected millet hybrids were grown in field

plots and their performance compared to that of commercially available sorghum hybrids of the same maturity. In the second experiment, heterosis was studied among certain parental lines of pearl millet and their F_1 offspring. In both experiments, attention was focused on yield, seed weight, plant height, and head number per unit area.

Results indicate that millet hybrids are capable of yielding as well as sorghum hybrids under the same conditions. The highest yielding pearl millet hybrids are still typified by excessive height. Heterosis was demonstrated in a number of F_1 millet crosses, indicating that hybrid seed production is one of the better approaches to the problem of increasing yields. Very large seeded types were not found, though some hybrids did produce much larger seed than others.

Objective 2. "Determine factors related to and genetic variability in seed and seedling vigor, water use, drought resistance, and herbicide susceptibility of pearl millet."

Herbicide Susceptibility of Pearl Millet [*Pennisetum americanum* (L.) K. Schum.]

W. B. Ndahi, O. G. Russ, and M. C. Lundquist

In 1977 and 1978, herbicides commonly used in sorghum production were evaluated on pearl millet at Manhattan and Minneola, Kansas. In 1977 as a result of chinch bug attack at Manhattan and drought at Minneola, there were no treatment differences observed. In 1978 at Manhattan, marked differences in treatments were observed. Millet tolerated the following herbicides: Atrazine, Cyanazine, Modown, Propazine, and Igran. Bexton alone or with any other herbicide did not allow emergence, but replanting Bexton-treated plots three weeks after the first planting gave some yield. Eradicane killed all the millet on both first planting and the replanting.

Seed Vigor Measurements and Their Use in Predicting Field Establishment of Grain Pearl Millet [*Pennisetum americanum* (L.) K. Schum.]

G. J. Mwageni and R. L. Vanderlip

Seed vigor is one of the problems that limits pearl millet production because it directly affects field establishment. Laboratory and field tests were conducted in 1977 and 1978 to investigate the degree to which laboratory tests could predict field establishment of pearl millet. Laboratory tests included standard germination,

electrical conductivity of soaked seeds, and stress tests of soaking the seeds in ammonium chloride solution, soaking seeds in sodium hydroxide solution, artificially aging at high temperature and relative humidity, and soil cold testing. In 1977, 20 varieties were used while in 1978 a different set of 30 varieties were used.

Germination percentages from the stress tests were lower than those from standard germination as seeds of low vigor were killed after being subjected to the adverse treatments while vigorous seeds remained relatively unaffected.

Criteria used to evaluate vigor tests were: correlation with field establishment, and ranking millet varieties according to field performance.

These criteria suggest that all laboratory tests used except the electrical conductivity following 30 minute soaking were able to screen vigorous from non-vigorous seeds. Soaking the millet seeds in 5% sodium hydroxide solution for 2 minutes prior to normal germination seemed to be the best vigor test although NH_4Cl, accelerated aging, and standard germination treatments were significantly similar in ranking the varieties.

The Effect of Seed Size and Density on Field Emergence and Yield of Pearl Millet [*Pennisetum americanum* (L.) K. Schum.]

J. C. Gardner and R. L. Vanderlip

This study was conducted to determine whether seed size and seed density had an effect on field emergence, stand establishment and grain yield. Five pearl millet varieties were utilized, with eight treatments per variety. The seeds were separated into four seed sizes, two density fractions, seeds from the original seed lot soaked in sucrose like those separated by density and the original seed lot. The data were collected from two planting dates at two locations. Medium to large seeds and high density seeds improved both field emergence and yield.

Drought Resistance Screening of Pearl Millet [*Pennisetum americanum* (L.) K. Schum.]

P. Singh and E. T. Kanemasu

Pearl millet is primarily grown in areas and in periods of low precipitation. It is recognized as one of the most drought resistant cereals. Its drought resistant characteristics are not well known

or documented. This study investigates the water use and leaf temperatures of pearl millet. The data from one growing season indicates that the genotypes having the highest leaf temperatures produce the greatest grain yield.

Objective 3. "Determine the nutritional quality and digestibility of pearl millet grain by analyzing protein in germplasm introductions and breeding materials and determining magnitudes of variation in lysine content among and within populations and varieties. Determine the characteristics and digestibility of pearl millet protein and carbohydrates."

Nutrient Content of Pearl Millet
[*Pennisetum americanum* (L.) K. Schum.]

E. Varriano-Marston, R. C. Hoseney and Y. F. Yeh Chung

Crude protein, ash, mineral content, amino acid analysis, and riboflavin content were run on 4 bulk populations and 17 HMP550 lines. The results indicated that there was little variability among cultivars with respect to the factors measured.

Pearl Millet Proteins
[*Pennisetum americanum* (L.) K. Schum.]

B. Mason and R. C. Hoseney

The classification of cereal proteins according to their solubility properties determines why certain cultivars contain more nutritious protein. The alcohol soluble prolamines are generally deficient in lysine while the saline soluble and alcohol insoluble are comparatively rich in this amino acid. The amino acid composition of each solubility class has been fairly uniform among the cereals studied. It is not known whether the proteins of pearl millet will follow a similar pattern. Work is continuing to identify a protein fractionation procedure which adequately solubilizes pearl millet protein and yields consistent and distinct protein fractions.

Pearl Millet Starch
[*Pennisetum americanum* (L.) K. Schum.]

A. Beleia and E. Varriano-Marston

Starch comprises the major carbohydrate of pearl millet; the average content ranges from 60-65%. The properties studied to date

include starch granule size, shape, gelatinization range, and pasting properties of washed starch. The study has been expanded to include water binding capacity, iodine affinities, swelling and solubility patterns, amylose-amylopectin ratios, intrinsic viscosity, and susceptibility to enzyme attack.

Grain Quality Tests to Predict End-Use Properties [*Pennisetum americanum* (L.) K. Schum.]

A. de Francisco and R. C. Hoseney

Evaluation of cereal grains has shown the best measure of the functional quality of grain is its ability to produce a product that is acceptable to the consumer. As pearl millet is not a food crop in the U.S., it is difficult to judge consumer acceptability. We are working to develop simple tests that characterize the cooking characteristics of various cultivars. Examination of the simple tests of water absorption, hardness and alkali disintegration are being studied to differentiate pearl millet cultivars. Standardized tests for making chapaties and other products from pearl millet are being developed.

Animal Feeding Studies [*Pennisetum americanum* (L.) K. Schum.]

S. Dassenko and B. Fryer

The study of pearl millet quality requires an evaluation of the nutritional quality of the grain with respect to living biological systems. Weanling rats were fed for a 28 day period on 10% protein diets which were adequate in all other nutrients. Protein efficiency ratios, protein digestibility and calorie digestibility of five diets were determined. The sources of protein were casein, raw whole wheat, raw millet, wheat chapaties and millet chapaties. When weight gain was adjusted to feed intake, rats on casein diet gained more than rats on any cereal diet. Of the cereal diets tested, rats gained more on raw millet than raw wheat. Cooking millet in the form of chapaties resulted in a significant decrease in weight gain compared to the raw product.

Objective 4. "Determine the storage stability of pearl millet grain and millet meal by determining the factors contributing to grain losses during storage and determining the factors contributing to the development of rancidity in millet meal."

Characterization of Lipids in Pearl Millet [*Pennisetum americanum* (L.) K. Schum.]

C. Lai and E. Varriano-Marston

Free and bound lipids and fatty acids were determined for four populations and 18 HMP 550 S_1 lines. The free lipid content ranged from 5.87% to 7.08%; bound lipids ranged from 0.57% to 0.90%. Non-polar lipids were tentatively identified as sterol esters, triglycerides, diglycerides, free fatty acids and partial glycerides. Monogalactosyl glycerides, phosphatidyl choline and lysolecithin were tentatively identified as components of the bound, polar lipid fraction.

Quality Deterioration During Storage [*Pennisetum americanum* (L.) K. Schum.]

C. Lai

The HMP 550 bulk population of pearl millet was ground and the whole meal stored in cotton bags under the following conditions: 19°C, 58% relative humidity, 27°C, 64% RH and 42°C, 75% RH. After designated storage periods tests were conducted to determine titratable acidity, moisture content, mold counts and organoleptic (sniff) tests using a trained panel. The total titratable acidity increased rapidly for millet stored at high temperatures and relative humidity during the first 108 hours of storage compared to millet stored at lower temperatures and relative humidity. The organoleptic evaluation of stored millet meal indicated that high temperature and humidity resulted in a decrease in the time necessary for detection of off-odors. Organoleptic evaluation appears to be a more sensitive measure of deteriorative changes during storage than total titratable acidity.

Field Fungi in Pearl Millet [*Pennisetum americanum* (L.) K. Schum.]

R. Burroughs

The field fungi invading pearl millet at harvest were determined by plating 100 surface disinfected kernels on malt agar. Fungi were identified after 6-7 days incubation at room temperature. The predominant fungus was *Alternaria* with smaller percentage of kernels invaded by *Fusarium* and *Claclosporium*. Also identified on the millet kernels were the genera *Curvularia*, *Helminthosporium*, *Penicillum*, *Phoma* and

Rhizopus. The principal field fungi found are of the same genera, and approximately the same percentages, as found in grain sorghum grown in Kansas.

Initial Screening of Pearl Millet to Determine Insect Susceptibility [*Pennisetum americanum* (L.) K. Schum.]

D. Kossou and J. Pedersen

A bulk population of pearl millet grown in Kansas was used to determine the susceptibility of infestation by certain species of stored-product insects. Fifteen of the major insect pests species which attack cereal grains were used in a "no-choice" screening test. Twenty-five gram samples of millet at 13.5% moisture content were infested with either 30 adult, 30 newly emerged larvae or 50 eggs, depending on species of insect. Infested millet samples were stored in small glass jars in a rearing room maintained at 27°C and 65% relative humidity for a period of 6-8 weeks. At the end of the exposure period each sample was examined for number of insects, loss of seed weight and weight of frass (excrement, dust, etc.). Rice

Research Results. (Year 2, October 1978 - September 1979)

Objective 1. "Accelerate improvement in pearl millet yield by creating widely adapted high yielding populations and synthetic varieties and investigate possibilities of creating inbred lines and hybrids for use in developing countries."

PEARL MILLET BREEDING
[*Pennisetum americanum* (L.) Leeke]

W. D. Stegmeier

Pearl millet breeding in 1979 has shown advancement in most areas of the program. Hays Millet Population (HMP) 550 and HMP 1700 have been advanced to the cycle 3 recombination generation and the cycle 2 S_1 progeny performance testing phase, respectively: HMP 559 and the World Collection Composite were advanced by selection for desirable agronomic characteristics. 1978 Series 5 and 2 have progressed to the F_2 and F_3 generations, respectively, in a program to introduce genes for dwarfness and cytoplasmic male-sterility maintainer systems into the World Collection Composite and Plant Introduction material. Development of inbred lines to be used as parental material of hybrid combinations involved the growing of over 200 pairs of A_1B_1 and A_2B_2 dwarf derivatives of PI 185642 and Serere 3A, selection within 500 advanced generation male-fertility restorer lines, and selection of over 3,000 F_2 segregates from crosses involving 31 PI lines. Four male-fertility restorer lines were planted in isolated crossing blocks, each with a group of 39 to 48 female lines, to produce F_1 seeds for 1980 testing purposes. Several experimental F_1 hybrids performed favorably in comparison with an early-maturing sorghum check, but later maturing sorghum checks, responding to late rains, produced larger grain yields than did the millets.

HETEROSIS STUDIES OF PEARL MILLET
[*Pennisetum americanum* (L.) Leeke]

J. C. Palmer, H. A. Praeger, Jr., and R. L. Vanderlip

Heterosis was studied for a second year among eighteen pearl millet hybrids and their inbred parents. Emphasis was placed on yield, plant height, one thousand seed weight, number of heads per unit area, and plant population.

In each of the hybrids, heterosis was clearly demonstrated. Hybrid yields were substantially higher than parent yields in all cases. In addition, increases in plant height, seed weight, head numbers per unit area, and plant population were noted.

YIELD EVALUATIONS OF PEARL MILLET
[*Pennisetum americanum* (L.) Leeke]

PART 1

J. C. Palmer, R. L. Vanderlip, and W. D. Stegmeier

Pearl millet hybrids developed at the Fort Hays Branch Experiment Station, Hays, Kansas were tested in yield trials at six locations. Five pearl millet populations and three commercial sorghum hybrids were included for comparison. Attention was focused on yield, plant height, seed weight, head number per unit area, and plant population.

At all but one location, pearl millet hybrid yields often were not significantly different than grain sorghum hybrid yields. The highest yielding millet hybrids exhibited short stature. Millet seed weights were less than sorghum seed weights but showed a slight increase over millet seed weights determined in 1978. There was no apparent relationship between the number of heads produced and yield, though higher yielding millets tended to produce greater yields per head and greater yields per plant.

YIELD EVALUATIONS OF PEARL MILLET [*Pennisetum americanum* (L.) Leeke]

PART II

J. C. Palmer, H. A. Praeger, Jr., and W. D. Stegmeier

Pearl millet hybrids developed at the Coastal Plains Station, Tifton, Georgia by Dr. Glenn W. Burton, USDA, SEA, were tested in yield trials at two locations. For comparison, two pearl millet populations and two commercial sorghum hybrids were included. Attention was focused on yield, plant height, head number per unit area, and plant population.

At one location, pearl millet hybrid yields in many cases were not significantly different than grain sorghum hybrid yields. The highest yielding millet hybrids were quite tall. Millets producing more heads per unit area tended to have higher yields, but this relationship was not consistent at both locations. There was no apparent relationship between yield and plant population, head number per plant, yield per head, nor yield per plant.

Objective 2. "Determine factors related to and genetic variability in seed and seedling vigor, water use, drought resistance, and herbicide susceptibility of pearl millet."

GROWTH OF PEARL MILLET [*Pennisetum americanum* (L.) Leeke] AS INFLUENCED BY HERBICIDE APPLICATIONS AND DELAY IN PLANTING

W. D. Ndahi, O. G. Russ, and L. J. Moshier

Seedling tolerance of 'RMP1' pearl millet 10 days after treatment was excellent to atrazine, propazine, terbutryn or bifenox applications and moderate to cyanazine applications. Emergence of pearl millet was severely reduced for propachlor or butylate plus R-25788 applications and did not occur for propachlor applications in combination with other herbicides or EPTC plus R-25788 applications. Height, number of heads and yield was not significantly reduced by applications of triazine herbicides or bifenox. Pearl millet was less susceptible to propachlor applied alone or in combination with other herbicides when replanted 3 weeks after herbicide applications.

Tolerance to atrazine, propazine or terbutryn generally was not affected by delay between herbicide application and planting in green-

house studies. Tolerance to metolachlor, xylachlor or propachlor was greater if a two or four week delay occurred between herbicide application and planting.

EFFECT OF SEED SIZE AND DENSITY ON FIELD EMERGENCE AND YIELD OF PEARL MILLET [*Pennisetum americanum* (L.) Leeke]

J. C. Gardner and R. L. Vanderlip

Seed sizes and densities of pearl millet were studied under field conditions in 1979 at the Ashland Research Farm south of Manhattan and Sandyland Experiment Field, St. John. Serere 3A and RMP1 along with two inbred lines from Fort Hays were utilized to observe both wide and narrow based genetic material.

Size of the seed planted affected stand establishment, head production, and grain yield. The smallest seed size was lowest in vigor. The relationship between seed size and quality does not seem to be a linear function, however, because the largest seeds also often were associated with a drop in performance.

Density separations were made regardless of seed size. The effect of high density seeds upon emergence was positive. Though a significant variety x treatment interaction was found, the general effect of density was consistent in both varieties and inbreds at both locations. Seed density had a strong effect upon the initial vigor of the pearl millet plant. The relationship between seed density and yield seems to be different than that of seed size and yield. With seed size we have seen that the effect at emergence influenced grain yield. Seed density does not appear to remain as effective at harvest. Seed density was shown to be a consistent and effective criteria for improving seedling vigor. Small seeds seem associated not only with poor seed quality but also with a plant lacking the capability to adjust yield components to be an efficient grain producer.

WATER USE AND WATER USE EFFICIENCY OF PEARL MILLET [*Pennisetum americanum* (L.) Leeke]

P. Singh and E. T. Kanemasu

Meteorological and physiological measurements were made on several millet genotypes at Manhattan, Kansas and Hissar, India. Because of the abnormally high rainfall at Manhattan, the irrigation treatment was omitted. Detailed analysis of the water use and water extraction pattern

of millet is presented in this report. There was a difference in water use, water use efficiency, and soil water extraction patterns among the genotypes. Complete analysis of 1978 and 1979 data has not been accomplished. A manuscript on the floral development of millet has been accepted for publication and will appear in Field Crops Research.

The results of the Hissar experiment were not satisfactory as anticipated because of the extremely dry conditions in India this year. Irrigation was poor and frequently unavailable. Plans have been made to avoid some of these problems in the future.

Objective 3. "Determine the nutritional quality and digestibility of pearl millet grain by analyzing protein in germplasm introductions and breeding materials and determining magnitudes of variation in lysine content among and within populations and varieties. Determine the characteristics and digestibility of pearl millet protein and carbohydrates."

PROXIMATE AND AMINO ACID ANALYSES OF PEARL MILLET [*Pennisetum americanum* (L.) Leeke]

Dave Wetzel and Max Jones

Proximate and amino acid analyses of hybrid pearl millet grain was studied for the hybrids developed by Dr. Glenn W. Burton and grown at Manhattan, Kansas 1978 and 1979. There were different hybrid entries for the two growing seasons. For 1978 the protein content ranged from 14.0 to 17.6%. During 1979 the range in protein content was 10.6 to 13.4%. The range for protein content for the bulk populations during 1978 was 11.1 to 14.7%.

NOTE ON MINERAL CONTENT AND LOCATION IN PEARL MILLET [*Pennisetum americanum* (L.) Leeke]

E. Varriano-Marston and R. C. Hoseney

Mineral contents (Ca, Mg, Zn, Fe, Na, K and P) of 17 HMP550 S_1 lines and 4 bulk populations were studied. Mg, K, and P were present in the greatest concentrations in the whole grain. High levels of K and Fe were found in the germ and covering layers while the major portion of the phosphorus was located in the germ.

CHARACTERIZATION OF STARCH FROM PEARL MILLETS [*Pennisetum americanum* (L.) Leeke]

Adelaide Beleia and E. Varriano-Marston

Starch isolated from five random-mating populations of pearl millet varied in cold water-binding capacity (83.6 to 99.5%) and initial (59 to 63 C) and end-point (68 to 70 C) gelatinization temperatures. Swelling power at 95 C varied between 14.1 and 16.4; starches with low swelling powers also were less soluble during heating. More variations among starch amylograms were observed during the cooling than the heating cycle, suggesting that some starches tend to retrograde less than others. Small variations in amylose contents (20 to 22%) among starches indicate that other physicochemical factors, such as molecular dimensions, may be more important than amylose content in determining the characteristics of pearl millet starches.

CHARACTERIZATION OF PEARL MILLET PROTEINS [*Pennisetum americanum* (L.) Leeke]

B. Mason and R. C. Hoseney

The amino acid composition of pearl millet grain and its milled fractions and the distribution of grain nitrogen among protein solubility classes was studied. Grain from a bulk composite was milled into bran, low ash flour, and high ash flour on a Brabender Quadrumat Junior Experimental Mill. Whole meal had appreciably more lysine, arginine, and glycine and less methionine than the low and high ash flours. Low ash flour contained slightly more lysine and arginine than high ash flour.

Flour and meals were extracted successively with saline, ethanol, and alkaline sodium dodecyl sulfate (SDS) solutions. Minimal differences were observed in the nitrogen distributions of meal and flour samples derived from the millet population, but the low ash flour contained more prolamine protein than the corresponding meal. In addition, meal samples from four pearl millet lines had similar nitrogen distributions among the different protein solubility classes. Our data did not suggest that a direct relationship existed between lysine concentration and nitrogen distribution in those samples.

The protein fractionation scheme was modified to include 2-mercaptoethanol with the SDS-containing solvent and a final extraction with 0.1 N sodium hydroxide. The fractions produced by that revised procedure were analyzed for amino acids. The saline solubles were found to be rich in lysine, arginine, histidine, and aspartic acid. The prolamines were rich in leucine, alanine, phenylalanine, and glutamine. The pH 10 solvent-

SDS-2-mercaptoethanol extracted proteins that were rich in basic amino acids, threonine, and cysteine. The sodium hydroxide solubles and the insolubles fraction were comparable in amino acid composition.

PRELIMINARY REPORT ON DECORTICATION OF PEARL MILLET AND GRAIN SORGHUM [*Pennisetum americanum* (L.) Leeke]

Alicia de Francisco, Allan Shepherd, R. Carl Hoseney, and E. Varriano-Marston

A modified Udy Cyclone Mill was used to evaluate the decortication of small samples of pearl millet and grain sorghum. In general, grain sorghum decorticated much easier than did pearl millet. When millet was decorticated, the point of detachment was between the endosperm and the aleurone layer. However, with sorghum the point of detachment was in the mesocarp. Two millets obtained from Sudan decorticated much easier than millet populations grown in Kansas. A Kansas-grown sorghum originally obtained from Sudan decorticated much easier than U.S.-developed varieties grown in Kansas.

EFFECT OF MILLING, FERMENTATION AND COOKING ON NUTRITIONAL VALUE OF PEARL MILLET [*Pennisetum americanum* (L.) Leeke]

Sandra Dassenko and Beth Fryer

Pearl millet meal and a 67% extraction flour were evaluated for amino acids, vitamins, minerals, protein efficiency ratio, protein digestibility, and calorie digestibility. In addition, fermented, cooked, and fermented and cooked samples of the meal and flour were studied. In general, milling did not lower the B vitamin content of samples, but mineral concentrations were lowered. When samples were fermented, the B vitamin content increased. No changes were observed in amino acid content of samples due to milling, fermentation or cooking.

Pearl millet diets had lower PER's than the casein control (1.7 vs. 2.5). In general, milling increased and fermentation decreased PER of millet diets. Millet diets were less digestible (both protein and calories) than the casein diet. Milling or fermentation had no effect on digestibility. However, cooking of millet flour increased calorie digestibility.

INFLUENCE OF CERTAIN GRAIN DIETS ON CHOLESTEROL LEVELS IN GUINEA PIGS

Carol Klopfenstein

Guinea pigs were fed diets containing fiber from different cereal grains: hard red wheat, oats, pearl millet and grain sorghum. Diets consisting of wheat, oats, or millet did not lower serum or liver cholesterol levels when compared to the casein control diet. However, serum cholesterol levels in the animals fed grain sorghum diets appeared lower than the other diets, even though the differences were not significant. Liver cholesterol concentrations were, however, significantly lowered when guinea pigs were fed diets containing grain sorghum.

PEARL MILLET: ITS CHEMISTRY AND UTILIZATION [*Pennisetum americanum* (L.) Leeke]

R. C. Hoseney and E. Varriano-Marston

This is a paper prepared for and presented at the International Conference on Cereals for Food and Beverages; Recent Progress in Cereal Chemistry and Technology, American Chemical Society, sponsor, Copenhagen, Denmark. The paper will be included in the proceedings of the conference and is included in this report.

Objective 4. "Determine the storage stability of pearl millet grain and millet meal by determining the factors contributing to grain losses during storage and determining the factors contributing to the development of rancidity in millet meal."

LIPID CONTENT AND FATTY ACID COMPOSITION OF FREE AND BOUND LIPIDS IN PEARL MILLETS [*Pennisetum americanum* (L.) Leeke]

C. C. Lai and E. Varriano-Marston

Lipid content and fatty acid composition of pearl millets were studied. Free lipid content ranged from 5.55% to 7.08%; bound lipid content ranged from 0.57% to 0.90%. Unsaturated acids averaged 70.25% of the free and 51.7% of the bound lipid fractions. Linoleic, oleic, and palmitic were the principal fatty acids in both free and bound lipids. Trace levels of myristic and behenic acids were found in the free lipids.

Of the total bound lipids, 1.34% to 2.16% had an odd number of carbon atoms (C13:0, C15:0, and C17:0). The total percentage of long chain fatty acids (C20:0 and above) was greater for the bound than the free lipids.

CHANGES IN PEARL MILLET MEAL DURING STORAGE [*Pennisetum americanum* (L.) Leeke]

C. C. Lai and E. Varriano-Marston

Pearl millet meal was stored at 19 C, 58% R.H., 27 C, 64% R.H., or 42 C, 75% R.H. Changes in sensory attributes (odor), mold count, fatty acid composition, total titratable acidity, and peroxide value were followed.

A trained panel detected changes in the odor of stored millet after 108 hr., 60 hr., and 12 hr. for these respective storage conditions: 19 C, 27 C, and 42 C. A reduction in mold count the first 6 wks. of storage suggested that fungal growth had little effect on odor changes observed the first week of storage. However, periods for detecting odor changes in all stored samples corresponded to fat acidity of 30 mg KOH/ 100 g meal and coincided with the end of the induction period for peroxide formation. TLC and GC studies further confirmed that alterations in lipid components were responsible for rapid quality deterioration in pearl millet meal.

SUSCEPTIBILITY OF TWELVE LINES OF PEARL MILLET IN THRESHED AND HEAD STORAGE TO THREE SPECIES OF INSECTS [*Pennisetum americanum* (L.) Leeke]

D. Kossou, J. R. Pedersen, and R. B. Mills

The susceptibility of 12 pearl millet lines, stored in the head or in the threshed form, to Angoumois grain moth, rice weevil, and red flour beetle was studied. Red flour beetle populations did not increase in either the threshed or head millet lines whereas the rice weevil and Angoumois grain moth populations did. Larger increases in weevil populations were noted in threshed millet than head millet. The reverse was true for Angoumois grain moth. Some millet lines were more susceptible to insect attack than others.

Research Results

(Year 3, 1979-1980)

Objective 1. "Accelerate improvement in pearl millet yield by creating widely adapted high yielding populations and synthetic varieties and investigate possibilities of creating inbred lines and hybrids for use in developing countries."

Pearl Millet Breeding
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Yield Evaluation of Pearl Millet
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Objective 2. "Determine factors related to and genetic variability in seed and seedling vigor, water use, drought resistance and herbicide susceptibility of pearl millet."

Effect of Crop Management on Seed Quality, Subsequent Seedling Establishment and Grain Yield of Pearl Millet
[*Pennisetum americanum* (L.) Leeke]

Julius Okonkwo and R. L. Vanderlip
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Soil Water, Plant Water and Temperature Relation and Their Relationship to Crop Yields

Piara Singh and E. T. Kanemasu
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Effects of Seed Size and Density on Performance of Pearl Millet
[*Pennisetum americanum* (L.) Leeke]

Mahmud Lawan, F. L. Barnett, and R. L. Vanderlip
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Objective 3. "Determine the nutritional quality and digestibility of pearl millet grain by analyzing protein in germplasm introductions and breeding materials and determining magnitudes of variation in lysine content among and within populations and varieties. Determine the characteristics and digestibility of pearl millet protein and carbohydrates."

Pearl Millet Amylases I. Properties of Partially Purified Alpha-Amylase
[*Pennisetum americanum* (L.) Leeke]

Adelaide Beleia and E. Varriano-Marston

(Page 102)

Pearl Millet Amylases II. Activity Towards Intact Granules and Heated Starch
[*Pennisetum americanum* (L.) Leeke]

Adelaide Beleia and E. Varriano-Marston

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Analysis of Pearl Millet for Proanthocyanidins, Tannins and Other Phenolics
[*Pennisetum americanum* (L.) Leeke]

Larry Butler, R. C. Hoseney and E. Varriano-Marston

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Preliminary Pearl Millet Roti Method
[*Pennisetum americanum* (L.) Leeke]

B. Mason and R. C. Hoseney

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Development of Pearl Millet Based Gruels and Steamed Cakes Designed for Infant and Preschool Children Feeding in Cameroon
[*Pennisetum americanum* (L.) Leeke]

Julienne Ngo and Jean Caul

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Hardness of Pearl Millet and Grain Sorghum
[*Pennisetum americanum* (L.) Leeke]

Alicia de Francisco, E. Varriano-Marston and R. C. Hoseney

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Decortication of Pearl Millet and Grain Sorghum
in Laboratory Abrasive Mill
[*Pennisetum americanum* (L.) Leeke]

Alicia de Francisco, Allan D. Shepherd, R. C. Hoseney
and E. Varriano-Marston

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Effects of Pearl Millet and Sorghum Diets on
Growth Rates and Cholesterol Levels in Guinea Pigs
[*Pennisetum americanum* (L.) Leeke]

Carol Klopfenstein

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Note on Rate of Water Penetrating into Sorghum During Tempering

A. A. Abdelraham and E. P. Farrell

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Grits from Grain Sorghum Dry Milled on Roller Mills

A. A. Abderlraham and E. Farrell

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Sorghum and Millets

Chapter for

Advances in Cereal Science and Technology, Vol. IV

Y. Pomeranz, Editor

R. C. Hoseney, E. Varriano-Marston and D. A. V. Dendy

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Objective 4. "Determine the storage stability of pearl millet grain and millet meal by determining the factors contributing to grain losses during storage and determining the factors contributing to development of rancidity in millet meal."

Solubility of Pearl Millet Proteins
[*Pennisetum americanum* (L.) Leeke]

B. Mason and R. C. Hoseney

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Moisture Content/Relative Humidity Equilibrium of Pearl Millet
[*Pennisetum americanum* (L.) Leeke]

Donsou Kossou

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Planning Meetings Four IN-PROGRESS-REVIEWS were attended by the principal researchers and graduate students working with pearl millet. During these meetings plans for research projects were coordinated among the personnel and evaluations of the progress of research were made. Minutes of these reviews are in Section II.

International Travel Drs. E. Varriano-Marston and R. C. Hoseney visited the Tropical Products Institute, Culliam, England; Food Research Center, Khartoum, Sudan; Bhabha Atomic Research Center, Bombay, India; Central Food Technological Research Institute, Mysore, India; International Crop Research Institute Semi-Arid Tropics, Hyderabad, India; Home Science College, Hyderabad, India; Food Science Technology Institute, Punjab Agriculture University, Ludhiana, India; and USAID and Institute for Tropical Agriculture, Dakar, Senegal. Their trip report is Section III.

Contacts Established The personnel contacted in the research of this project are listed in Section IV.

Personnel There are seven principal research personnel assigned to the project. Other members of the faculty, experiment station personnel and graduate students provided input to the program. A listing of the personnel who assisted in this project is in Section V.

Budget The original contract was approved as a three-year program and funded for the first two years. Later, the program was funded for three years in the amount of $770,000.00. These funds were utilized to support the program. The financial statement for this program is Section VII.

II. Planning Meetings

Improvement of Pearl Millet

The tenth IN-PROGRESS-REVIEW of the project, "Improvement of Pearl Millet", was held 1000 hours 11 December 1979 in Room 106, Waters Hall, Kansas State University. This was a cooperative meeting including personnel of the original contract and the expanded KSU program, Grain Sorghum/Pearl Millet, CRSP grant AID/SDAN/XII-G-0149, INTSORMIL.

Personnel attending: Richard L. Vanerlip, R. Carl Hoseney, Barry Michie, Janet E. Benson, James Converse, Francis L. Barnett, Edward T. Kanemasu, Robert B. Mills, John R. Pedersen, Herman A. Praeger, Jr., Wm. D. Stegmeier, Piara Singh, John Gardner, John Palmer, Mithlesh Kumar, David Andrews, principal pearl millet breeder, ICRISAT, on sabbatical at the University of Nebraska, and Earl R. Leng, Program Director, INTSORMIL, University of Nebraska.

The agenda was organized to provide a thirty-minute period for each of the principal researchers of the six programs of INTSORMIL. Four of these six projects are the basis of the original contract and are continued or expanded in the INTSORMIL program. There are two new programs in INTSORMIL, Storage and Preservation of Pearl Millet and A Farming-Systems Approach to Sorghum and Pearl Millet Production in India.

These minutes contain a synopsis of the presentations, as abstracts and detailed results of research are to be included in the Second Annual Report which is currently in preparation.

Nutritional Quality: presented by R. Carl Hoseney, discussed storage of ground material, the lipid content, type of lipids, fatty acids and the rancidity problem of ground material. Starch, its chemical composition, physical properties and milling problems, and problems associated with the decortication of the grain were presented. The program to prepare ethnic foods from pearl millet was discussed. Feeding studies with rats and guinea pigs were outlined. They are studying the total digestible nutrients, protein efficiency ratios for raw rations, processed rations by cooking and fermentation. The vitamin content is being analyzed by High Performance Liquid Chromatography. Storage of milled products is being studied. The mineral content of milled products is being analyzed. Currently two papers have been submitted for publication in scientific journals.

Physiological and Developmental Processes Adversely Affected by Environmental Stresses was presented by Edward T. Kanemasu. His research includes water use efficiency, uptake of water from various levels of the soil profile, transpiration and leaf temperatures under varying conditions and the influence of different levels of stress during different stages of growth on yield components. This research is being conducted at Manhattan, Kansas, Hays Branch Experiment Station, Hays, Kansas and Harayana Agricultural University, Hissar, India.

Seedling Vigor, Stand Establishment, and Developmental Physiology of Pearl Millet. Dr. Vanderlip had two of his graduate students present an update of the papers they presented at the ASA meeting, Ft. Collins, Colorado. John Gardner discussed the results of his thesis research on seed

size and seed density on emergence, stand establishment and grain yield. John Palmer reported on the results of the yield trials of the various pearl millet populations and hybrids and comparison with commercial grain sorghum hybrids of similar maturities. These trials were planted at six locations throughout the state on varying soil types and under different climatic conditions. There are significant environmental differences in the results of the yield trials over the various locations in the state. The results of the herbicide study in the growing of pearl millet were discussed.

Farming Systems Approach to Sorghum and Pearl Millet Production in India was presented by Dr. Barry Michie. As this is a new program requiring in-country coordination, the presentation was a plan on the implementation of their program.

Pearl Millet Improvement Program was presented by Wm. Stegmeier. Harvesting of his nursery plots has been completed, but there are many plots to be threshed. He has four new populations of hybrid seed that produced over 1000 grams of grain for next year's yield trials so far. Some of his new hybrids' grain yield was calculated to be in the 4000-5000 lb/acre range. There was a male sterility problem this year that was not present last year. The winter nursery and grain increase program in Hawaii was discussed. ICRISAT is sending eighty-two samples of their pearl millet germplasm for grow out in the glasshouse at Hays, KS under our APHIS permit so we will have the same material here in Kansas and at various locations of ICRISAT. He has provided 4000 seeds of a line to David Andrews for growth chamber studies at the University of Nebraska.

Storage and Preservation of Pearl Millet. Dr. Robert Mills reported on this program. Although this is a new program and not funded until September 1979, samples of pearl millet grain were provided to Departments of Entomology and Grain Science and Industry last year so they could initiate a preliminary study. They have studied various grain storage insects response and compared these observations in corn, wheat, sorghum and pearl millet. The observations included population increase over time, size of adult, number of eggs produced, size of egg, percent damage to grain sample and other characteristics associated with the insect problem of stored grain. They will be studying the effect of mechanical harvesting on susceptibility to insect damage, storage of grain in the unthreshed head, and use more species of insects in the reseach that is currently underway.

There was then a period for the research presonnel to ask questions of Earl Leng, Program Director, INTSORMIL. Many of the questions were project specific. Then Earl presented an overview of the INTSORMIL program and the administrative requirements, overseas linkages, list of contacts and foreign training programs.

The personnel of the project, "Improvement of Pearl Millet", then discussed their annual report requirements, the utilization of remaining funds and the grain and plant material requirements for 1980.

During his visit to KSU to attend this IN-PROGRESS-REVIEW, Dr. Earl Leng consented to present a seminar to the Agronomy Faculty and Graduate Students on Title XII Grain Sorghum/Pearl Millet CRSP.

IMPROVEMENT OF PEARL MILLET

The eleventh "IN PROGRESS REVIEW" of the project "Improvement of Pearl Millet" and Title XII was held 1315 hours 15 April in Room 106 Waters Hall, Kansas State University.

Personnel Attending: Richard L. Vanderlip, Edward T. Kanemasu, Robert B. Mills, John R. Pedersen, William D. Stegmeier, R. Carl Hoseney, Elizabeth Varriano-Marsten, Barry Michie, Herman A. Praeger, Jr., Hartmut Stutzel, Julius Okonkwo, and Piara Singh.

Richard Vanderlip reported on the two technical committee meetings. The February meeting was in Washington, D. C. where the committee met with AID Bureau Personnel. It was apparent that these personnel were receptive to the TITLE XII program. The bureau and in-country AID personnel control the foreign travel of this program. Requests for foreign travel and coordination must be submitted at an early date to obtain all necessary approvals.

The meeting 10 April was held in Lincoln. Richard L. Vanderlip did not attend the meeting, but has talked toJerry Eastin and has received a copy of minutes of the meeting from Darrell Rosenow. It appears most of the meeting was devoted to the External Review scheduled 15-19 September at Lubbock, Texas. All members of the Review Board have not been identified and some who have been selected, declined to serve. Hugh Doggett will be chairman of the External Review Committee. Each project will be scheduled time to present their program. There are forty-one (41) projects in INTSORMIL TITLE XII program. It was mentioned and discussed that the pearl millet crop will not be harvested by 15 September and there will be no results for 1980 to be presented. The 1978 and 1979 results that can be presented were not supported by INTSORMIL funds or program.

The program director has requested a one page, double spaced, summary of results and accomplishments of each project. This to be written in popular language.

The annual report and the requested financial support for the third year (1981-82) INTSORMIL was subitted to the program director. The budget for the six projects was $524,873.00.

The annual report for TITLE XII INTSORMIL is six separate reports and financial statements. The possiblity of combining this into one report similar to the "Improvement of Pearl Millet" program was discussed. It was considered this should be coordinated with the program director to see how he wanted the report. If it can be consolidate, then we will request the change through appropriate channels.

The annual report "Improvement of Pearl Millet" was completed and distributed to project personnel and mailed to personnel on the mailing list.

Plans for the summer programs and grain requirements were discussed. Entomology has a need for a large amount of grain, 200 - 300 pounds, just to raise insects for their research. This can be bulk and unidentified. Bill has reminant seed and Richard has a quantity in his lab that satisfies this

requirement. They are interested in small samples of identified genotype and growth location for their studies. One hundred grains to a few grams are adequate for this. They are also interested in adequate number of heads and threshed grain, 60 heads and one pound or more grain for larger studies. This amount of materials will be available at the six locations where we have yield trials. They are planning macro- size studies when thousands of heads and bushels of grain are available.

Grain Science has requirement for a large quantity of bulk material, They could use five pounds of grain of each genotype at the various locations of the yield trials. They would like small samples of any new or unusual material.

Bill Stegmeier is to provide the seed for the yield trials. Hopefully there is adequate seed for twenty-five entries including the four entries of Glenn Burton for six locations. The yield trials are to be two rows 30 feet long with three replications. Sixty grams of seed will be adequate.

Bill has provided seed to Texas, Nebraska and Arizona. Chuck Francis, Nebraska, would like seed so he could have a yield trial the same as the Kansas trials in Western Nebraska. This will be coordinated with him 18 April when Richard is in Lincoln coordinating the intercropping study. Carl requested when this seed is provided other states we should request a sample of the grain be provided so we can study the location effects on grain quality.

International Coordination was discussed. The farming systems program does not have approval for its program in India. The project manager is trying to solve this problem. It is not known here what the problem is, but ICAR (India Council Agriculture Research) and AID India have not approved the collaboration required of our proposal.

Requests for international coordination and travel for this summer and fall should be initiated now. Format for these requests will be provided.

The financial condition of the two contracts were discussed. The project "Improvement of Pearl Millet" terminates 30 September 1980. The harvest will not be completed by that time and there can be no laboratory work accomplished. As this project is incorporated into INTSORMIL 1 October 80, funds are not a problem. It was decided to request a six month non-funded extension to the project to be able to complete the project and prepare the final report.

The utilization of INTSORMIL funds is lower than programmed. The principal investigators would like a copy of the monthly financial statement provided to Nebraska. They have little or no information on the financial status of their program. Thanks to Xerox this is no problem to comply with their request.

The Farming Systems Workshop at Purdue University 22 - 23 May was discussed. Barry Michie plus two personnel from Grain Science, Post Harvest Storage will attend the conference.

The feasibility of expanding the pearl millet yield trials to Nebraska, Colorado, New Mexico, Texas and Oklahoma were discussed. At this time we do not have the ability to provide the seed for this type program. Performance testing should be included in the program over a large area of the semi-arid plains region. This will be explored at a later date.

IMPROVEMENT OF PEARL MILLET

The twelfth "IN-PROGRESS-REVIEW" of the project "Improvement of Pearl Millet" and TITLE XII "INTSORMIL" was held 1315 hours 26 August in Room 106 Waters Hall, Kansas State University.

Personnel attending: Edward T. Kanemasu, Robert B. Mills, John R. Pedersen, William D. Stegmeier, R. Carl Hoseney, Elizabeth Varriano-Marston, Barry Michie, Janet Benson, Herman A. Praeger, Jr., Francis L. Barnett, and Babrak Khaleeq.

The External Review Panel to be convened at the Lubbock Civic Center, Lubbock, Texas 14-19 September was discussed. Ed Kanemasu reported that he had called Earl Leng informing him of a conflict with his schedule. Earl informed Ed that there was no need for the principal investigators to attend all the meetings that week. They should attend when their program was scheduled for evaluation.

The organization of the reports was discussed. The time allocated for each report is ten minutes, with six minutes for presentation and four minutes for questions. A written report is to be provided. This report to be organized similar to the oral report so the reviewers may make notes and references for later discussion. One page summary should be adequate, with an absolute two page maximum.

Each of the six KSU projects will determine who will present the project to the External Review Panel. They will make their own travel arrangements and reservations. They are to notify Richard Vanderlip who will be attending and during what period.

Carl Hoseney and Liz Marston completed an international coordination trip during the summer to India, and Sudan and Senegal in Africa. Their trip report will be completed in the near future.

Barry Michie completed a coordination trip to India coordinating a Farming Systems Program with the University of Udiapur in Rajasthan. He also visited AID India prior to departing the country. His trip report will be completed in the near future.

Some of the research plantings did not survive the harsh summer weather. There are many plots that survived, produced grain and should provide results to support the research. There will be adequate supply of grain and heads to support the studies for grain storage and nutritional quality.

The termination of project 5597, "Improvement of Pearl Millet" 30 Sept 80 was discussed. The utilization of the unallocated funds for the four projects was discussed. There appears to be no problem to expend the funds prior to 30 September. There should be no overexpenditure of funds on this project. Funds are available in TITLE XII to adequately support the program.

The current status of TITLE XII funds by project was provided to each project leader. As of 31 July 1980 there is $413255.00 to support the KSU projects until 30 June 81. Consideration should be given for reallocation of these funds within the various projects of KSU. This was not a popular subject, but it was considered that the funds should be effectively utilized

within an institution prior to the pressures of adjusting funds between institutions.

The project proposals that are in the preliminary stages of development that may be of interest to KSU were discussed. Carl Hoseney was informed of the Senegal proposal prior to his trip to Africa. While in Dakar he contacted ITA (Institut Technologique Alimentaire, The Senegalese Food Technology Institute) and discussed the proposal. The major outputs are to develop and evaluate millet-based machine processed traditional foods, non-traditional snack foods, non-traditional staple foods and weaning foods. Basically, this is a request for funds with most of the allocation to be utilized by ITA. Consultation and advice would be provided by a U.S. institution. KSU is interested in this project. The status of the project is the development of the Program Identification Document (PID) by AID. The program is planned to be initiated during 1981.

Harold Dickherber, Project Officer, Niger Cereals Project U.S. AID Mission to Niger has written a letter to Richard Vanderlip informing him of a Sorghum and Pearl Millet research program. They are in the planning stages of a five year bilateral project with the Government of Niger's Research Institute to improve the ongoing research programs. He has requested that KSU consider submitting a proposal for the Niger Cereals Research Project when proposals are requested.

The Tanzania proposal is in the office of International Agriculture Programs. There is a large Farming Systems Program in the proposal in addition to research programs for the various crops.

The meeting adjourned 1500 hours.

A film produced by IDRC (International Development Research Centre, Canada) entitled "No More Pounding", showing the milling machinery they developed for the decortication and milling of sorghum, corn and legumes for the Lesser Developed Countries of Africa was shown. This machinery has been developed for large scale use and small scale where a housewife can bring in a small quantity of grain (10 kilo or less) to be milled. It was an interesting film - but the discussion that followed indicated this process may not be utilized for pearl millet. The decortication of sorghum and maize is a much simpler process than for pearl millet. Pearl millet germ is not removed in the process as it is in sorghum and maize. The high oil content of pearl millet germ will cause rancidity in the flour even though this is a dry milling process.

IMPROVEMENT OF PEARL MILLET

The thirteenth "IN-PROGRESS-REVIEW" of the project "Improvement of Pearl Millet" and TITLE XII "INTSORMIL" was held 1315 hours 6 November in Room 106 Waters Hall, Kansas State University.

Personnel attending: Richard L. Vanderlip, Edward T. Kanemasu, Francis L. Barnett, Robert B. Mills, John R. Pedersen, Barry Michie, William D. Stegmeier, Babrak Khaleeq and Herman A. Praeger, Jr. Elizabeth Varriano-Marston was briefed concerning the meeting later.

The project "Improvement of Pearl Millet" was completed 30 September. The final financial report will be completed next week. Preliminary reports indicate we spent $769908.50 of the allocated $770000 during the three years of this program. We are required to prepare a final report for the project. The format for this report is to be the same as for our first and second annual reports. We will use this report for both the annual and final requirement. The contributions to the report should be completed by the time of the Experiment Station Conference which is scheduled for early January 81. Contributions that can be completed at an earlier date should be submitted when completed.

Barry Michie briefed the group on the problems encountered in the Farming Systems attempts to finalize the linkage required with India and the University of Udaipur. At the Board of Directors meeting in Kansas City 31 October, Floyd Smith was informed that the linkage with India for this program was doubtful. Dr. Friedmann and Barry had a meeting with Floyd Smith to discuss this matter. Barry then called Bob Jackson, AID, Washington, Bob was pessimistic regarding any linkage with India for this project but recommended Barry contact a Mr. Williams, AID, Washington, who attended the meetings in Delhi. He was also pessimistic concerning the linkage. Then Barry contacted Earl Leng, INTSORMIL Project Coordinator, Lincoln, Nebraska. Barry went to Lincoln 5 November for conference with Earl. Earl is not as pessimistic concerning this program. The India Council for Agriculture Research (ICAR) is favorable toward this TITLE XII program as is the University of Udaipur. There are communications that should be answered in the near future which may give an insight on how to resolve this problem.

Bill Stegmeier reported on the Technical Committee meeting at Kansas City 30 October and the Joint Meeting of the Technical Committee and the Board of Directors 31 October. The Technical Committee prepared their reply to the report of the External Evaluation and Review Panel. There were two Kansas projects, KSU I (Breeding) and KSU 6 (Stand Establishment), that received some unfavorable comments. The Technical Committee reply was not only favorable to the Kansas programs, but recommended enlargement of the KSU I program as is, plus subcontracts with other states in arid areas. It also included a recommendation that KSU establish at least a breeding program in Africa. Funds for the enlargement and extension of the program to Africa will not come from the current Kansas allocation, but will be provided from other sources.

Dick Frederiksen had written Richard Vanderlip concerning a trip he, Darrell Rosenow, Texas, Jerry Maranville, Nebraska, plus one other are making to Sudan week of 10 November to establish linkage with Sudan and TITLE XII INTSORMIL. It was decided that Bill Stegmeier would contact Frederiksen to have him include the KSU millet program in the linkage agreement with Sudan. At a later date Vanderlip and Stegmeier are to visit Sudan to organize the millet cooperative program with KSU.

The Management Entity, INTSORMIL, has received a request from AID, Zambia, for technical assistance. They have requested that Vanderlip be a member of the Technical Assistance Team. The visit will be early 1981.

The administration to extend the TITLE XII INTSORMIL one more year has been requested by the Management Entity. The original contract was for the period 1 July 1979 to 30 June 1984. It is the intent to extend the program until 30 June 1985. It is now required to have a year six budget - have it approved here at KSU and be available for the Board of Directors Meeting 19 Nov. Budgets for years 1-2-3 have been prepared and submitted. The budgets for years 4 and 5 must be prepared prior to developing year six. After much discussion, it was decided to use the budget of year 3 as submitted as the base and developbudgets for years 4-5-6. It was decided to use a 10% inflation rate in developing the budget. The method of determining the Indirect costs was discussed. The original contract for years 4 and 5 can use the percentage figure of salaries, wages and fringe benefits. The budget for year six must be developed using the modified total direct cost (MTDC) procedure as outlined in the procedure manual. These are to be developed and provided to Al Praeger by Monday 10 November for consolidation.

Al Praeger is to develop the budget for the Africa Pearl Millet Program in cooperation with International Agriculture Office.

The meeting adjourned 1500 hours.

III. International Travel

Improvement of Pearl Millet

Trip report for Dr. E. Varriano-Marston and Dr. R. Carl Hoseney

July 5 through July 26, 1980

On July 7, we visited Dr. D. A. V. Dendy of the Tropical Products Institute in Culham, United Kingdom. Dr. Dendy is collaborating with us on a chapter on sorghum and millets; thus a good share of our time was spent discussing the content and organization of the chapter. Dendy explained that TPI is funded partly by the government with increasingly larger amounts of support coming from grants of various types. Their cereal staff consists of 8 people, and much of their time is spent in developing countries on short (several weeks) to medium (several months) length assignments. Thus, the institute does relatively little research work at Culham.

Dr. Dendy showed us a large number of machines developed at TPI. In general, most of them were very simple, hand or foot operated machines used to shell, dehull, or grind various grains. The technology was simple but practical and could readily be used at the village level in developing countries. TPI has developed a decorticator for grain sorghum which employs a wire brush. The decorticator appeared effective although it was impossible to evaluate it during the brief demonstration. A large scale model has been designed and will be built and sent to Sudan to be evaluated along with other machines under a FAO project. However, TPI is about 1 year behind schedule in supplying the machine.

On July 8, 1980 we visited the Flour Milling and Baking Research Association in Chorleywood, United Kingdom. Norman Chamberlain served as our host and gave us an overview of their organization. Their financial support comes from member firm dues (50%), from the government (40%), and from contract research (10%).

During our visit we had discussion with Dr. E. E. McDermitt on the role of α-amylase in bread. Of particular interest was the method they have developed to measure stickiness. We have used their basic method to measure stickiness in cakes and various millet products (tuwo), but have had limited success. We understand that Rooney's group at Texas A & M have also been using the procedure for sorghum tuwo.

A productive discussion was held with Dr. P. L. Russell who is working on staling. Dr. Russell is using a DSC of the same model that we have just received. The discussion was mainly on problems in setting up the hardware and how to handle the data. We felt that several points that were covered would save us time in setting up our instrument, and that Dr. Russell would be an excellent contact for future reference on the use of the instrument.

We visited with T. H. Collins and Norman Chamberlain on air incorporation in doughs and had lunch with Dr. D. W. E. Axford, Director of Research for the institute. In the late afternoon Dr. Chamberlain provided transportation to the airport for our flight to Khartoum.

On July 9, we visited Dr. Sitt Badi of the Food Research Center, Khartoum North and discussed their research program on sorghum and millet. They are involved in an FAO sponsored project to evaluate a number of different types of decortication equipment. Study is in progress even though some equipment (see TPI) is not yet there. Preliminary work shows rather large differences in the efficiency of decortication and on the percentage of broken kernels.

We also visited Dr. Abdoul Hafiz Abdoula, Head, Department of Agricultural Engineering, Khartoum University. They have a FAO project on grain storage. The project has two major emphasis: first, to determine storage losses, both type of losses and extent of loss; and second, to study types of storage fcailities used in Sudan such as ground huts, buildings, or metal bins. We discussed K.S.U. work in the grain storage area and suggested that he contact Dr. Pederson or Mills or AID for futher details.

We also met, very briefly, with Prof. Kambal, a Sudanase trained at Nebraska but now working as a plant breeder in Yemen.

Working with Dr. Badi is Mrs. Laila Yahia Monawar, a PhD student who is doing a nutrition project. She plans to feed chicks and rats to determine the nutritional value of certain sorghum dishes.

We also met with Dr. Paul Ladu Bureng, a Sudanase who recently completed his PhD at Reading, United Kingdom and returned to the FRC. His thesis which is extremely long (500 pages) was on the malting characteristics of sorghum, particularly the production of dried flakes. The title is "A Study of the Malting Characteristics of Sorghum Grain and the Preparation of the Fermented Food Huller-Murr." He used a feterita as the only sorghum variety. We are planning to obtain a copy of his thesis through the interlibrary loan system.

From July 9th through July 11th, we attempted to reconfirm our scheduled flight from Khartoum to Jeddah via Mid-East Air and then from Jeddah to Bombay via Saudi Air. However, Mid-East Air stated they would not carry us unless we had a Saudi Arabian in-transit visa. We were not familiar with an in-transit visa and only had a 3 hour lay over in Jeddah. Personnel at Saudi Air told us that we did not need a visa, and a note to that effect was sent to Mid-East Air. However, the note did not appease Mid-East so we had to make new travel plans from Khartoum to Bombay.

To make a long story short, the next few days a great deal of time was spent attempting to arrange travel from Khartoum to Bombay. We tried to obtain routes through Ethiopia, Egypt, Kenya, and Kuwait but all were unsuccessful. The fact that telex machine was not working was not helpful. Also our tickets were billed on the basis of mileage and no one, including us, understood how they were computed. Thus others would not accept them or endorse them for TWA. Finally with the help of a highly placed Sudanase Government Official, who was a friend of Dr. Badi, we were able to obtain confirmed reservations from Khartoum to Athens.

There was a flight from Athens to Bombay after a 9 hr lay over, but it could not be confirmed. We felt our chances in Athens was much better than Khartoum and thus took the flight. We did however have to purchase new tickets from Khartoum to Bombay. To date, TWA has refused to refund the Khartoum to Bombay part of our original ticket. We are still discussing the matter with TWA.

With the additional time in Khartoum, we finally left on the 13th, in addition to sitting in various airline offices we did make a number of visits. We met with Mr. Wendal Morris of USAID in Khartoum and explained our work. He sent a cable to India for us to let the Indians know our schedule was revised. However, the cables had not arrived by the time we left India.

We met with Mr. Abdoul Fahab Musa of Khartoum who has invented a machine to make kisra and has a kisra factory on the outskirts of Khartoum. The factory was not working at the time we were there but he planned to start production again soon. He was very proud of his equipment and quite willing to show it and discuss the process.

The following are notes on kisra production according to Mr. Musa. The amount of water varies but in general the formula consists of 1 part water to 2 parts meal. The milling of the meal was not thought to be critical. The mixture is allowed to ferment 10-16 hours, longer times are necessary in the winter due to lower temperatures. In general, the pH will drop to about 3.8. Different varieties of grain sorghum will definitely give different products. Color is viewed as a very important factor in consumer acceptance. There is a bleaching effect with fermentation. This is particularly true with pearl millet which is used to make kisra in the western part of the country. The strength of the sheet is another important characteristic; it must be strong to peel as a sheet from the cooking surface. The product should not taste pasty. Another important factor is staling. The product becomes more brittle with time. The products will develop mold in 2-3 days which is the maximum storage time. Some varieties of sorghum will give a thicker kisra even though you dilute the batter with water. This appears to be a quality difference. Other varieties will give a pasty product. Mr. Musa feels that the most difficult part of the process is fermentation which manifests itself as differences in thickness and flavor.

His kirsa machine was basically a cast iron wheel about 30 inches in diameter. The wheel was heated to 200°C by a propane flame positioned inside the wheel. The batter was spread on the outside surface in a thin sheet and peeled from the surface at the bottom. The speed of the wheel could be varied to give a moist kirsa or a dried, and therefore, stable product.

After visiting the factory, we felt that the machine would undoubtedly work, but a major problem would be handling, shipping and selling the limited shelf life product.

That same day (July 9th) we also were taken to a poorer section of Khartoum to visit a house where Marisa (a fermented beer from grain sorghum) was produced, consumed, and sold. Alcohol consumption in Moslem countries is not widespread but occurs to a reasonable extent particularily among the poorer people. It took a guide to find the house, and there was considerable discussion before we were allowed into the compound. Once

inside they were quite willing to show us the Marisa process and to be photographed. The process was explained as follows. The sorghum meal is pasted (cooked to gelatinize the starch), cooled and mixed with flour (uncooked) made from germinated sorghum. They are mixed together along with a starter from a previous batch and allowed to ferment for about 2 days. The mixture is then strained through a cheese cloth to remove the pericarp and other larger pieces; the overs are fed to chickens. The material passing the cheese cloth was a thick, grey mixture resembling a hog slop and having a pH of about 3.4. Dr. Badi and associates stated that many of the people's diets consited almost entirely of Marisa, including some apparently healthy children that we observed. The alcohol content of Marisa is not known; however, an elderly gentleman that allowed me to take his picture was feeling no pain. Thus the alcohol content was presumed to be in the area of 3-6%. The temptation to taste the product was easily resisted.

Arrangements were made with Dr. Badi to send us a number of samples of grain sorghum and pearl millet. We need to renew our import license before we can receive the samples.

On July 10th, we visited Mrs. Shahwa El Guzuli, head of the nutrition department, of Sudan Ministry of Education. She gave us a tour of the department and explained that they provide a nutrition educational service for teachers, cooks, and housewives. They teach the students how to plan balanced meals and the importance of nutrition in the health of children and adults. Their program is sponsored by FAO, UNICEF, and the Sudan Department of Agriculture. Mrs. Guzuli indicated that malnutrition was a problem in Sudan but was related more to ignorance concerning good nutrition than to socio-economic status. The problem is particularly prevalent among children 1 to 5 yrs. of age.

We left Khartoum on July 13, at 10:00 a.m. via Athens to Bombay arriving July 14 at 9:00 a.m. The next plane to Bangalore was not until July 15 at 8:50 a.m. While in Bombay we contacted Dr. and Mrs. V. S. Rao. The Rao's are KSU graduates and Sudha works as a Cereal Chemist at the Bhabha Atomic Research Center in Bombay. We wanted to follow up our 1978 visit to the center and see if atomic energy is being used to any extent to preserve grain. The report was that it is not being used.

On July 15, we went to Bangalore by plane and on to Mysore by a 3 hour taxi ride. At the Central Food Technological Research Institute (CFTRI) we met with Dr. C. P. Natarajan, Director of CFTRI, Dr. S. R. Shurpalekar, Head of the Milling and Baking Division of CFTRI. In Dr. Shurpalekar's laboratory we were given a demonstration of chapatti making by Mr. H. P. Rao. Mr. Rao had worked in Dr. Hoseney's lab at KSU for 2 months in 1979. In general, Mr. Rao reported that for wheat chapatti the farinograph water absorption minus 14% gave the correct water for chapatti. He had also found that the Research Water Meter was useful in measuring the water for chapattis. A flow time of 62-65 sec. was thought to be optimum. He stated that housewives allow the dough to rest overnight before baking. He rolled his chapatti dough to a 2 mm thickness and baked them in a gas tandoor cooker. The cooker consists of

a rack with a indirect gas heater in the bottom and a dome above the rack. It appeared to be capable of supplying intense heat and did a nice job of puffing the chapatti. Chapattis brushed with oil during cooking are called pareatta. He used a tear test to evaluate the strength of his chapattis. The machine used was a paper tester (Elmendorf Paper Tearing Tester, H. T. Messmer Ltd., London, No. 16500). He felt this gave him reproducable results.

Another project in the group was the baking of Nan (a leavened Indian bread). Mr. Rahim headed this project. From our discussion Nan appears to be more similar to our U.S. bread than is the unleavened chapatti. Other projects they are working on include: the effect of grain storage on baking quality, the effect of extraction rate on quality, and replacement of wheat flour with legume or cassava flours.

On July 16, we visited with the cereals section (all cereals other than wheat) which is headed by Dr. H. S. R. Desikachar. Unfortunately, he was out of the country during our visit. We met with Dr. K. R. Bhattacharva and S. N. Raghavendra Rao. Much of their work is with rice but since the mid 1960's they have worked with sorghum, millets, and legumes, and have published a number of studies on pearling of sorghum and millet. Much of the millet work was with ragi (finger millet). Traditionally the grain is pounded and made into dumplings. They have developed weanling foods containing 70% malted ragi and 30% green gram. Ragi has a very high calcium content. They are doing considerable work on developing new foods, mainly snacks, from sorghum. They are also working with Kodo millet (also called Varagu millet), *Paspalum scorbiculatum*, a dark brown small seed. The process for ragi milling is as follows: the seeds are soaked overnight, allowed to germinate for 48 hours, sun dried, pearled or dehulled and toasted at 70°C. After toasting 10%, water is added and it is ground in a hammer and or plate mill and screened to remove the pericarp. With the small seed size the 65% extraction that is obtained is a high yield and probably contains a part of the pericarp.

On July 17, we arrived in Hyderabad and visited the National Nutrition Institute (NNI) that afternoon. Dr. Tulpule, the director, told us of the problem of pellagra with sorghum eaters. Work with dogs and humans has shown that adding isoleucine will alleviate the symptoms and adding leucine will make the diet more pellagragenic. There appears to be little question that the isoleucine/leucine ratio is an important factor in the nutritional quality of sorghum.

Dr. Tulpule feels that, in general, except for 1-2 year old children, there is little problem in obtaining adequate protein in the diet if sufficient calories are eaten. He made the point that at weanling the child often has diarrhea because he is now consuming much more water of doubtful purity. The diarrhea causes losses of injested nutrients which means that the child must eat more to make up for losses. He also stated that their studies have shown that poor women on insufficient diets give the same quantity and quality of milk as a woman consuming diets high in nutrients.

In a discussion with B. S. Narasinga Rao (NNI) we learned that 40 to 60% of the people in India are anemic. People consume 20 to 30 mg of iron per day from the diet but the absorption is very low, 0.5% from millet and about 2% from wheat. Fortification of cereals is impractical as most are processed and consumed within the home. They are looking at salt as a possible carrier of iron. It is consumed by almost everyone and is already fortified with iodine. Ferrous sulfate does not work well because of water uptake etc. However, they have identified other iron salts which are stable and readily absorbed by humans. He did not identify which salts they were testing.

They have a simple method of estimating iron absorption. The sample is digested at pH 1.35 with pepsin, the pH is adjusted pH to 7.5, and the iron is determined in the supernatant. The method apparently gives good estimations of iron bioavailability.

According to Dr. Deosthale studies on iron adsorption indicate that there is improved absorption with pearled grain and a good correlation with degree of pearling. They used the method given above to estimate absorption. Low iron absorption was thought to be related to tannins and phytic acid. However to date, is not very clear on which, if either are involved. They are continuing work in this area.

For preschool children the staff at the institute estimate protein requirements at 1.75 mg/Kg body weight. In India 2.00 mg/Kg is commonly consumed. Energy requirement is 100 KCal/Kg body weight. Below 80 KCal/Kg or 1.75 mg protein/Kg body weight, nutritional problems are encountered.

We had further discussions with Dr. Pant on the importance of the isoleucine/leucine ratio in sorghum. He could not produce black tongue in dogs with opaque-2 maize. In a study of 350 varieties of grain sorghum they found little variation in isoleucine/leucine ratio.

Dr. Pant and associates are also working on storage stability of grains. In a 10 month storage study in Indian households, they found one variety that was resistant to storage insects (J. Sci. Food Agric. 28:963, 1977).

They are also working on oligosaccharides in grams and have found that germination lowers the level and cooking increases the level of oligosaccharides detected. The increase was thought to be due to improved recovery resulting from cooking.

On July 18, we visited ICRISAT. The goal of Dr. A. Patanothai and Dr. Kumar, millet breeders, is to select for increased protein and lysine without reduction in yield. In general, they thought they could increase protein with no loss in yield. They have found a strong negative correlation between protein and lysine. Resistance to downy mildew have been found in pearl millets. They also are finding millets that are resistanct to ergot.

Discussion with D. S. Murthy, dealt with the differences between field and storage molds in sorghum. He stated they are screening their sorghum breeding material for product quality; using a roti (chapatti) as a test product. Some varieties make good rotis, others do not. The factor responsible for the difference is unknown. With their trainees from West

Africa, they are working to produce typical products (tuwo etc.). He has found that the particle size index (developed by L. Rooney, Texas A & M) is useful. They are looking at traditional pounding as an index of millability which is thought to be an important factor in acceptability. He also showed us a sample of a scented sorghum. The sorghum has been described in a recent publication (Current Sci. 48:823, 1979).

In our discussions with Lee House, sorghum breeder, he emphasized that we should look at quality differences within visually acceptable grain types. He and Dr. Murthy expressed a willingness to select and grow grain for us. He also suggested that we contact J. Schrewring in Mali for seed samples and food preparation methods.

Drs. R. Jambanathan and Subramanian showed us slides on food products made from sorghum and millet in India. Their work will be described in the Vienna paper that will be published by TPI. They also demonstrated the making of millet rotis. Basically they use a method similar to ours. They do not use high heat but agree that villagers generally do. Their procedure for millet roti was as follows: to 50 g meal add 50 ml water, knead for 5 min, roll to 3 mm thickness for millet and 1.5 mm for sorghum. Bake on a hot plate (240°C) 1.5 min on first side then wet top surface with water and bake second side. There was very little puffing although they suggest that a good millet would give some puffing.

They have also completed some work on sugars in millet and sorghum using Bio-gel P-2. The sorghum paper has been submitted for publication, and the millet data is being verified. They will send us copies of both papers.

On July 19, we visited the Home Science College in Hyderabad and had discussions with Dr. Pushpumma and Dr. Geervani. They felt that there were pressures on villagers to switch to rice and wheat from sorghum and millet because sorghum and millet must be processed each day.

Dr. Pushpumma is writing a monograph on traditional processing and consumption of sorghum, millets, and legumes in India. It will be published by IDRC.

Drs. Pushpumma and Greevani felt that color is an important quality factor; with sorghum, white or yellow is preferred. Villagers generally believe that new varieties are not as good for their health. In addition, they have found that sorghum stores with more difficulty than does millet.

Their feeding studies with children ages 1 to 5 on diets of sorghum and rice in combination with legumes showed that growth rates were good by Indian standards when sorghum was included in the diet and was often better than diets with rice alone. She (Dr. Pushpumma) feels that although protein is not a problem if calorie requirements are met using a typical Indian diet, it is impossible for the child to consume sufficient calories (insufficient capacity in stomach - even 6 meals/day failed to provide the necessary calories).

She feels strongly that niacin deficiency in sorghum eaters has been overemphasized. Although sorghum may be deficient in niacin, most people eating sorghum also consume sufficient pulses so niacin deficiency is not a real problem. She also feels that diet surveys are worthless and that you can only learn by living with the people.

The afternoon of July 19, we flew to Delhi. On July 20, we flew to Amristar. Dr. J. S. Sidhu met us for the 3 hr car trip to Ludhiana. On July 21, Dr. Sidhu and Mr. G. S. Baines gave us a tour of the new Food Science and Technology building at Punjab Agriculture University. A new building is being constructed (construction is slow because all concrete in the country is being sold to the Middle East for hard currency) to house the cereal section. At present they are working on the following problems: the milling of cereals; the use of durum wheat for bread-making (durum allows them to avoid certain diseases); and α-amylase activity in both wheat and rice.

We met briefly with Dr. Kirpal Singh, Director of Food Processing and Technology and with Dr. A. S. Cheema, Vice Chancellor of Agriculture. A major problem now in India is over production. This presents large problems with grain storage and transportation. They are currently suggesting that cereal production be limited. It seemed incongruous that food production in India be restricted. During our car trips from Amristar to Ludhiana, we saw many tons of grain stored on the ground in gunny bags under black plastic. The temperature was near 40°C and the humidity near 90%, thus this grain is going bad very rapidly. Over production of both wheat and rice in the Punjab is indeed a problem. Also during our drive we saw many fields of pearl millet growing. However, the people we talked with did not want to discuss millet, but would talk about wheat and rice whenever we asked about millet. It obviously is a important crop in the area, but the very pround Punjab's would not discuss the crop.

On July 22, we visited Punjab Breweries, a very modern brewery producing 40,000 liter bottles per day. They were using 10% sugar and 10% rice with the remainder being barley malt to produce the beer. The hops used were half imported and the other half domestic. On July 23, we visited a typical Indian "chucky" mill. This mill, as do many of the modern ones, had a pearling device and the wheat was lightly pearled before it was ground. The pearling removed about 6% of the kernel. The flour produced was rather white and more refined than what had been produced in the past. This is a new trend in India and is a concern to some nutritionists. The flour we examined was very gritty indicating that the white wheat they were grinding was extremely hard.

The afternoon of July 23, we drove to Amristar for a flight to Delhi and from there to Bombay. We spent the 23rd in Bombay visiting the Dr. Rao. The flight from Bombay to Niarobi was delayed due to engine trouble and we arrived at 6:00 a.m. on July 24. We left Kenya that afternoon for Dakar and arrived in Dakar at 1:30 a.m. on July 25.

Dr. Ken Steinke of USAID-Dakar met us at 8:30 a.m. and took us to ITA where we visited with Dr. Thiam and Mme N'Deye Niang of their cereal section. We discussed the basic composition of sorghum and millet and the traditional processing of millet. The grain is cleaned, placed in a large mortar and pestle, wet with a small amount of water; pounded, dried and winnowed to separate the light pericarp. Water may be added 2 to 3X during the process. The decorticated grain is then washed and dried before being pounded into a flour. The flour must be produced each day because it deteriorates in storage. During the milling process the grain may attain a moisture content of 25%. They feel the high moisture leads to lipase activity and thus hydrolytic rancidity. They feel lipoxygenase activity is low in millet and thus not much oxidative rancidity occurs during storage. They think that with dry decorticating and milling a flour with 6 months storage stability can be produced, even though the germ is still in the flour. He feels the problem is moisture not fat. We were not convinced that both oxidative and hydrolytic would not occur in the dry milled grain.

They also stated that in Senegal millet is preferred to sorghum for cous cous. They expressed concern that nutrients were lost in the traditional processing because water was used. It was not clear to us where the nutrients were going.

They described the preparation of a number of traditional foods. Cous cous is made from a coarse ground meal, water is added, and the meal is agglomerated and then steamed. By law, bread is Senegal contains 15% millet flour, but it was not clear how well the law was being enforced. Cakes containing 50% millet flour can be produced. They were prepared for us to sample, and we found the cakes to be very heavy but with a reasonable taste. Biscuits are made with 20% millet and cous cous with 100% millet. Traditional milling gives about 65% yield of flour.

They have developed weanling food based on millet with mixtures of groundnut and soy flours. Some traditional millet foods include:

Dakh: There are at least two types: one is prepared with semolina, vegetables and fish; the other with millet flour.

Millet: Millet is mixed with H_2O to make small dough balls which are cooked in boiling water. The product is eaten with curds and sugar.

Fonde: a more fluid paste, taken with sugar, curds, or tammer and pods.

Rouye: millet flour cooked in water - very thin gruel - often given to babies.

Mr. Thiam also discussed fermented foods. He thought lipase would cause a sour taste due to free fatty acids. We had a problem with that explanation. We were given a tour of ITA and shown a millet, (souna variety), supposedly the most popular variety in Senegal. It was very small seeded and yellow in color.

Next we visited Mr. Gupta, the ICRISAT millet breeder, in Senegal. He said that a common practice in Senegal was to plant millet in one hill per square meter and maybe 50 seeds per hill. He wants to reduce the height of souna millet from 3 to 2 meters. We asked about the small seed size we had seen at ITA but he tells us that souna is large green-gray and what we were shown was not souna.

In the afternoon we visited with Paul Rusby of AID Senegal to try and clear up the confusion on the pearl millet grown in Senegal. He stated that souna was the most preferred with a second variety sanio as less preferred. He had a young Senegalese lady help explain the difference. She stated that souna is green-grey and smaller in seed size and sanio is reddish and larger in seed size. This left us confused about what the yellow variety was that at ITA. We arranged for the lady to accompany us to a local market to see the varieties. In the market the only variety available was souna, it was quite yellow, just as we had seen at ITA but much larger seeds. We were told that sanio was not available because of the time of the year. We are still not sure about the millets in Senegal.

During our visit with Paul Rusby, we made several suggestions concerning his millet proposal. We suggested that the first step of the project should be to determine which millet flour is shelf stable. Can it contain the germ or not. Once this is known a milling system to make the proper separation could be developed. We also discussed what should be done with the material removed during processing, i.e. the pericarp and perhaps the germ. We suggested that it could be defatted, the oil recovered as a cooking oil and the defatted germ and perhaps part of the pericarp could be added back to the flour to improve the yield. We also questioned whether a simple cooking or even extrusion cooking could stabilize the product against rancidity as he assumes in his proposal.

The Senegalese lady that accompanied us to the market stated that if millet was dried after decorticating, the flour would last 15 days (she didn't appear very certain) however, we saw millet in the market that had been decorticated. She stated that there was normally a price differential between souna and sanio.

Having accomplished most of our goals for Senegal that day we checked on flights leaving earlier than our scheduled flight on July 29. We found a flight leaving Dakar at 2:00 a.m. July 26, and arrived in Manhattan at 3:00 p.m., July 26.

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V. Project Personnel

A list of project staff members for the period 1 October 1977 - 30 September 1980.

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VI. Results of Research

Objective 1. "Accelerate improvement in pearl millet yield by creating widely adapted high yielding populations and synthetic varieties and investigate possibilities of creating inbred lines and hybrids for use in developing countries."

PEARL MILLET BREEDING
[*Pennisetum americanum* (L.) Leeke]

W. D. Stegmeier

Introduction

Pearl millet, native to the semi-arid tropics, is consumed by millions of people throughout the dry tropics. However, as one of the world's major food crops it has received relatively little attention by the scientific community compared to the other major cereals. Since the start of the millet breeding program at the Fort Hays Experiment Station in 1971 a large number of introduced materials have been converted from tall, late-maturing types to dwarf early-maturing populations, inbred lines and F_1 hybrids. At this time it appears that pearl millet grain yield potentials will approach and possibly equal that of sorghum of similar maturity, that crude protein contents will exceed those of sorghum, and that present crude protein levels can be maintained at relatively high levels while yield levels increase.

Seeds of materials developed by this project have been sent to workers in several locations in the United States, Canada, India, and Africa. Interest has been expressed to evaluate pearl millet in Mexico and Honduras. It is believed that materials from this program can be used as germplasm for breeding programs in the dry tropics, particularly where monsoon seasons are short, and in developing countries in the mid-latitudes.

Materials and Methods

Experimental designs used in the performance testing of S_1 progenies and F_1 hybrids were 7 x 7 and 9 x 9 simple and triple lattices and randomized complete blocks with three or more replications. Plots were either single or double rows depending on seed quantities and were planted with a four-row John Deere Flex planter equipped with cone seed feeders. Planting rates were three to six times the desired stand and mechanical and hand-thinning reduced final stands to populations of either 35,880 or 47,840 plants per hectare. Nitrogen fertilizer was applied at rates of 0, 33, and 45 kg per hectare based on the objectives of the planting and previous field history. Weed control involved the use of triazine and 2,4-D herbicides and mechanical and hand cultivation. Performance test plots were harvested either by hand or with a plot combine equipped with "Hesston Head-Hunters" to gather lodged culms.

1. Population Improvement

Five populations and composites have been undergoing improvement as part of this project.

Hays millet populations (HMP) 550 and 1700 are undergoing improvement using the S_1 progeny performance testing method. Following recombination in a winter nursery grown on Molokai Island, Hawaii, HMP 550 Cycle 3 S_0 was planted to 0.4 ha to generate S_1 selections for 1981 testing. Between

3,000 and 4,000 plants were self-pollinated and approximately 500 of these were selected for harvesting. Characteristics considered in the selection process include early maturity, drought tolerance, synchrony of heading, lodging resistance, seed set, seed size, head exsertion and plant type.

A total of 225 HMP 1700 Cycle 2 S_1 selections and several millet and sorghum checks were performance tested in 9 x 9 triple lattices.

HMP 559, a tall, long-headed population, was again planted in the same isolated 0.8 ha field that it has occupied since 1978. This field has been continuously cropped for five years to induce a depleted soil fertility and moisture-stress environment. Each year the population is mass-selected for phenotypically superior plants that have lodging resistance, drought tolerance, good seed set and head exsertion, and dark green plant color. Seeds are sized by screens to 2.8 mm and separated on a gravity table to obtain the larger, denser portion for replanting.

Composite 1978 Series 2 was planted in an isolated 0.75 ha field. The 1979 harvested seed had been screened to separate seeds larger than 2.8 mm in diameter and the denser portion of the large-seeded fraction was obtained by gravity table separation for the 1980 planting. Primary heads of 800 open-pollinated plants of D_2 height plants were selected for harvest from the population of D_2, D_1, and tall plants. Harvest was delayed until culm lodging of approximately 50 percent of the plants had occurred. In addition to lodging resistance and dwarf height, selection was based on plant conformation, synchrony of heading, head exsertion, and apparent drought tolerance.

Composite 1978 Series 5 was not planted in 1980 due to inadequate isolation of the field prepared for its culture.

2. Inbred Line Development

A series of crosses were made during the period 1972 to 1976 between 56 plant introduction lines, Tift $23D_2B_1$, Tift $239D_2B_2$, PI185642 and Serere 3A to introduce earlier maturity, increased seed size, dwarf plant height, and the B_1 or B_2 male fertility maintainer reaction into the PI's. Nearly all of the crosses were made in the following form: PI_i/Tift $23D_2B_1$/2/PI_i/PI185642 and PI_i/Tift $239D_2B_2$/2/PI_i/PI185642. Serere 3A was used in addition to PI185642 in crosses with several of the PI lines. The F_2 seeds of these crosses have been planted as time and field space permit. A total of 105 F_2 families from crosses involving 35 Plant Introduction Station lines, several materials of African and Indian origin and sources of D_2 dwarf plant height and early maturity were planted to 1.5 ha. Desirable segregates were self-pollinated and will undergo further development for use as parental lines in hybrid combinations and populations. Approximately two hectares were planted to inbred nurseries and crossing blocks containing male-fertility restorer materials ranging from F_3 to F_{13} and male-sterile lines to be used as female parents of experimental F_1 hybrids. More than 200 A_1 and A_2 cytoplasmic male-sterile lines, their respective fertility maintainer lines and over 100 B_1 and B_2 selections were planted in the backcross nursery for selection and advancement.

Eighty-three lines of agronomic and physiologic interest were obtained from ICRISAT, Hyderabad and grown in the 1980 winter quarantine greenhouse under APHIS permit. Crosses were made between 72 of the introductions and several D_2 dwarf, early-maturing lines in the greenhouse. The 83 lines and their F_1's were field grown under limited irrigation for observation, seed increase and the production of F_2 families.

3. Production of F_1 Hybrids

Five F_1 seed production blocks, each containing one male line and 40 to 70 advanced A_1 and A_2 female lines, were grown in isolated fields to produce seeds of F_1 hybrid combinations. Row lengths of the females varied from 15 to over 100 feet, depending on anticipated seed needs. Pedigrees of the male lines are:

Senegal population (possibly GAM 73)
78-7024: Tift $239D_2B_2$/4* Serere 3A
78-7088: Tift $239D_2B_2$/4* Serere 3A
79-4104: PI287049/Tift $239D_2B_2$/2/PI287049/PI185642
79-1137: PI295126/Tift $23D_2B_1$/2/Tift $23D_2B_1$/PI185642

4. F_1 Hybrid Performance Testing

Evaluation of F_1 hybrids included the following plantings: a single row observation nursery of 120 experimental hybrids, performance tests of 225 hybrids planted in 9 x 9 triple lattice designs, and a factorial involving all possible combinations between 30 female lines and 4 males. An advanced yield test of 30 entries including 3 sorghum hybrids and 4 Georgia millet hybrids was planted at six locations in Kansas, two locations in Nebraska and a test at Lubbock, Texas.

5. Insect Resistance Studies (cooperative work with Dr. Tom Harvey)

The parental lines, F_1 hybrids and F_2 families derived from diallel crossing of inbred selections of the four parental lines of Georgia hybrid Gahi 1 were planted in a greenhouse screening test to determine the inheritance of resistance or tolerance to the phytotoxin produced during the feeding activity of the greenbug aphid, *Schizaphis graminum* (Rondani). A total of 210 items derived from these crosses were tested in comparison with sorghum checks of known reaction.

Results and Discussion

The 1980 growing season is characterized as being one of the three hottest, driest summers in 113 years of weather record keeping at Hays, Kansas. The 45 day period from late June to August 10 had 24 days with maximum daily ambient air temperatures ranging from 40 to 45° Celsius. The lack of rainfall during June and July and extremely high surface soil temperatures prevented secondary root development of about 80 percent of the materials planted in mid-June. These materials died or became severely stunted upon reaching plant heights of 25 to 50 cm. As the plants reached this size the primary root either could not anchor the plant to the soil

during the windy weather, or it was unable to supply sufficient water for further growth. Materials planted in late May and early June had developed sufficient canopy and soil shading at the base of the plants to allow good secondary and brace root development. Stand losses of these materials due to heat and drought were less than 10 percent. All of the 1980 millet plantings emerged to acceptable stands.

The 1979-1980 fall and winter precipitation was above normal and the fields planted to millet in 1980 had subsoil moisture reserves extending to the four to six foot levels of the soil profile. Extended periods of hot, dry weather also occurred during the 1978 and 1979 growing seasons, and in a manner similar to the fall and winter periods of 1979-1980, above average precipitation before and after the growing seasons of 1978 and 1979 provided good reserves of stored subsoil moisture for the plantings in those years.

1. Population Improvement

Cycle 2 S_1 progeny performance tests of HMP 1700 were planted June 6, thus allowing time for sufficient growth to shade the soil surface during the period of hot weather from late June to mid-August. Stand losses due to heat and drought were less than 10 percent but several S_1 lines were severely stunted by the stress. Yields of the S_1 lines ranged from 190 to 2090 kg/ha. Table 1 gives the average responses of the S_1 lines selected for recombination compared to the performance of the parental population used as checks. Several F_1 hybrids have been made using S_2 selections from the first cycle of improvement as males. These hybrids will be evaluated in 1981.

Selection of S_0 plants to generate S_1 lines in population HMP 550 Cycle 3 S_0 was aided by the severe drought stress. Individual plants selected for self-pollination had good plant development, synchrony of heading, and produced several tillers. Selection at harvest discriminated against plants that had poor seed set, tillers with variable heights, lodged tillers, charcoal stalk rot and poor head exsertion. Approximately 500 plants were harvested and 225 of these will be performance tested in 1981. Several S_2 selections from Cycle 2 have been crossed to PI185642 D_2A_1 lines to determine their fertility reaction and suitability for back-crossing to develop new cytoplasmic male-sterile lines.

The random-mated, mass-selected populations HMP 559 and 1978 Series 2 Composite had differential plant responses to drought stress. Primary heads of about 800 superior plants were harvested in each population. Harvest was delayed until lodging was readily apparent because of weak culms, poor root development and charcoal rot. Series 5 Composite was not planted because a production field of millet was planted too close to the site prepared for it. Alternate sites could not be used because of dry surface soils or lack of isolation.

2. Development of Inbred Lines

The nurseries of F_2 families and early generation inbred materials were planted during the June 14 to 17 period and emerged to excellent

stands. With the continuation of dry weather and high temperatures approximately 80 percent of the materials died upon reaching plant heights of 25 to 50 cm. Heading and anthesis was delayed 10 to 20 days in over 50 percent of the surviving materials. Several F_2 families derived from lines originating in northern Upper Volta had good survival and a relatively large number of segregates with the ability to grow and develop at normal rates. Nearly all of the early-maturing segregates within these families were self-pollinated. Superior segregates and lines were identified within several other groups of materials, but they occurred at much lower frequencies than the rate observed in the Upper Volta materials. Several superior F_4 and F_5 segregates and lines that survived under these conditions have been placed in the greenhouse to be crossed to male-sterile lines. Several hundred crosses were made in an irrigated crossing nursery containing some 500 advanced inbred lines. In this nursery about 10 F_7 to F_{10} inbred lines appeared to have poor plant development as a result of heat stress whereas they had appeared normal in previous years. The male-sterilization backcross nursery was abandoned because of severe heat and drought stress.

Eighty-three lines and selections were obtained from ICRISAT. These included materials from several African countries, Southern Russia, several locations in India, and lines developed by ICRISAT possessing varying levels of seedling drought tolerance. Seventy-two of these lines have been crossed to dwarf, early-maturing lines. Sixty of the 83 lines were able to flower within 85 days of planting and produce mature seed under field conditions. In most crosses the PI185642 and Serere 3A types of early maturity are either dominant or partially dominant and the majority of the F_1's flowered within 75 days. However, there are a few crosses in which these sources of early maturity act as recessive characters and the F_1's required over 100 days to reach anthesis.

P-924-B, a line received from ICRISAT and derived from material collected at an oasis in Niger, reached anthesis in 38 days. The earliest maturing lines previously developed in this program had required 52 to 55 days to reach anthesis. Hybrid combinations of P-924-B and four D_2 dwarf, early-maturing lines had flowering time responses of 58 and 65 days which are similar to the requirements of the dwarf parents. Maturity segregation will be studied in the F_2 generation of these crosses. At this time it appears that this new source of earliness may greatly extend the maturity range available to the breeding program.

3. Production of F_1 Hybrids

Production of F_1 hybrid seeds in five isolated crossing blocks containing 40 to 70 A_1 and A_2 female lines ranged from 50 grams to several kilograms. Several of the male-sterile lines died in two of the blocks planted on fields having silty-clay loam soils but had good survival on silty loam soils. The F_1 hybrid combinations produced in these blocks will be used in combining ability studies, hybrid performance tests, and as sources of seed for agronomic studies.

4. Evaluation of F_1 Hybrids

With the exception of the early June planted unit of the performance test planted at nine locations, all of the experimental F_1 hybrid performance trials and the observation nursery were planted during the June 14 and 17 period. Seedling emergence was excellent in all tests, but the severe drought and heat stress occurring from late June to mid-August caused severe stand losses. None of these tests were harvested, however; several hybrid combinations were identified as having plant stand survival ratings of 50 to 100 percent, good plant development and drought tolerance. Examination of their pedigrees indicate that 12 male-sterile lines and 24 male-fertility restorer lines were each involved in two or more hybrid combinations giving superior performance.

Grain yield results of seven of the nine trials of the F_1 performance test are given in Table 2. Results of two of the tests have not been received at this time. This test contained 23 dwarf (D_2) hybrids from the Hays program, four hybrids from the USDA program in Georgia and three commercial grain sorghum hybrids used as plant height, maturity and yield controls. Kansas locations of the trials are presented in Table 3 as they occur from west to east across the state with Tribune located on the west-central border of the state to the Ashland field at Manhattan, which is located in eastern Kansas. Topographic elevation decreases from 1080 m at Tribune to 310 m at Ashland. Average annual precipitation increases from west to east with Tribune receiving 410 mm and Manhattan, 770 mm. In 1980, the area of the Great Plains affected by the drought extended to western Kansas and eastern Colorado, with Tribune located on the west edge of this area. The Tribune location had fewer hot days, cooler nights, and good seasonal distribution of rainfall, although the amounts received were below normal. All of the other locations were located within the heat and drought affected area and received only 30 percent of the precipitation normally expected.

Grain yield levels as affected by the weather conditions showed a wide variation. Average yields at Tribune were 4039 kg/ha compared to the lowest average yield level of 863 kg/ha at Garden City, (severely drought stricken) which is located only 100 kilometers southeast of Tribune. Several of the locations received large rains in mid-August. Responses of the test entries were variable depending on interactions between planting dates, dates of anthesis and dates of rainfall. At Hays, sorghum hybrid DeKalb F67 had heading delays of up to 20 days and flowered after receiving rain. Acco 1014 flowered early and then produced a flush of secondary heads following the rains. Georgia hybrids 1 and 2 had a large number of secondary tillers that remained dormant until rain was received, and they headed, flowered and set seed late in the stummer. Nearly all of the millet hybrids had at least a few late developing secondary tillers, but within the group of Hays hybrids, reporduction had been completed by the time the rains occurred.

5. Insect Resistance Studies (cooperative work with Dr. Tom Harvey)

A set of F_1 and F_2 progenies derived from diallel crosses of selections from the parental lines of Georgia hybrid Gahi 1 were exposed to

greenbug aphid infestations. Inconclusive results were again obtained because the variability in response to the phytotoxin produced by the greenbug has not been eliminated from the parental lines following one cycle of inbreeding and screening. Consideration is being given to substituting another set of early-maturing inbred materials for the Georgia lines in this study because of the late maturity of the Georgia lines and the difficulties encountered in reproducing these lines and their progenies under field conditions.

In the beginning of this study the Gahi 1 parental lines were selected because it had been reported that hybrid Gahi 1 was resistant to the toxic effects of greenbug feeding activity. When the parental lines were examined, however, it was found that two lines were resistant, one line appeared to be partially resistant, and one line was susceptible; thus, it appeared that these materials would be suitable for this type of study. However, several problems have been encountered in producing good quality seed of these materials because of late maturity. For example, plantings of the four parental lines in 1980 failed to produce mature seed before cold weather. Germination percentages of seeds of the one line that was harvested are less than 20 percent.

6. Seed Requests and Distribution

Seeds of several populations, inbred lines, and F_1 hybrids were given to several workers for their use and evaluation in the states of Arizona, Colorado, Nebraska, and Texas during the period of 1978 and 1980. Requests have been received for several items from workers in the LDC's and seeds were sent to them either during the contract period (AID/ta-C-1458) or soon after the expiration of the contract. Following is a list of the workers and the numbers of items provided:

Dr. Shadrack Okiror	ICRISAT	Kano, Nigeria	4	1978
Dr. D. J. Andrews Dr. C. Francis	ICRISAT	Univ. of Neb. Univ. of Neb.	8	1979
Dr. D. J. Andrews	ICRISAT	Hyderabad, India	50	1981
Dr. R. P. Jain	ICRISAT	Wad Medani, Sudan	54	1981
Dr. Keith Byergo	(seeds forwarded to Mauritania)		7	1981

Table 1. Combined results of the HMP 1700 Cycle 2 S_1 Progeny performance test, Hays, Kansas, 1980. 1/

Kind	Plant stand score 0-9 2/	Visual appearance score 1-9 3/	Lodging score 0-9 4/	Plant height cm	Head exsertion cm	Test weight kg/hl	Crude protein %	Grain yield kg/ha
Averages of 28 HMP 1700 Cycle 2 S_1 lines selected for recombination	7.0	4.1	2.1	81	2	77	16.1	1641
HMP 1700 Cycle 2 S_0	6.0	5.7	2.0	71	1	76	16.2	775
HMP 1700 Cycle 1 S_0	4.3	5.7	2.1	69	0	75	17.1	745
HMP 1700 1976 mass-selected bulk	4.3	6.3	1.1	71	1	76	16.4	622
Average of all entries	5.9	5.0	2.4	80	1	76	16.0	1035

1/ Results are averages of three tests containing a total of 225 S_1 lines.

2/ Plant score: 0 = no plants to 9 = 100% stand.

3/ Visual appearance score: 1 to 3 = good, 4 to 6 = fair, 7 to 9 = poor.

4/ Lodging score: 0 = no lodging to 9 = 90-100% lodged.

Table 2 Grain yields (kg/ha) of dwarf (D_2) pearl millet hybrids planted at seven locations, 1980.

	Tribune		Garden City		Minneola		St. John		Hays		Ashland		Lubbock		Seven test average	
	Yield	Rank	Yield	Rank	Yield	Rank	Yield	Rank	Yield	Rank	Yield	Rank	Yield	Rank	Yield	Rank
Sorghum																
Acco 1014	4541	9	955	10	2519	9	818	30	3209	2	2050	15	1948	4	2291	5
Pioneer 8324	5576	1	2376	1	3672	1	1568	11	4008	1	3083	1	2252	2	3219	1
DeKalb F67	3565	23	703	19	3380	2	1945	1	3093	3	2275	13	3248	1	2601	2
Hays pearl millet																
79-2017/78-7024	3910	16	1169	2	2662	5	1713	6	1906	21	1626	25	1693	10	2097	13
2042/78-7024	4554	8	683	21	1854	25	1562	12	2557	6	1662	23	1347	26	2031	19
2055/78-7024	3783	18	987	9	2092	20	1123	29	1925	20	2562	5	1853	5	2046	18
2059/78-7024	4580	7	951	11	2222	18	1752	4	2071	16	1735	22	1240	27	2079	16
2148/78-7024	4161	13	637	23	2615	6	1914	2	2007	18	2282	12	1730	9	2192	9
2157/78-7024	3732	19	1159	3	2555	8	1656	8	1882	23	2300	10	1522	16	2115	10
2159/78-7024	4908	4	1073	5	2598	7	1203	28	2556	6	1474	27	1544	15	2194	8
2161/78-7024	3541	24	710	18	2910	3	1517	15	1886	22	827	30	1352	25	1820	25
2216/78-7024	3542	24	721	17	2308	16	1541	14	2050	17	1080	28	1666	12	1844	23
2221/78-7024	3958	15	1071	5	2004	23	1437	17	2244	11	1640	24	1673	11	2004	20
2201/78-7024	3850	17	885	13	2423	13	1562	12	2125	12	2027	16	1778	6	2093	14
2208/78-7024	3515	26	843	15	1799	26	1290	24	2277	10	2591	4	1363	24	1954	22
79-2017/79-4104	2966	28	880	14	1667	27	1311	23	1580	27	1796	20	1512	18	1673	29
2042/79-4104	4647	6	686	20	2158	19	1518	15	2096	14	1903	17	1474	21	2069	17
2055/79-4104	4737	5	631	24	2279	17	1435	17	1661	26	2562	5	1491	20	2114	11
2059/79-4104	4415	12	564	27	2412	14	1624	10	2125	12	2455	9	1166	28	2109	12
2148/79-4104	5424	2	935	12	2480	10	1332	22	2267	9	2817	3	1421	22	2382	3
2157/79-4104	4150	14	1073	5	2073	22	1725	5	1561	28	1799	20	1512	18	1985	21
2161/79-4104	3684	21	1000	8	2443	11	1705	7	2346	8	2471	8	1981	3	2233	6
2216/79-4104	3634	22	543	28	2711	4	1788	3	1820	24	2549	7	1522	16	2081	15
2221/79-4104	5211	3	648	22	2406	15	1249	27	1957	19	2289	11	1751	7	2216	7
2201/79-4104	2985	27	1081	4	2087	21	1435	15	1498	29	2079	14	1613	14	1825	24
2208/79-4104	2708	29	619	25	1358	30	1263	26	1265	30	1574	26	1102	30	1413	30
Georgia pearl millet																
1 T23DAE/653 & 653	2260	30	473	29	1634	28	1349	21	2634	5	1871	18	1640	13	1694	28
2 T23DAE/656 & 653	4489	10	834	16	2434	12	1659	8	2970	4	2875	2	1416	23	2382	3
3 T23DAE/756 & 756	4437	11	605	26	1400	29	1378	20	1699	25	1078	28	1735	8	1762	26
8 "/756/2/656&653	3707	20	391	30	1902	24	1287	24	2080	15	1801	19	1108	29	1754	27
Location Average	4039		863		2302		1489		2178		2038		1622		2076	
LSD .05	1931		572		767		619		1018		1295		703			

Yield Evaluations of Pearl Millet

(*Pennisetum americanum* (L.) Leeke)

H.A. Praeger Jr., R. L. Vanderlip and W. D. Stegmeier

Field trials of pearl millet were planted at six locations in Kansas. There were at the Tribune Experiment Station, Tribune, Kansas; Garden City Experiment Station, Garden City, Kansas; Southwest Kansas Experiment Field, Minneola, Kansas; Sandyland Experiment Field, St. John, Kansas; Ft. Hays Branch Experiment Station, Hays, Kansas and Ashland Experiment Field, Manhattan, Kansas. This was a continuation of yield trials of the two previous years. As in previous years, the highest yielding pearl millet hybrids were comparable to hybrid grain sorghum of the same maturity.

Materials and Methods

The trials were organized to include three hybrid grain sorghums, one early maturity; one of midseason maturity and one late season maturity. Five of the pearl millet hybrids were developed by Dr. Glenn Burton, USDA, SEA, Coastal Plains Experiment Station, Tifton, GA. The other pearl millet hybrids were developed by William D. Stegmeier, Ft. Hays Branch Experiment Station, Hays, Kansas. The entries were planted in two row plots 10 m long. Row spacing was 75 cm with seeded depth of 2.5 cm. Rate of planting was 13 seeds per meter. The experiment was a randomized complete block design with three replications. From each plot the best 5 meters of each row was harvested. Data obtained was grain weight (adjusted to 12.5% moisture) and number of heads.

Results and Discussion

Results of the hybrid yield studies and the number of heads are shown in Tables 1 and 2.

At all locations the pearl millet entries matured prior too or at the same time as the early maturity grain sorghum hybrid. It is considered that any comparisons that can be made should be with material that matures within a similar growing season. During this growing season the temperature was above normal from 1 July until mid August with no measurable precipitation. Some locations then received rain with the late fall frost the later maturing grain sorghums produced grain. The grain filling period for the later maturing grain sorghum occurred after the pearl millet had reached physiological maturity.

At all locations the higher yielding pearl millet hybrids were not significantly different than grain sorghum hybrids of similar maturity. The pearl millet entries did perform admirably in comparison to grain sorghum, and these results are encouraging.

In addition to these yield trials and to define geographical area of adaptation, pearl millet was grown at the Colby Branch Experiment

Station, Colby, Kansas (northwest) and at the Southeast Kansas Experiment Station, Parsons, Kansas. The researchers are enthused with the preliminary results and have requested to be included in the complete trials as seed becomes available. Another planting was at the Meade Experiment Field, Lincoln, Nebraska. These plots matured and produced grain. This field is located at 41° North latitute and is farther north than any recorded planting of pearl millet.

Literature Cited

Palmer, J. C., H. A. Praeger, Jr., and W. D. Stegmeier. 1978. Yield and heterosis studies of pearl millet (*Pennisetum americanum* (L.) K. Schum). First Annual Report, Improvement of Pearl Millet, Contract AID/ta-C-1458.

_____, R. L. Vanderlip, and W. D. Stegmeier. 1979. Yield evaluations of pearl millet (*Pennisetum americanum* (L.) Leeke). Second Annual Report, Improvement of Pearl Millet, Contract AID/ta-C-1458.

Table 1. 1980 Pearl Millet Comparison Yield, kg/ha.

Entry	Yield, kg/ha					
	Tribune	St.John	Ashland	Minneola	Garden City	Hays
ACCO 1014	4541	818	2050	2519	955	2634
Pioneer 8324	5576	1568	3083	3672	2376	2970
DeKalb F67	3565	1945	2275	3380	703	1699
79-2148 x 79-4104	5424	1332	2817	2480	935	2007
23DAE x 656+653	4489	1659	2875	2434	834	3209
79-2221 x 79-4104	5211	1249	2289	2406	648	1925
79-2055 x 79-4104	4737	1435	2562	2279	631	1561
79-2148 x 78-7024	4161	1914	2282	2615	637	1580
79-2059 x 79-4104	4415	1624	2455	2412	564	2267
79-2157 x 78-7024	3732	1656	2300	2555	1159	1906
79-2161 x 79-4104	3684	1705	2471	2443	1000	2071
79-2159 x 78-7024	4908	1203	1474	2598	1073	2891
79-2059 x 78-7024	4580	1752	1735	2222	951	2095
79-2216 x 79-4104	3634	1788	2549	2711	543	1925
79-2017 x 78-7024	3910	1713	1626	2662	1169	1265
79-2042 x 79-4104	4647	1518	1903	2158	686	1882
79-2157 x 79-4104	4150	1725	1799	2073	1073	2125
79-2201 x 78-7024	3850	1562	2027	2423	885	1820
79-2055 x 78-7024	3783	1123	2562	2092	987	1497
79-2042 x 78-7024	4554	1562	1662	1854	683	2277
79-2208 x 78-7024	3515	1290	2591	1799	843	1886
79-2201 x 79-4104	2985	1435	2079	2087	1081	2080
79-2161 x 78-7024	3541	1517	827	2910	710	1986
79-2216 x 78-7024	3542	1541	1080	2308	721	1957
(23DAE x 756)x656+653	3707	1287	1801	1902	391	3093
23DAE x R83D28	--	1676	1806	--	--	--
79-2017 x 79-4104	2966	1311	1796	1667	880	2346
79-2221 x 78-7024	3958	1437	1640	2004	1071	2050
23DAE x 756 + 756	4437	1378	1078	1400	605	4008
Senegal Bulk Hybrid	--	1888	1317	--	--	--
23DAE x 653 + 653	2260	1349	1871	1634	473	2072
79-2208 x 79-4104	2708	1263	1574	1358	619	2557
LSD .05	1931	619	1295	767	572	1002

Table 2. 1980 Pearl Millet Comparison, 1000 heads/ha

Entry	Tribune	St.John	Ashland	Minneola	Garden City	Hays
ACCO 1014	165.2	144.7	146.5	105.6	85.5	247.2
Pioneer 8324	---	143.9	167.6	111.3	114.5	312.0
DeKalb F67	---	113.9	170.8	102.2	92.6	303.3
79-2148 x 79-4104	345.6	372.4	180.6	166.5	107.8	190.8
23DAE x 656+653	384.7	378.2	293.6	196.9	136.3	109.9
79-2221 x 79-4104	282.6	305.6	169.5	157.0	76.5	207.3
79-2055 x 79-4104	297.9	400.8	203.9	176.9	91.3	175.7
79-2148 x 78-7024	268.8	493.0	155.8	155.9	97.8	197.6
79-2059 x 79-4104	261.4	377.3	204.3	178.5	111.1	212.4
79-2157 x 78-7024	162.4	443.9	167.4	136.0	110.0	244.4
79-2161 x 79-4104	239.6	452.1	168.4	155.2	75.2	196.5
79-2159 x 78-7024	301.4	293.0	151.3	143.5	108.5	239.0
79-2059 x 78-7024	262.7	436.5	195.6	124.3	71.7	194.2
79-2216 x 79-4104	283.0	416.5	156.7	169.3	126.5	219.1
79-2017 x 78-7024	321.6	544.9	190.4	149.5	74.2	240.3
79-2042 x 79-4104	318.2	384.7	158.7	167.0	107.4	189.5
79-2157 x 79-4104	289.9	360.4	147.4	156.9	111.3	194.2
79-2201 x 78-7024	277.8	466.9	195.3	139.5	120.9	201.7
79-2055 x 78-7024	279.9	377.3	220.0	158.2	131.0	179.1
79-2042 x 78-7024	255.5	322.3	122.6	108.2	133.3	260.5
79-2208 x 78-7024	291.2	403.0	302.1	197.5	106.1	208.7
79-2201 x 79-4104	177.4	396.0	197.4	141.3	94.7	224.3
79-2161 x 78-7024	283.9	431.7	196.9	159.0	100.0	189.0
79-2216 x 78-7024	232.4	405.6	170.8	134.3	98.0	214.0
(23DAEx756)x656+653	426.4	369.9	288.9	185.7	123.9	118.2
23DAE x R83D28	---	284.8	246.4	---	---	---
79-2017 x 79-4104	228.3	304.7	176.1	144.3	90.9	215.5
79-2221 x 78-7024	259.8	340.8	200.2	131.3	79.5	192.7
23DAE x 756+756	381.8	220.0	227.7	179.8	65.6	97.5
Senegal Bulk Hybrid	---	305.2	174.8	---	---	---
23DAE x 653+653	159.9	296.9	169.5	147.8	65.9	247.5
79-2208 x 79-4104	395.9	420.8	219.1	163.0	82.2	222.5
LSD .05	149	167	61	51	71	57

Objective 2. "Determine factors related to and genetic variability in seed and seedling vigor, water use, drought resistance, and herbicide susceptibility of pearl millet."

Effect of Crop Management on Seed Quality, Subsequent Seedling Establishment and Grain Yield of Pearl Millet

Julius Okonkwo and R. L. Vanderlip

Pearl millet, Pennisetum americanum (L.) Leeke, is a major food crop of the semi-arid areas of Africa and Asia. The crop has problems of poor seed vigor and establishment which also affect the grain yield (3,6). These problems have necessitated a search for good production management to improve seed quality.

Characteristics of seed quality we attempted to improve were seed size, density, and protein content. Studies have shown a close positive relationship between seed size, vigor and grain yield (2,4,5,9), also between seed density and grain yield (2,5). Ries et al. (7) reported that seed protein was positively related to seed size, vigor and grain yields.

Application of nitrogen fertilizers was reported to increase seed protein (1,7,8). Little work has been done on the effect of tiller removal on seed size and density. Although such treatment may reduce grain yield, it was thought that by directing the photosynthates to the main head only, seed size and density could be improved. Hill planting is widely practiced in Africa as an insurance against drought and low seed germination. We thought that shaving part of millet head could allow the remaining developing seeds more space to expand.

The objects of this study were: (1) to determine the effect of some production management factors on millet seed quality, (2) to see if the management effects on seed quality also affected seedling establishment and grain yield of the subsequent crop.

This report is on the first phase of the study.

Materials and Methods

We studied the effects of removing tillers, removing 1/3 of the florets from the head, hill planting, and nitrogen application on seed size, density, and protein content in 1980 at the Sandyland Experiment Field, St. John. Senegal population was planted under dryland and irrigated conditions and Serere 3A under dryland only. Plant populations were 47,860 and 43,500 plants/ha for the irrigated and dryland locations, respectively. To obtain pure seeds, each variety was grown in isolation.

Tillers were removed once a week until plants reached maturity. Florets were removed from 1/3 of the head from the top, and on one side to the base as the head emerged from the flag leaf. We applied ammonium nitrate at 120 and 80 kg N/ha for the irrigated and dryland locations, respectively, at the heading stage. Eight seeds were hill planted at 60 and 40 centimeters for the dryland and irrigated locations, respectively, then thinned down to four plants/hill. Treatments were replicated four times.

A 50 gram seed sample produced from each treatment was separated into different sizes, using 8/64, 7/64, 6/64, 5½/64, 4½/64, and 2½/64 inch sieves, then calculated the average seed diameter. We obtained seed volume by placing the same 50 gram seed sample in graduate cylinder containing 40 milliliters of water stirred to eliminate air bubbles, then read the rise of water. Density was calculated from volume and weight. Protein was estimated by macro-Kjeldahl procedure with a conversion factor of 6.25.

Results and Discussion

Analysis of variance for Senegal population showed that seed density, average seed diameter, protein content and weight per 1000 seed were significantly affected by the treatments under both dryland and irrigated conditions. Average seed diameter and protein content for Serere 3A also were affected; seed density and weight/1000 seeds were not. In addition to bird damage, the hot dry summer of 1980 adversely affected this variety. Duncan's multiple range test showed that nitrogen application and shaving of millet head consistently improved seed protein and size, respectively (Table 1). Higher seed densities were obtained from the control and hill planting indicating that tiller removal and shaving of the head under the prevailing hot and dry summer may have interfered with the translocation of the photosynthates to the seeds. Senegal population produced heavier seeds under irrigation but the effects of the treatments were the same for other variables under dryland and irrigated conditions (Table 1).

Our results agree with previous studies which showed increased in seed protein when nitrogen fertilizer was applied (1,7). Shaving of millet heads reduced the number of seeds for the photosynthates to accumulate in and allowed more space for the seeds to expand. Our results also support this hypothesis (Table 1).

Literature Cited

1. Deosthate, Y. A., K. Visweswar Rao and K. C. Pant. 1972. Influence of levels of N fertilizer on the yield, protein and amino acids of pearl millet. Indian J. Agric. Sci. 42(10):872-876.

2. Gardner, J. 1980. Effect of seed size and density on field emergence and yield of pearl millet. Master's thesis. Kansas State University.

3. Craig, D. K., M. L. Kaul, and S. P. Singh. 1973. Correlations among seed characteristics of 41 varieties of pearl millet. Indian J. Agric. Sci. 43(1):21-24.

4. Kiesselbach, T. A. 1924. Relations of seed size to the yield of small grains. Agron. J. 16:670-682.

5. Maranville, J. W. and M. D. Clegg. 1977. Influence of seed size and density on germination, seedling emergence and yield in grain sorghum. Agron. J. 69:329-330.

6. Mwageni, A. J. 1978. Seed vigor measurements and their use in predicting field establishment of grain pearl millet. Master's thesis. Kansas State University.

7. Ries, S. K., O. Moreno, W. F. Meggitt, C. J. Schweizer, and S. A. Ashkar. 1970. Wheat seed protein: Chemical influence on the relationship to subsequent growth and yield in Michigan and Mexico. Agron. J. 62:746-748.

8. Shah, H. C. and B. V. Mehta. 1959. Comparative studies of effect of ammonium chloride and other fertilizers on yield and protein content of pearl millet. Indian J. Agron. 41:105-113.

9. Smith. T. J. and H. M. Camper. 1975. Effects of seed size on soybean performance. Agron. J. 67:681-684.

Table 1. Duncan's multiple range test for weight/1000 seeds, average seed diameter, density and protein content as affected by management.

Treatment No.	Wt/1000 seeds	Avg. seed Diameter	Density	Protein
		Senegal Population, Dryland		
1	8.38 b*	5.12 b	1.24 a	10.09 c
2	8.38 b	4.99 b	1.23 bc	9.69 c
3	9.18 a	5.47 a	1.22 c	10.71 b
4	8.53 b	5.23 ab	1.24 ab	12.57 a
5	9.18 a	5.42 a	1.23 bc	9.63 c
		Senegal Population, Irrigated		
1	9.60 c	5.32 b	1.24 ab	9.81 c
2	10.32 b	5.55 ab	1.23 bc	10.40 b
3	10.80 a	5.72 a	1.22 c	10.44 b
4	10.08 b	5.20 b	1.22 c	12.72 a
5	9.58 c	5.29 b	1.24 a	9.42 c
		Serere 3A, Dryland		
1	11.98 b	6.04 b	1.24 a	8.99 c
2	12.33 ab	6.12 b	1.24 a	10.07 b
3	12.88 a	6.29 a	1.24 a	9.75 b
4	12.33 b	6.15 b	1.23 a	11.61 a
5	---	---	---	---

Treatment

1 Control
2 Tiller removal
3 Head shaving
4 Nitrogen fertilizer application
5 Hill planting

*Means with the same letter are not significantly different.

Soil Water, Plant Water and Temperature Relation of Millet (*Pennisetum americanum* (L.) Leeke) and Their Relationship to Crop Yields

Piara Singh and E. T. Kanemasu

Pearl millet is believed to be one of the most drought resistant cereals. It is extensively grown in arid and semi-arid parts of the world. Unfortunately, there is not sufficient work, particularly on its drought resistance characteristics and the manner of its response to water stress, to draw any reliable conclusions (Rachie and Majmudar, 1980). Four early maturing genotypes (HMP600, HMP1700, Serere-3A, and HMP550), two late maturing genotypes (Senegal bulk and HMP559) and four hybrids (2221 x 7024, 2221 x 4104, 2094 x 4104, and 2094 x 7024) were grown both under irrigation and no-irrigation conditions in a split-plot experiment to study their soil - plant - water relations, and canopy temperatures and their relationships to crop yields.

This study indicates that a plant type with (1) short to intermediate height, (2) minimum reduction in number of mature tillers, and (3) maximum soil-water depletion under stress, would be most drought resistant.

Method and Materials

Millet was planted on May 22, 1980 at Evapotranspiration Site, Ashland Agronomy Farm, Manhattan (KS). The experiment was a split-plot having three replications and arranged in a randomized complete block design. Two main treatments were irrigation and no-irrigation (rainfed) each divided in to ten 20' x 30' plots to which ten genotypes were randomly assigned. Total number of sub-plots thus amounted to 60. Planting was done with a two-row planter in 76 cm wide rows. Plants were later thinned 10 cm apart within a row. Each plot had 8 rows. Irrigated plots received total 3719 cm of water in six irrigations applied at weekly intervals starting July 1. Total rainfall received during the crop growth period was 15.6 cm.

Four early maturing genotypes (HMP600, HMP1700, Sarere-3A, and HMP550), 2 late maturing genotypes (Senegal bulk and HMP559) and 4 hybrids 2221 x 7024, 2221 x 4104, 2094 x 4104, and 2094 x 7024) were studied in this experiment. Various morphological characteristics of these genotypes are presented in Table 1. Genotypes differed, within a maturity gruop, in plant height and maximum leaf area attained.

Observations were taken on water use, xylem water potentials, leaf and stem osmotic potentials, leaf diffusion resistance and canopy temperatures. Neutron probe access tubes were installed within a row in each plot to monitor changes in soil water. Soil moisture observations were taken every other week in each plot from 15 to 165 profile depth at every 15 cm depth increment. Soil moisture of 0 to 15 cm layer was determined gravimetrically. Xylem water potentials were determined with a pressure chamber. Two leaf samples were taken from each plot and then enclosed in a plastic bag and transported to a nearby temperature controlled room, and xylem water

potential determined. To determine osmotic potentials, leaf and stem samples were enclosed in plastic disposable syringes and frozen over dry ice. Later the samples were thawed and squeezed to release cell contents. Osmotic potentials were determined with a C52 psychrometer (Wescor Sample Chamber).

Leaf diffusion resistance (LDR) was determined with a steady state porometer (Model LI 1600, LI-COR, Inc.). Two leaves were sampled from each plot and observation was taken on both abaxial and adaxial surface of a leaf. Average leaf diffusion resistance for leaf was determined from the following relationship:

$$\text{Average LDR} = \frac{(\text{Abaxial LDR})\ \ (\text{Adaxial LDR})}{\text{Abaxial LDR} + \text{Adaxial LDR}}$$

Canopy temperature and canopy - air temperature differentials were taken with an infrared therometer (Teletemp Model 44). These observations were taken both in the morning and afternoon on clear and warm days. Canopy and canopy-air temperatures were summed over the crop growth period, separately for morning and afternoon hours, to calculate average and cumulative canopy and canopy-air temperature for a given genotype.

Crop was harvested during the second and third week of August as the genotypes matured.

RESULTS

Growth stages: Growth stages of different genotypes under irrigation and no-irrigation are presented in Table 2. There was no significant difference between irrigation and no-irrigation treatment in number of days taken by a genotype to reach half bloom stage. Some genotypes under no-irrigation reached physiological maturity about a week earlier. Early maturing genotypes including hybrids took 46 to 52 days to half bloom and 76 to 84 to physiological maturity. There was a uncertainty in pinpointing the hard dough and physiological maturity stage of some genotypes because of rain during those stages.

Grain, stover and total yields: Millet crop experienced a very high moisture and temperature stress this season. About 50 to 60% reduction in grain and total biomass yield was observed in different genotypes (Table 3). Under irrigation hybrids produced more grain and stover yields as compared to early and late maturing genotypes but their yields were drastically reduced under no-irrigation. Hybrids reduced their grain and stover yields by 50 to 70% under no-irrigation. Early maturing genotypes, on the other hand, produced less grain and stover yield under irrigation but, in general, a higher grain yield under no-irrigation as compared with hybrids. About 30 to 50% reduction in their grain yields was noticed under stress (Table 3). Total yield reductions ranged from 35 to 46%. Short stature genotypes (whether hybrid, population, or a variety) which produced higher grain yields under irrigation had higher grain yield reductions under no-irrigation. All the tall genotypes namely Serere-3A, HMP559 and 2221 x 4104 produced less grain yield both under irrigation and no-irrigation. They reduced their

yields relatively to a lesser degree under no-irrigation. But absolute yields of short genotypes were higher under no-irrigation.

Yield Components: Significant reduction in number of heads per m^2 under no-irrigation was observed in all genotypes which varied from 47 to 58% in early maturing genotypes, 13 to 50% in late maturing genotypes, and 42 to 66% in hybrids (Table 4). Reduction in number of heads was highly correlated with their respective yield reductions. Genotypes having high yield reduction had high reduction in number of heads under no-irrigation. Thus, head number may be an index of drought resistance. Reduction in grain weight per ear head was non-significant. Similar results were obtained on 500-seed weight under no-irrigation (Table 4).

Water Use: Total water use by various genotypes ranged from 50 to 64 cm and 20 to 42 cm under irrigation and no-irrigation, respectively. In general, late maturing genotypes used more water both under irrigation and no-irrigation because of their longer active growing season (Table 5).

Significant differences were also observed among genotypes in their subsoil (60 - 165 cm) water use. Subsoil water use under irrigation was much less than under no-irrigation. This may be due to suppression of root growth into deeper soil layers under irrigation. Water use both under irrigation and no-irrigation was highly correlated to crop yields. Genotypes with low yield under no-irrigation or those with high yield reductions had either low total water use or low water use from the subsoil. Similar trends were obtained in crop yield under irrigation.

Water depletion patterns: Distinct differences were observed in water depletion patterns among genotypes both under irrigated and non-irrigated conditions. In general, the genotypes that yielded high depleted soil water from the entire depth of soil profile and to a greater extent than the low yielding genotypes.

Water use efficiency: In general, water use efficiency (yield/water used) for grain yield was reduced under no-irrigation (Table 5). Among genotypes, WUE varied from 20 to 81 kg/ha.cm under irrigation and from 31 to 62 kg/ha.cm under no-irrigation. Similarly, WUE for total above ground biomass also decreased under no-irrigation. It varied from 269 to 484 kg/ha.cm and 263 to 620 kg/ha.cm under irrigation and no-irrigation, respectively.

Leaf diffusion resistance: Significant genotypic differences in leaf diffusion resistance were observed among genotypes under irrigation and no-irrigation. In general tall genotypes namely Serere-3A and HMP 550 showed higher leaf diffusion resistance both under irrigation and no-irrigation as compared to other genotypes (Fig. 1). This may indicate that tall genotypes were stressed even under irrigation in 1980 dry and hot season. It appears that leaf diffusion resistance is correlated to amount of soil water depletion. The higher the leaf diffusion resistance, the lower the soil water depletion except in case of HMP559 which used more water under irrigation but had higher stomatal resistance as compared to Senegal Bulk. Cumulative afternoon leaf diffusion resistance - which is

defined as the leaf diffusion resistance observed between 12:00 to 17:00 hours and summed over the season was inversely related to crop yield (Fig. 1). Serere 3A, HMP559, 2221 x 7024, and 2094 x 7024 had high cumulative leaf diffusion resistance and yielded low under no-irrigation.

The relative leaf diffusion resistance, which is further defined as the ratio of cumulative afternoon leaf diffusion resistance under no irrigation for a given genotype to its cumulative afternoon resistance under irrigation, was also directly related to the percent reduction in grain and total yields under rainfed treatments (Fig. 2).

Leaf xylem water potential: Average values of beforenoon (am) and afternoon (pm) xylem water potentials for various genotypes are presented in Table 6. Beforenoon xylem water potentials among genotypes ranged from -13.8 to -16.4 bars in irrigated plots. These potentials decreased in the afternoon and ranged from -21.8 to -25.2 bars. There was nearly a 2 to 3 bar difference among genotypes in their xylem water potentials. Afternoon xylem water potentials were directly related to the yields under irrigation for a given genotype. Genotypes with low afternoon water potentials yielded low.

Under no-irrigation xylem water potential of genotypes were lower by about 3 bars and 5 bars for the beforenoon and afternoon values, respectively, as compared to irrigation treatment. Differences among genotypes were only about 1 bar. Under no-irrigation, xylem water potentials were not strongly correlated to crop yields.

Leaf and stem osmotic potentials: Plant leaves had lower osmotic potentials than those for stems (Table 7), and in general, osmotic potentials decreased by 2 to 3 bars as the stress increased on plants in the afternoon. Osmotic potentials were generally lower for the no-irrigation treatments compared to irrigated treatments.

Leaf osmotic potentials were not related to crop yields under stress. But stem osmotic potentials under rainfed treatment showed some relationship to percent yield reduction. Genotypes with lower stem osmotic potential had higher yield reductions and vice-versa.

Canopy temperatures: Afternoon canopy temperatures averaged over the season for various genotypes are presented in Fig. 3. There was only 3 to 4°C difference in canopy temperatures between irrigated and rainfed plots. Canopy temperature differences between genotypes were even less, therefore, canopy temperature is difficult to correlate to their crop yield or yield reductions. Afternoon canopy-air temperature cumulated over the crop growth period were, however, correlated to the crop yields and leaf diffusion resistance under no irrigation (Fig. 4). Genotypes having low yields under no-irrigation, in general, had less negative value of canopy-air temperature. Also genotypes having high leaf diffusion resistance had less negative value of canopy-air temperatures. (Fig. 4).

Difference between rainfed canopy temperature and irrigated canopy temperature summed over the crop growth period for a given genotype also showed relationship to percent reduction in crop yields under stress. These differences were more for HMP1700, Senegal Bulk and hybrid 2094 x 7024

(Fig. 5) which had higher reductions in both grain and total yields.

Summary and Conclusions

Four early maturing genotypes (HMP600, HMP1700, Serere-3A, and HMP550), two late maturing genotypes (Senegal bulk and HMP559) and four hybrids (2221 x 7024, 2221 x 4104, 2094 x 4104, and 2094 x 7024) were grown both under irrigation and no-irrigation conditions in a split-plot experiment to study their soil - plant - water relations, and canopy temperatures and their relationships to crop yields. In general, 50 to 60 percent reductions in grain and total dry matter yields were observed under no-irrigation than under irrigation treatment. High yielding genotypes had the maximum percent yield reduction under no-irrigation treatment as compared to low yielding genotypes. Reduction in crop yields of genotypes under no-irrigation was strongly related to number of ear heads produced of mature tillers.

Genotypes differed significantly in their total water use and profile soil water depletion under both irrigation and no-irrigation. Total water use was strongly correlated to yield performance under stress.

Tall genotypes were apparently stressed more than short genotypes as indicated by the cumulative leaf diffusion resistance. Genotypes having high cumulative leaf diffusion resistance yielded less under no-irrigation and had greater percent yield reduction.

There was only 2 to 3 bar difference among genotypes in their average afternoon xylem water potential under irrigation treatment, and this difference was even less under no-irrigation. Xylem water potentials were not strongly related to crop yields under stress.

No distinct differences in leaf osmotic potentials were observed among genotypes both under irrigation and no-irrigation. Stem osmotic potentials were higher than leaf osmotic potentials.

Afternoon average canopy temperatures of genotypes under no-irrigation were 3 to 4°C more than those under irrigation. Differences in canopy temperature among genotypes were small both for irrigation and no-irrigation treatments. However, afternoon canopy-air temperatures summed over the crop growth period of a given genotype showed a relationship to percent yield reductions.

This study indicates that a plant type with (1) short to intermediate height, (2) minimum reduction in number of mature tillers, and (3) maximum soil-water depletion under stress, would be most drought resistant.

Among several indices of drought resistance considered in this study for screening plant genotypes, percent reduction in number of mature tillers or heads, water use and profile water depletion, cumulative leaf diffusion resistance and cumulative afternoon canopy-air temperature under stress were significantly correlated to crop yields and percent yield reduction. On the other hand, xylem water potential, leaf and stem osmotic

potentials, relative canopy temperatures and canopy temperatures *per se* of genotypes were weakly related to their crop yields.

Literature Cited

Rachie, K. O., and J. V. Majmudar (1980). Pearl Millet. The Pennsylvania State University Press, University Park and London.

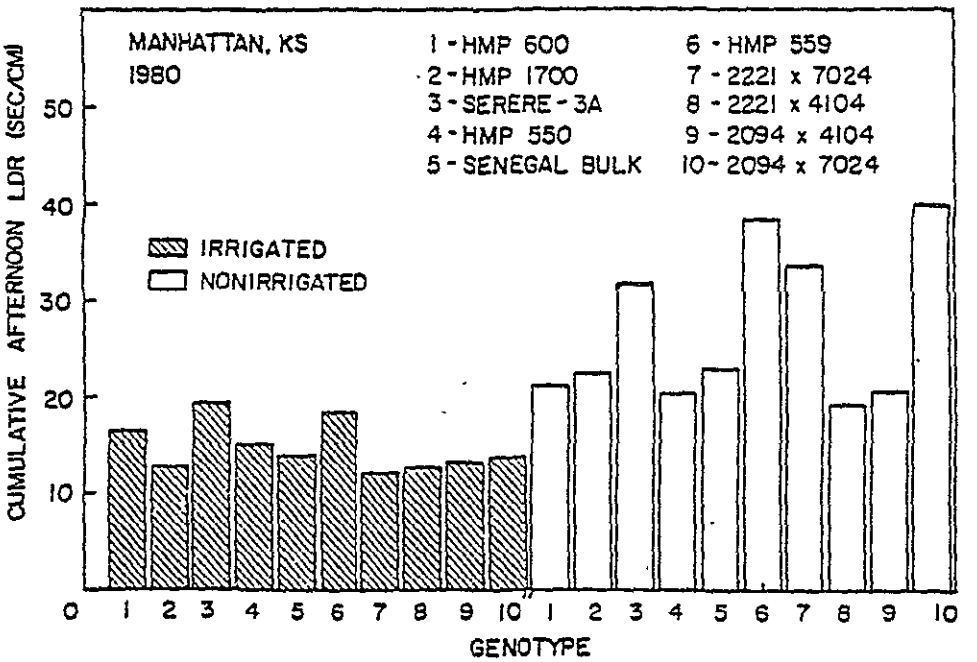


Fig. 1 Cumulative afternoon leaf diffusion resistance (LDR) of various genotypes under irrigated and nonirrigated treatment.

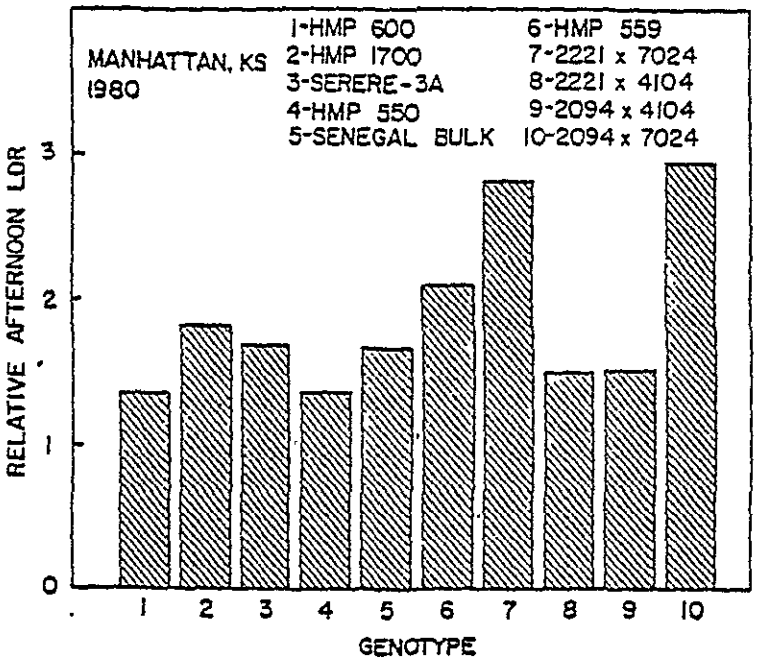


Fig. 2 Relative afternoon leaf diffusion resistance (LDR) of various genotypes.

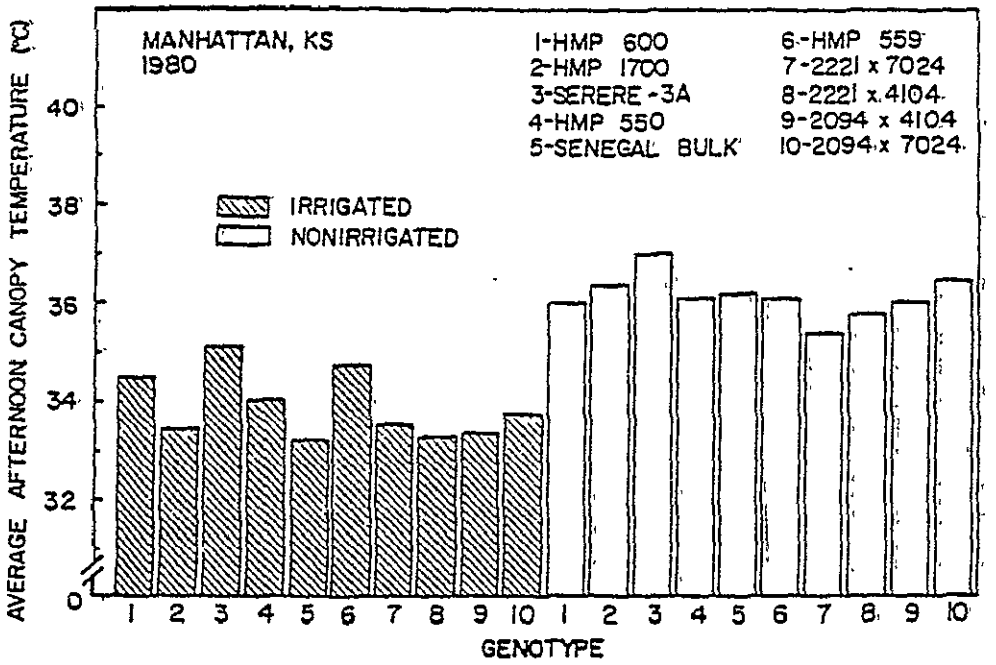


Fig. 3 Average afternoon canopy temperature of various genotypes under irrigated and nonirrigated treatment.

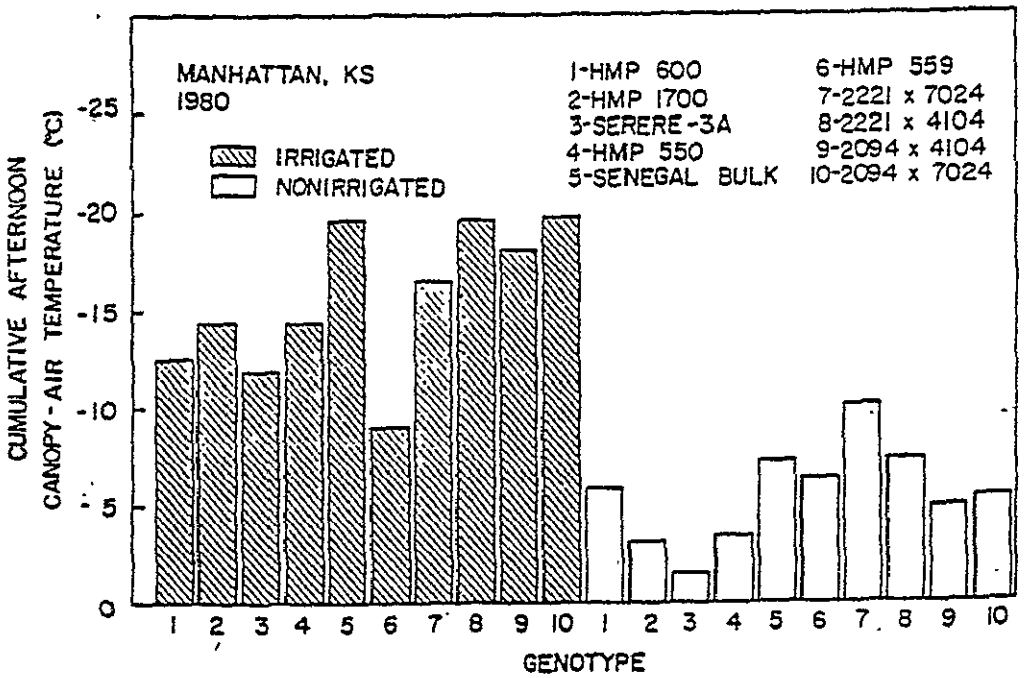


Fig. 4 Cumulative afternoon canopy-air temperature of various genotypes under irrigated and nonirrigated treatment.

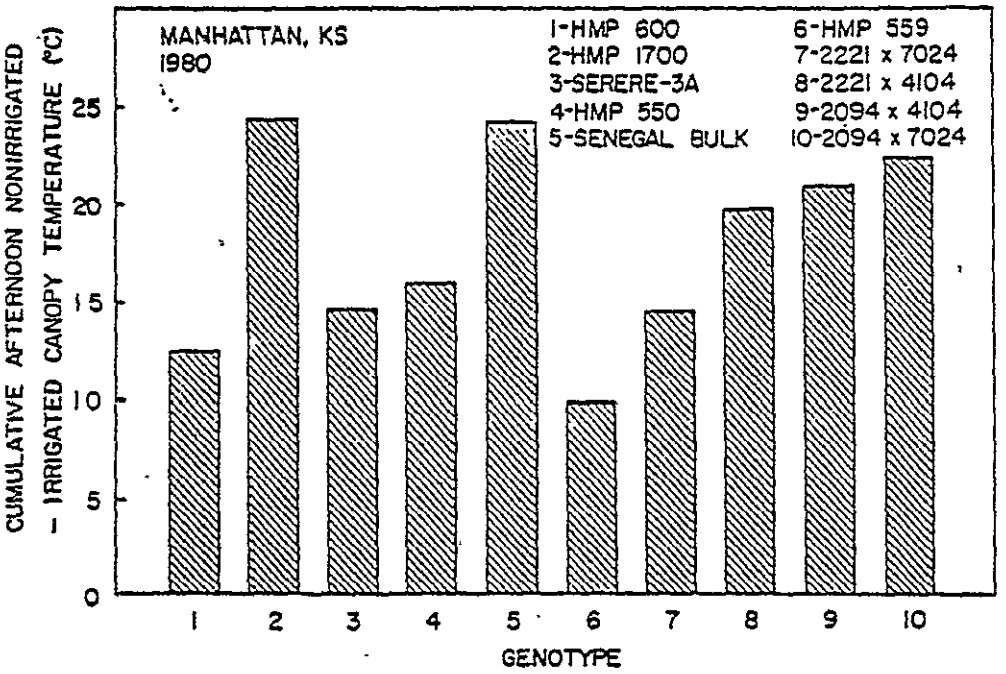


Fig. 5 Cumulative afternoon nonirrigated-irrigated canopy temperature of various genotypes.

Table 1. Morphological characteristics of the genotypes studied in 1980.

Genotype	Plant Height (cm)	Max. LAI	Days to Flowering	Days to Maturity
Early Maturing				
1) HMP600	135	2.9	46	76
2) HMP1700	86	4.3	49	76
3) Serere-3A	181	4.0	52	84
4) HMP550	98	4.7	46	84
Late Maturing				
1) Senegal Bulk	123	4.2	57	91
2) HMP559	219	5.6	57	84-87
Hybrids				
1) 2221 x 7024	77	4.1	46	76
2) 2221 x 4104	105	3.6	49	84
3) 2094 x 4104	95	4.9	52	84
4) 2094 x 7024	82	4.5	47	84

Table 2. Days after emergence to various plant growth stages under irrigation and no-irrigation creatment.

growth stages	HMP 600	HMP 1700	Serere 3A	HMP 550	Senegal Bulk	HMP 559	2221x 7024	2221x 4104	2094 4104	2094x 7024
				GENOTYPES						
				Irrigated						
1. final leaf visible	41	--	42	-	-	46	41	-	43	41
2. boot stage	43	41	46	41	49	52	-	43	46	43
3. panicle emergence	44	46	49	43	52	-	43	46	49	44
4. half bloom	46	49	52	46	57	57	46	49	52	47
5. seed set	-	--	57	52	60	60	49	52	--	49
6. Grain filling										
a) Milk stage	57-60	52-57	60-71	57-60	67-71	67-71	52-60	57-60	57-60	52-67
b) Soft dough	67	60-67	---	67	-	--	67	67-71	67-71	71
c) hard dough	71	71	76-80	71-80	71-84	76-80	71	76-80	76-80	76-80
7. Physiological maturity	76	76	84	84	91	84	76	84	84	84
				Non-irrigated						
1)	43	--	43	41	--	--	--	43	46	--
2)	44	43	46	43	51	52	41	45	--	43
3)	46	46	52	45	52	--	43	47	49	46
4)	49	49	--	47	57	60	46	49	52	49
5)	52	--	57	49	60	67	49	52	--	52
6)										
a)	57-60	52-57	60-71	52-60	67	71	52-60	57-60	57-60	57-60
b)	67-71	60-67	76	67	71	--	67	67	67	--
c)	76	71	76-80	71	76-84	76-80	71	71-80	71	67-71
7)	80	76	84	76	91	87	76	84	76	76

Table 3. Grain yield, stover yield and total yield of genotypes under irrigation and no-irrigation treatment.

Genotype	Irrigated			Non-irrigated			% Reduction in Yield under no-irrigation		
	Grain	Stover	Total	Grain	Stover	Total	Grain	Stover	Total
HMP600	2617c	13872d	16489e	1862a	8854bc	10717b	28.8	36.2	35.0
HMP1700	3746ab	16435cd	20181cde	1891a	9039bc	10930b	49.5	45.0	45.8
SERERE-3A	2523c	20296abc	22819abcd	1205a	11488abc	12693ab	52.2	43.4	44.4
HMP550	3249bc	15115d	18363de	1807a	9043bc	10850b	44.4	40.2	40.9
Average	3304	16429	19463	1691	9606	11297			
SENEGAL BULK	3245bc	23674a	26920a	1325a	9970bc	11295b	59.2	57.9	58.0
HMP559	1277d	21519ab	22796abcd	1096a	16141a	17238a	14.2	25.0	24.4
Average	2261	22596	24858	1210	13055	14266			
2221 x 7024	3928ab	16697cd	20625cde	1543a	7639c	9182b	60.7	54.2	55.5
2221 x 4104	3340bc	17618bcd	20958bcde	1924a	10974bc	12897ab	42.4	37.7	38.5
2094 x 4104	3590ab	20375abc	23965abc	1379a	12411ab	13790ab	61.6	39.1	42.5
2094 x 7024	4298a	21301ab	25599ab	1270a	9814bc	11084b	70.5	53.9	56.7
Average	3789	18998	22787	1529	10209	11738			
L.S.D. (α=.05)	946	4536	4890	946	4536	4890			

Within each column, values followed by the same letter are not significantly different (α = 0.05)

Table 4. Yield components of genotypes under irrigation and no-irrigation treatments.

Genotypes	IRRIGATED			NON-IRRIGATED			
	No. of heads per m^2	Grain wt. per head(gm)	500 seed wt. (gm)	No. of heads per m^2	Grain wt. per head(gm)	500 seed wt.(gm)	%Reductic in no. of heads
HMP600	32.1	8.15	4.75	16.9	11.02	4.40	47.3
HMP1700	56.7	6.61	3.56	24.0	7.88	3.53	57.7
SERERE-3A	25.6	9.85	5.16	13.0	9.27	4.50	49.2
HMP550	31.9	10.18	4.59	15.9	11.36	4.63	50.2
SENEGAL BULK	24.4	13.30	4.56	12.1	10.95	3.46	50.4
HMP559	16.4	7.79	3.69	14.2	7.72	3.56	13.4
2221 x 7024	35.6	11.03	5.45	15.8	9.76	4.96	55.6
2221 x 4104	37.5	8.91	4.93	19.9	9.67	4.75	46.9
2094 x 2104	37.1	9.68	4.83	21.5	9.41	4.52	42.0
2094 x 7024	56.9	7.55	5.62	19.1	6.65	4.84	66.4

Table 5. Total water use (from 165 cm soil profile) and subsoil water use (from 60 to 165 cm layer) of various genotypes under irrigated and no-irrigation treatment.

	Genotypes									
	HMP-600	HMP-1700	SERERE-3A	HMP 550	SENEGAL BULK	HMP-559	2221 x 7024	2221 x 4104	2094 x 4104	2094 x 7024
	Irrigated									
Total water use cm	61.3	58.6	53.6	59.2	62.0	64.3	50.1	58.8	60.4	52.9
Subsoil water use (cm)	7.3	7.2	4.3	4.6	6.5	8.0	1.5	6.7	8.1	2.2
WUE for grain yield (kg/ha · cm)	42.7	63.9	47.1	54.9	52.3	19.9	78.4	56.8	59.4	81.2
WUE for total yield (kg/ha · cm)	269.0	344.4	425.7	310.2	434.2	354.5	411.7	356.4	396.8	483.9
	Non-irrigated									
Total water use (cm)	35.6	30.6	27.9	34.9	43.0	27.8	33.2	34.6	36.9	30.0
Subsoil water use (cm)	14.8	15.1	15.4	17.4	17.8	17.0	17.0	17.0	14.9	14.1
WUE for grain yield (kg/ha · cm)	52.3	61.8	43.2	51.8	30.8	39.4	46.5	55.6	37.4	42.3
WUE for grain yield (kg/ha · cm)	301.0	357.2	454.9	310.9	262.7	620.1	276.6	372.7	373.7	369.5

Table 6. Beforenoon and afternoon average leaf water potentials (BARS) of various genotypes.

Genotypes	Irrigated		Non-irrigated	
	Beforenoon	Afternoon	Beforenoon	Afternoon
HMP60	-16.1	-25.2	-17.8	-29.3
HMP1700	-15.9	-23.6	-16.4	-27.3
SERERE-3A	-15.2	-23.8	-17.8	-28.8
HMP550	-15.6	-23.3	-17.5	-28.5
SENEGAL BULK	-13.9	-23.6	-16.4	-26.2
HMP559	-13.8	-23.6	-16.4	-26.2
2221 x 7024	-15.1	-22.5	-17.1	-29.1
2221 x 4104	-15.8	-24.1	-18.7	-28.7
2094 x 4104	-16.4	-24.7	-18.0	-28.2
2094 x 7024	-15.7	-22.2	-16.8	-28.2

Table 7. Beforenoon and afternoon average leaf and stem osmotic potentials of genotypes.

	Leaf osmotic potential (Bars)		Stem osmotic potential (Bars)	
	Beforenoon	Afternoon	Beforenoon	Afternoon
HMP600	-23.1	-21.0	-16.9	-16.0
HMP1700	-21.5	-24.0	-18.3	-18.5
SERERE-3A	-21.8	-21.0	-15.4	-18.0
HMP550	-21.8	-20.2	-18.5	-15.5
SENEGAL BULK	-18.2	-20.2	-11.7	-14.4
HMP559	-16.6	-19.6	-11.4	-14.4
2221 x 7024	-20.7	-22.2	-16.8	-19.0
2221 x 4104	-20.7	-23.7	-14.1	-16.8
2094 x 4104	-21.3	-22.8	-14.0	-17.5
2094 x 7024	-20.9	-20.7	-16.7	-17.2
		Non-irrigated		
HMP600	-20.9	-24.2	-16.4	-18.5
HMP1700	-22.3	-24.0	-18.2	-20.3
SERERE-3A	-20.5	-24.1	-16.7	-20.9
HMP550	-21.8	-22.4	-19.6	-20.8
SENEGAL BULK	-18.8	-22.6	-15.7	-18.8
HMP559	-17.8	-20.0	-14.4	-15.7
2221 x 7024	-21.4	-24.5	-20.0	-21.8
2221 x 4104	-23.2	-24.6	-17.7	-19.5
2094 x 4104	-24.8	-25.1	-18.1	-19.9
2094 x 7024	-21.5	-25.0	-19.4	-23.3

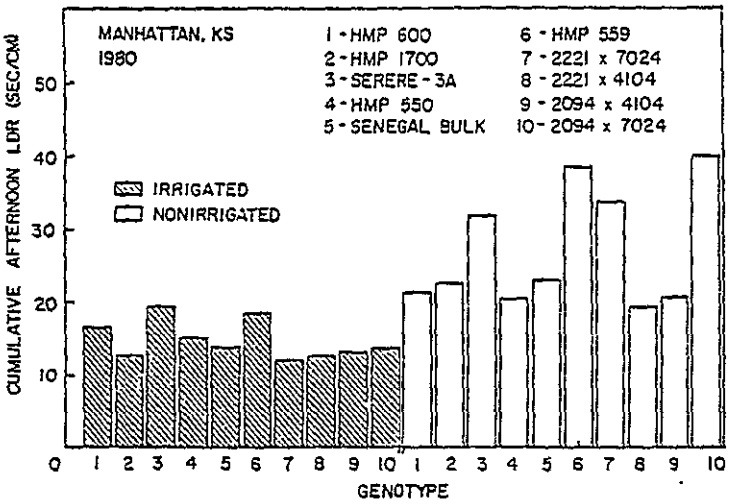


Fig. 1 Cumulative afternoon leaf diffusion resistance (LDR) of various genotypes under irrigated and nonirrigated treatment.

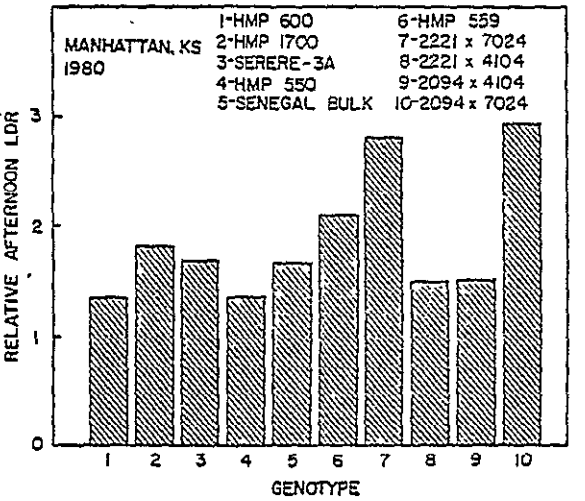


Fig. 2 Relative afternoon leaf diffusion resistance (LDR) of various genotypes.

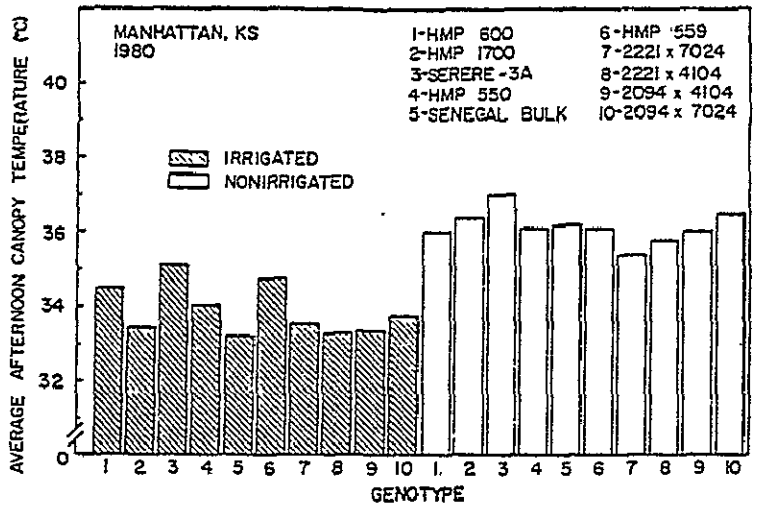


Fig. 3 Average afternoon canopy temperature of various genotypes under irrigated and nonirrigated treatment.

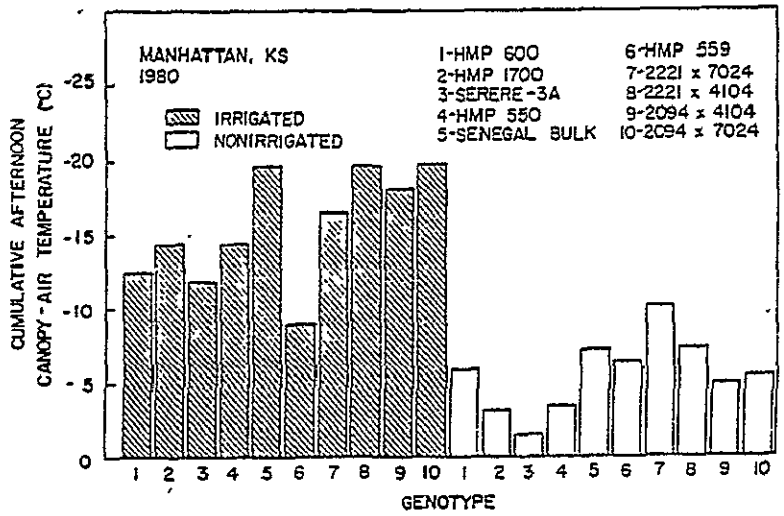


Fig. 4 Cumulative afternoon canopy-air temperature of various genotypes under irrigated and nonirrigated treatment.

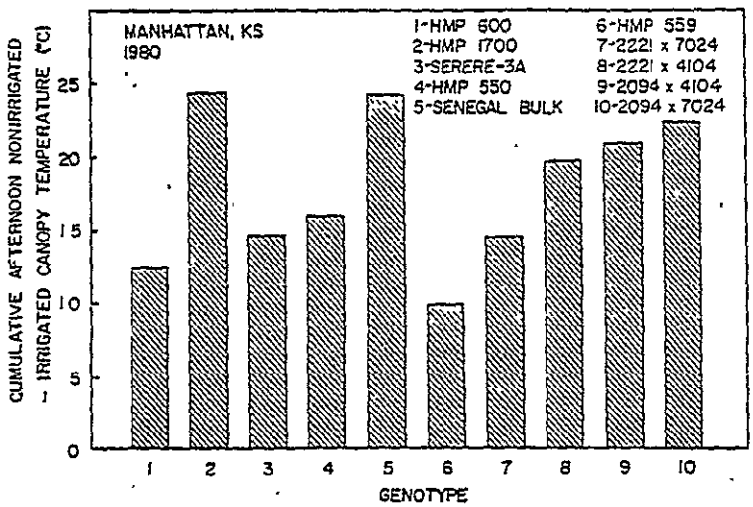


Fig. 5 Cumulative afternoon nonirrigated-irrigated canopy temperature of various genotypes.

EFFECTS OF SEED SIZE AND DENSITY ON PERFORMANCE OF PEARL MILLET [*Pennisetum americanum* (L.) Leeke]

Mahmud Lawan, F. L. Barnett and R. L. Vanderlip

Research has shown that seed density and stand establishment are positively related. The objective of this study is to investigate interactions between seed density and size with regard to field establishment and growth.

MATERIALS AND METHODS

Seed of RMP1, HMP550, Serere 3A and Senegal populations were used. The seed of each population was divided into high, medium, and low densities by gravity table separation at Mississippi State University. These density samples were then divided into three seed-size categories at Kansas State University, as follows:

Large: Retained on 7/64 of a round sieve
Medium: Retained on 6/64 of a round sieve
Small: Retained on 5½/64 or 4½/64 of a round sieve

A field experiment was conducted at the Kansas State University Agronomy farm in a split plot design with three replications. The four populations were the main plots and the density x size combinations were randomly assigned as sub-plot treatments.

Planting was on Julian day 157 in plots 54.8 m long with inter-row spacing of 76 cm. Each plot consisted of two rows with 110 seeds planted by vacuum planter in each row. The following field observations were made.

Percent Emergence - The percentage of seed that produced emerged seedlings. This was observed on Julian day 161 and counts made on Julian days 176 and 177, when the seedlings were in the 3 to 5 leaf stage.

Seedling Vigor - Three seedlings in each row were selected randomly and seedling heights (cm) were taken at the highest point of an extended leaf on Julian day 181.

Days to Anthesis - Number of days from planting to anthesis.

Heads per Hectare - Calculated from the total number of heads produced in each plot.

Head Weight - Calculated by dividing yield per hectare/heads per hectare.

Yield per Hectare - The amount of grain obtained per hectare, calculated from plot yield adjusted to 12.5 percent moisture content.

Laboratory observations were also made.

Percent Germination - The percentage of seedlings that germinated from 50 seeds in petri dishes at a temperature of 80-85°F for seven days. No germination was observed on first day.

Germination Index - Purpose of germination index was to emphasize speed of germination.

Germination index = number germinated on second day x 6 + number germinated on third day x 5 + number germinated on fourth day x 4 + number germinated on fifth day x 3 + number germinated on sixth day x 2 + number germinated on seventh day x 1.

RESULTS AND DISCUSSION

Analyses of variance for the field experiment are summarized in Table 1. Population had a significant effect on percent emergence, seedling vigor, heads per hectare, head weight, and yield per hectare. Density significantly affected percent emergence, seedling vigor, days to anthesis, heads per hectare, head weight and yield per hectare. The effect of seed size on seedling vigor and germination index was not highly significant. The interaction between seed size and density significantly affected percent emergence, days to anthesis, and heads per hectare.

The population and density interaction had a significant effect on percent germination and germination index. Days to anthesis was weakly affected by population by seed-size interaction.

The mean effects of population, density, and seed size are shown in Tables 2, 3, and 4. Serere 3A had the highest percent emergence, seedling vigor, heads per hectare, and yield per hectare. HMP550 had the highest head weight. High seed density resulted in the highest percent emergence, seedling vigor, heads per hectare, head weight, yield per hectare, and less days to reach anthesis, while low seed density was the opposite. The highest seedling vigor and germination index were obtained with the large seed size.

Table 5 shows the effects of seed size and density on percent emergence, days to anthesis and heads per hectare. The lowest percent emergence and heads per hectare were obtained with low density-small seed size. It also took longer to reach anthesis with the low density-small seed size.

Generally, the variables increased with different seed size category regardless of the density but in days to anthesis, there was a decrease from the small to large seeds. Significant differences are more pronounced in the low and high density than in the medium density for the variables.

The results for heads per hectare with medium density exhibited the opposite of low and high density.

The mean effect of population and density on percent germination and germination index are shown in Table 6. HMP550 and Serere 3A indicated significant differences within the density groupings for the variables.

Serere 3A indicated the highest percent germination within all the density groupings but in germination index, it did not exhibit such a trend.

Table 7 shows the mean effect of population and seed size on days to anthesis. Serere 3A with large seed size was the early population while RMP1 with small seed size was the late variety.

Simple correlation coefficients are indicated in Table 8. Days to anthesis were negatively correlated with all the variabiles. None of the variables indicated a perfect correlation but the highest correlation was between germination index and percent germination.

Table 1. Analysis of variance summaries.

Source of Variation	DF	Probability of F Value for Indicated Variables							
		Percent Emergence	Seedling Vigor (cm)	Days to Anthesis	Heads Per Hectare	Head Weight (g)	Yield (kg)	Germination Percent	Germination Index
Total	100								
Replication	2								
Population	3	0.0001	0.0001	0.0001	0.0010	0.0001	0.0016	0.0001	0.0001
Error a	6	45.0776[1]	17.43[1]	3.6957[1]	481.899[1]	27.69[1]	104117.78[1]	24.708[1]	526.76[1]
Density	2	0.0001	0.0001	0.0001	0.0001	0.0044	0.0001	0.0001	0.0001
Size	2	0.0810	0.0457	0.0855	0.3282	0.0661	0.1640	0.5869	0.0346
Density x Size	4	0.0010	0.9730	0.0134	0.0315	0.0865	0.1221	0.2202	0.0757
Population x Density	6	0.1010	0.7797	0.2745	0.9561	0.3100	0.5428	0.0058	0.0034
Population x Size	6	0.6678	0.1693	0.0494	0.6588	0.8210	0.5951	0.5946	0.3860
Population x Density x Size	10	0.3296	0.8515	0.0703	0.0900	0.2170	0.1119	0.5239	0.2714
Error b	59	47.6280[1]	8.554[1]	9.9027[1]	518.8[1]	9.6056[1]	76624.64[1]	39.128[1]	295.018[1]

1/ Mean square for indicated error.

Table 2. Effect of population on indicated variables.

Population	Percent Emergence	Seedling Vigor (cm)	Heads Per Hectare	Head Weight (g)	Yield Per Hectare (kg)
1. RMP1	36.25	19.30	72.12	4.41	390.25
2. HMP550	57.38	24.81	55.49	10.98	612.37
3. Serrere 3A	65.77	25.11	80.71	9.42	764.96
4. Senegal	52.62	21.44	69.31	7.05	532.40
LSD (.05)	4.62	2.86	15.12	3.62	222.22

Table 3. Effect of density on indicated variables.

Density	Percent Emergence	Seedling Vigor (cm)	Days to Anthesis	Heads Per Hectare	Head Weight (g)	Yield Per Hectare
Low	46.11	20.48	66.66	50.15	6.81	410.48
Medium	56.98	23.45	62.82	74.67	8.77	635.50
High	59.24	24.72	62.69	82.51	9.01	714.21
LSD (.05)	3.36	1.43	1.53	11.10	1.51	134.95

Table 4. Effect of seed size on seedling vigor and germination index.

Seed Size	Seedling Vigor (cm)	Germination Index
Small	21.9	242.5
Medium	22.4	238.5
Large	24.7	243.4
LSD (.05)	1.43	8.37

Table 5. Effects of seed size and density on percent emergence, days to anthesis, and heads per hectare.

Seed Density	Percent Emergence Seed Size			Days to Anthesis Seed Size			Heads Per Hectare Seed Size		
	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large
Low	39.9	42.5	59.1	69.8	66.0	63.3	31.9	57.2	65.1
Medium	56.7	56.5	57.8	62.9	62.6	63.0	80.7	79.9	62.2
High	59.1	57.0	62.4	63.0	63.0	61.8	77.6	80.5	91.7
LSD (.05)	5.83	5.83	5.83	2.66	2.66	2.66	19.23	19.23	19.23

Table 6. Effect of population and density on percent germination and germination index.

Population	Percent Germination Density				Germination Index Density			
	Low	Medium	High	LSD	Low	Medium	High	LSD (.05)
RMP1	69.7	78.8	74.3	3.05	179.2	207.1	199.2	8.37
HMP550	78.2	91.5	94.7	3.05	221.7	269.7	279.1	8.37
Serrere 3A	87.8	93.6	95.8	3.05	244.1	269.4	278.8	8.37
Senegal	83.3	90.4	82.7	3.05	221.3	254.2	233.8	8.37
LSD (.05)	6.02	6.02	6.02		20.78	20.78	20.78	

Table 7. Effect of population and seed size on days to anthesis.

Population	Seed Size			
	Small	Medium	Large	LSD (.05)
RMP1	67.9	64.4	66.0	1.53
HMP550	67.8	66.7	67.8	1.53
Serrere 3A	58.2	59.4	57.0	1.53
Senegal	67.1	64.9	62.8	1.53
LSD (.05)	2.81	2.81	2.81	

Table 8. Simple correlation coefficients.

	Percent Emergence	Days to Anthesis	Seedling Vigor (cm)	Heads Per Hectare	Yield Per Hectare (kg)	Head Weight (g)	Germination Percent	Germination Index
Days to Anthesis	-0.59259 0.0001							
Vigor	0.61878 0.0001	-0.43875 0.0001						
Heads per Hectare	0.34012 0.0005	-0.57938 0.0001	0.30561 0.0019					
Yield per Hectare	0.59471 0.0001	-0.59113 0.0001	0.60441 0.0001	0.65734 0.0001				
Head Weight	0.60234 0.0001	-0.33893 0.0005	0.59609 0.0001	0.15435 0.1233	0.74988 0.0001			
Germination Percent	0.70854 0.0001	-0.37504 0.0001	0.48418 0.0001	0.22338 0.0247	0.43784 0.0001	0.46470 0.0001		
Germination Index	0.74673 0.0001	-0.32446 0.0009	0.53644 0.0001	0.17789 0.0751	0.44931 0.0001	0.51612 0.0001	0.95544 0.0001	

Objective 3. "Determine the nutritional quality and digestibility of pearl millet grain by analyzing protein in germplasm introductions and breeding materials and determining magnitudes of variation in lysine content among and within populations and varieties. Determine the characteristics and digestibility of pearl millet protein and carbohydrates."

PEARL MILLET AMYLASES. I. PROPERTIES OF PARTIALLY PURIFIED ALPHA-AMYLASE

Adelaide Beleia and E. Varriano-Marston

ABSTRACT

Studies on miller alpha-amylases indicated that purification method affected the physiocochemical characteristics of purified alpha-amylases. Polyacrylamide gel electrophoresis showed three protein bands for alpha-amylases purified by glycogen complex formation, and seven protein bands for alpha-amylase purified by starch column procedures. All protein bands exhibited alpha-amylase activity. Alpha-amylase isozymes had molecular weights, determined by SDS gel electrophoresis, ranging from 22,000 to 53,000, and isoelectric points ranging from 4.8 to 6.2 The pH optima were between 4.4 and 4.8; temperature optimum was 55°C. Many of the above characteristics are similar to those reported for amylases purified from immature cereal grains.

INTRODUCTION

Pearl millet is grown extensively for human consumption in India and Africa, especially in semi-arid areas. Its resistance to drought often assures farmers and adequate yield under conditions considered unfavorable for other cereals. That makes pearl millet an important component in the diet of individuals in many countries.

Many food uses of pearl millet involve a steeping or fermenting period before cooking, and fermented beverages made from millet are common (Vogel and Graham, 1978). Although millet consumers subjectively distinguish "good" from "poor" quality grains for particular end-uses, little work has been done to determine what physical and chemical factors are related to grain quality.

Amylases are important enzymes for controlling the end-use quality of many food grains like wheat (Kulp, 1975) and sorghum (Novellie, 1962). However, little work has been published on amylases in pearl millet. Based on current information on uses of pearl millet (Vogel and Graham, 1978) and suggestions that pearl millet has an active amylase system (Badi et al., 1976), our objective was to isolate alpha-amylase from mature pearl millet grains and to determine some of its physical and chemical characteristics.

MATERIALS AND METHODS

Materials

Eleven random mating bulk populations and nine F_1 hybrids of pearl millet were screened for alpha-amylase activity. Location, year of growth, and proximate analysis of the samples are presented in Table I. Hays millet populations (HMP) were developed at the Hays Branch Experiment Station. All pearl millets studied were from sound grains, i.e. there was no visible sprouting damage.

Alpha-amylase Activity: Viscometric Methods

AACC Methods 56.81B and 22-10 were used to determine falling number and amylograph viscosity, respectively. Pearl millets were ground in a Quadrumat Jr. and the fractions were recombined before analyses were done.

Alpha-amylase Activity: Reducing Power Method

The activity of purified alpha-amylase preparations was determined by the method of Robyt and Whelan (1968) except that the temperature was maintained at 35°C instead of 25°C. Reducing sugars were determined by Nelson's colorimetric copper method (1944). Enzyme activity (Units of activity) was expressed as μmoles of apparent maltose produced per ml of alpha-amylase solution per min.

Specific Activity

Protein in the alpha-amylase solutions was determined by Miller's (1959) modification of the Lowry et al. (1951) method. Specific activity was expressed as milliunits (mU) per mg of protein.

Gel Electrophoresis

Electrophoresis of purified enzymes was done on polyacrylamide gels at pH 8.9 by the method of Davis (1964). Multiple forms of alpha-amylase were detected by incubating sliced electrophoresis gels, 2 to 3 mm sections, in a test tube containing 40 mg Phadebas amylase substrate and 4 ml of 0.05 M acetate buffer, pH 6.0 (0.01M $CaCl_2$) at 50°C for 0.5 to 3 hr. The reaction was stopped by adding 1 ml 0.5 N NaOH, the mixture was filtered, and the absorbance was read at 620 nm.

Molecular weight determinations were done by SDS gel electrophoresis according to the methods of Weber and Osborn (1969) as described in Sigma Technical Bulletin No. MWS-877 (Sigma Chemical Co., St. Louis, MO).

Isoelectric points were determined by the gel electrofocusing methods of Wrigley (1968). After electrophoresis, gels were stained overnight in 0.04% Coomassie Brilliant Blue G25 in 3.5% perchloric acid (Reisner et al., 1975).

RESULTS AND DISCUSSION

Alpha-amylase Activity in Pearl Millet

Based on amylograph data from one pearl millet sample, Badi et al. (1976) reported that millet flour contained an active alpha-amylase system. Whether high alpha-amylase activity was common to many pearl millet populations or hybrids was not known, so we used the falling number method to rapidly screen pearl millet samples for alpha-amylase activity.

Falling numbers of pearl millet bulk populations varied from 67 sec. for HMP 1700, harvested in 1977, to 383 sec. for Sudan Yellow, harvested in 1979 (Table II). Falling numbers for F_1 hybrids varied from 185 sec. for 1166 x 1700 to 319 sec. for 2224 x 7024, both harvested in 1978. Falling numbers for sound pearl millets were, in general, lower than those reported for sound wheat.

To further confirm the viscosity data of Badi et al. (1976), we also determined amylograph peak viscosities on millet meals with low, medium, and high falling numbers (Fig. 1). Amylograph pasting temperatures for millet meals varied from 64°C for HMP 02 to 74°C for HMP 559. Peak viscosities paralleled falling number data, i.e. millets with low falling numbers also had low amylograph peak viscosities. For example, HMP 02 had a falling number of 134 sec. and a peak viscosity of 520 B.U. Maximum amylograph viscosity was attained at temperatures from 80°C to 85°C.

The falling number and amylograph viscosity data indicate that many sound pearl millets have active alpha-amylase systems. Since many traditional food uses of pearl millet involve natural fermentations (Vogel and Graham, 1978), level of amylolytic activity in the grain may be one important factor in grain quality, so we conducted studies to determine the characteristics of purified millet alpha-amylases.

Isolation of Alpha-amylase from Pearl Millet

Alpha-amylase was extracted from millet (HMP 02) with 0.05M acetate buffer, pH 4.8, containing 0.01M $CaCl_2$. The ratio of buffer to meal was 2.5:1; extraction time was 2 hr. The slurry was centrifuged for 15 min. at 2000 rpm, and the precipitate was discarded.

The supernatant was brought to a concentration of 0.2% with calcium acetate and the pH was adjusted to 6.0 with NaOH before dividing it into 10 ml fractions and heat treating at 70°C for 15 min. to inactivate beta-amylase. After heat treatment the solution was rapidly cooled in an ice bath, centrifuged at 5000 rpm for 15 min., the precipitate was discarded, and the supernatant was dialysed overnight against 0.2% calcium acetate.

After the heat treatment two methods were used to further purify alpha-amylase: (1) the starch column procedure of Schwimmer and Balls (1949) and (2) organic solvent fractionation followed by glycogen complex formation (Loyter and Schram, 1962). Details of the isolation procedures are given in Fig. 2.

The procedure of Schwimmer and Balls (1949) includes an $(NH_4)_2SO_4$ precipitation followed by alpha-amylase adsorption on a starch column and elution with 0.5% Ca acetate. In this study pearl millet starch, washed from the grain as previously described (Beleia et al., 1980), was used as the adsorbent.

Before the glycogen complex was formed the heat-treated sample was fractionated with acetone. Cold acetone (-10°C) was slowly added to the dialyzed solution, maintained at -10°C in an ice-salt bath, to a concentration of 20%. The mixture was centrifuged for 30 min. at 10,000 rpm, then the precipitate was discarded. Additional cold acetone was added to the supernatant to a final concentration of 40%. The precipitate, containing the alpha-amylase, was recovered by centrifuging at 10,000 rpm for 30 min. and dissolving in acetate buffer. Cold (-10°C) 80% ethanol containing 0.5% $CaCl_2$ was then added slowly to the enzyme solution to a final concentration of 20%. The solution was centrifuged (10,000 rpm, 20 min.) and the precipitate was discarded. The alpha-amylase in the supernatant was complexed with purified glycogen in 0.2 M phosphate buffer (pH 8.9) by the method of Loyter and Schramm (1962).

Enzyme activity determinations were recorded at each step in purifying alpha-amylase by the starch-column procedure and glycogne complex formation; those data are presented Table III and IV, respectively. In both purification procedures, acetate buffer was used to extract alpha-amylase from millet meal; it was as efficient as 0.2% calcium acetate or 0.01M $CaCl_2$. The high enzyme activity of the initial extract resulted from both alpha- and beta-amylases. Heat-treating the crude extract increased specific enzyme activity but reduced amylase activity. Determination of alpha-amylase activity in buffer extracts before and after the heat treatment using the Phadebas substrate (specific for alpha-amylase) indicated that 15 to 20% of the alpha-amylase activity was lost during heating. A portion of the heat-treated extract was also treated for beta-amylase by first adjusting the pH to 3.2 with acetic acid and holding for 1 hr. at R.T. After the acid treatment the pH was adjusted to 4.6 with acetate buffer and beta-amylase activity was determined according to Robyt and Whelan (1968). Beta-amylase activity was found to be less than 30 mU/ml in all heat-treated extracts.

Controlling the pH before heat-treating the extract was crucial in obtaining an active enzyme preparation. If the pH of the buffer extract was not adjusted to 6.0 before the heat treatment, low recovery of the enzyme resulted. Even when the pH was adjusted, amounts of enzyme recovered varied. For example, heat treatment of the buffer extract that was later used in the starch column gave 58% recovery. An identical heat treatment of another buffer extract, used in glycogen complexing, gave 75% enzyme recovery. Variations in enzyme recovery could have been affected by the amount of protein solubilized during the extraction procedure (compare protein contents of dialyzed buffer extracts in Tables III and IV). Greenwood and Milne (1968b) also suggested that protein concentrations in the enzyme extract during heat treatment were critical for removing beta-amylase and recovering alpha-amylase.

Subsequent steps in both purification methods increased the specific activity several fold above that of the heat-treated extracts (Tables III and IV). In general, glycogen complex formation increased specific enzyme activity more than starch column procedures did. In fact, the glycogen complex formation increased specific activity of the purified alpha-

amylase 60-fold (Table IV) compared with a 21-fold increase with the starch column (Table III).

Greenwood and Milne (1968b) could not form the glycogen complex with alpha-amylases from mature oat, rye, or wheat, which they attributed to the low enzyme concentrations in the mature grains. Since they used a different method to measure alpha-amylase activity, we cannot directly compare our results with theirs to determine whether millet grain has a higher alpha-amylase content.

Properties of Purified Millet Alpha-amylases

Polyacrylamide gel electrophoresis. Polyacrylamide gel electrophoresis (PAGE) of pearl millet alpha-amylase purified by the starch column procedure revealed seven protein bands; alpha-amylase purified by glycogen complex formation exhibited three bands (Fig. 3). Alpha-amylase determinations on sliced gels, with the Phadebas substrate, indicated that all bands that stained for protein also showed alpha-amylase activity. The protein with the greatest mobility showed about two times greater alpha-amylase activity than the other bands.

The different electrophoretic properties of millet alpha-amylase purified by adsorption on starch granules or glycogen complex formation is a result of the purification method. Adsorption of alpha-amylase on starch granules or formation of a glycogen amylase complex is temperature, pH, and concentration dependent (Walker and Hope, 1963; Levitzki et al., 1964) so some forms of alpha-amylase may be preferentially adsorbed on starch granules or preferentially complexed with glycogen. Data reported by MacGregor (1977) lend some support to that hypothesis. He found that the elution pattern of a glycogen purified alpha-amylase (malted barley) from a CMC cellulose column differed from the elution pattern obtained when the enzyme was purified without glycogen complex formation. Apparently, dextrins produced from the hydrolysis of the glycogen inhibited adsorption of one form of alpha-amylase onto the column.

SDS gel electrophoresis. SDS gels of alpha-amylases purified by glycogen complex formation showed three distinct protein bands: one at a molecular weight of 31,000, one at 46,000, and one at 53,000 (Fig. 4). The molecular weight of alpha-amylases purified from the same millet population by the starch-column procedure showed two bands in the SDS gels: one at 31,000 and one at 22,000. Lower molecular weights of alpha-amylases from starch column purifications than from glycogen complex formation supports that hypothesis that only certain alpha-amylase isozymes are preferentially adsorbed onto starch or complexed with glycogen.

Molecular weights of most cereal alpha-amylases range from 42,000 to 46,000 (Greenwood and Milne, 1968a). But, Tkachuk and Kruger (1974) reported molecular weights from 20,000 to 57,000 for alpha-amylases from malted wheat, and molecular weights have exceeded 50,000 for some alpha-amylase isozymes from malted barley (MacGregor, 1978) and immature

wheat (Marchylo et al., 1976).

Isoelectric focusing. In isoelectric focusing a protein migrates in a gel support, which has a pH gradient, to the region of its isoelectric pH (Wrigley, 1968). We used isoelectric focusing between pH 3 and 10, and dissolved purified, freeze-dried alpha-amylases in water before mixing with the concentrated gel mixture and photopolymerizing. Alpha-amylases purified by either the starch column or glycogen complex showed three protein bands corresponding to isoelectric points of 4.8, 5.2, and 6.2. The isoelectric points of 4.8 and 5.2 agree with values reported by Marchylo et al. (1976) for immature wheat alpha-amylase isozymes. They also reported isoelectric points from 6.05 to 6.20 for isozymes from malted wheat.

pH and temperature optima. Optimum pH for activity of purified alpha-amylases from millet was determined with a soluble starch substrate and acetate or tris buffers in a pH range from 3.6 to 7.2 The enzyme was diluted with the buffer, and an aliquot was added to 1:1 mixture of soluble starch and buffer. Reaction time was 10 min. at 35°C, and reducing sugars were measured according to Nelson's method (Nelson, 1944).

Data on optimum pH of purified alpha-amylases, recorded as percentages of maximum activity, are presented in Figure 5. Optimum pH for alpha-amylase purified on the starch column was between 4.4 and 4.8; optimum pH for the glycogen complex alpha-amylase was 4.4. An optimum pH from 4.4 to 4.8 is lower than reported for other cereal alpha-amylases, especially for malted grain alpha-amylases (Greenwood and Milne, 1968a). However, alpha-amylase from malted sorghum had an optimum pH at 4.6 (Dube and Nordin, 1960), and alpha-amylase from immature wheat showed maximum activity in that pH region (Marchylo et al., 1976).

The activity of the glycogen complex alpha-amylase was not so drastically altered by changes in pH as was the activity of the alpha-amylase purified by the starch column procedure, particularly between pH values of 6.0 and 7.2 For example, at pH 6.0 the glycogen complex alpha-amylase still had 82% of its maximum activity while the starch-column alpha-amylase had only 48%. The glycogen complex alpha-amylase exhibited 32% of its maximum activity at pH 7.2, but at that pH the activity of the starch-column alpha-amylase was only 12% of the maximum.

Temperature optima for purified millet alpha-amylases were determined with acetate buffer at the optimum pH determined above (Fig. 6). The optimum temperature for enzymes purified by either procedure was 55°C, which is similar to that reported for immature barley alpha-amylase (MacGregor et al., 1974).

Table I. Proximate analyses of pearl millets.

Sample	Pro. (%)	Fat (%)	Ash (%)	Moisture (%)
Bulk Populations				
HMP 559[a]	10.3	5.2	1.5	7.6
HMP 557A[a]	9.5	5.6	1.6	8.4
HMP 561[a]	8.9	5.6	1.6	6.7
HMP 02[b]	13.4	5.2	1.5	8.9
HMP 1700[a]	10.7	6.2	1.6	6.7
HMP 1700[c]	14.7	6.9	1.6	10.4
HMP 550[c]	13.6	7.1	1.8	9.6
Serere 3A[c]	13.5	6.2	1.6	9.5
RMPI(S)CI[d]	15.7	6.8	2.0	10.4
Sudan Green[e]	12.0	5.9	1.5	7.8
Sudan Yellow[e]	14.5	7.8	2.0	7.4
F_1 Hybrids				
2090 X 7101[a]	11.6	5.7	1.7	7.3
2090 X 7101[f]	14.5	6.0	1.6	7.6
2279 X 7101[a]	10.4	5.6	1.6	7.0
1166 X 1700[a]	11.0	6.0	1.6	6.8
1166 X 1700[g]	9.0	6.6	1.7	7.5
2118 X 7024[a]	10.3	4.9	1.8	7.1
2118 X 7024[b]	12.9	6.1	1.7	10.0
2224 X 7024[a]	12.1	5.2	1.6	7.2
2224 X 7024[g]	9.1	5.3	1.7	8.8

Superscripts indicate growth location in Kansas: (a) Mineola, 1978; (b) Hays, 1978; (c) Hays, 1977; (d) Ashland, 1978; (e) Sudan, 1979; (f) Tribune, 1978; and (g) St. John, 1978.

Table II. Alpha-amylase activity in sound pearl millets as determined by Falling Number.

Sample	Growth Location[a]	Falling No.[b] (sec.)
Bulk Populations		
HMP 559	Mineola	248
HMP 557A	Mineola	261
HMP 561	Mineola	252
HMP 02	Hays	134
HMP 1700	Mineola	199
HMP 1700*	Hays	67
HMP 550*	Hays	230
Serere 3A**	Hays	203
RMPI(S)CI	Ashland	259
Sudan Green+	Sudan	346
Sudan Yellow+	Sudan	383
F_1 Hybrids		
2090 X 7101	Mineola	249
2090 X 7101	Tribune	243
2279 X 7101	Mineola	253
1166 X 1700	Mineola	185
1166 X 1700	St. John	324
2118 X 7024	Mineola	214
2118 X 7024	Hays	221
2224 X 7024	Mineola	247
2224 X 7024	St. John	319

[a]Some samples were harvested in 1977 (*), 1975 (**), and 1979 (+); all others were harvested in 1978.

[b]LSD = 13

Table III. Purification of millet alpha-amylase using salt precipitation and a starch column.

Fraction	mU ml^{-1} [a]	Protein mg ml^{-1}	Specific activity mU/mg protein	Volume (ml)	Recovery [b] (%)
Buffer extract	1780	5.9	302	140	100
Heat treated extract	1450	3.8	382	100	58
0.45 saturated $(NH_4)_2SO_4$	1930	2.2	877	33	26
Starch column	2010	0.3	6,700	14	11

[a] $\text{Units} = \frac{\mu g \text{ maltose/ml/min}}{342} \times 2$

[b] $\frac{\text{mU ml}^{-1} \times \text{Volume}}{\text{Total Acitvity of Buffer Extract}} \times 100$

Table IV. Purification of millet alpha-amylase using acetone fractionation and glycogen complex formation.

Fraction	mU ml^{-1} [a]	Protein mg ml^{-1}	Specific activity mU/mg protein	Volume (ml)	Recovery [b] %
Buffer extract	1600	6.7	238	150	100
Heat treated extract	1200	4.5	266	150	75
40% acetone	2500	2.4	1,042	50	52
Glycogen complex	4300	0.3	14,333	8	14

[a] $\text{Units} = \frac{\mu g \text{ maltose/ml/min}}{342} \times 2$

[b] $\frac{\text{mU ml}^{-1} \times \text{Volume}}{\text{Total Activity of Buffer Extract}} \times 100$

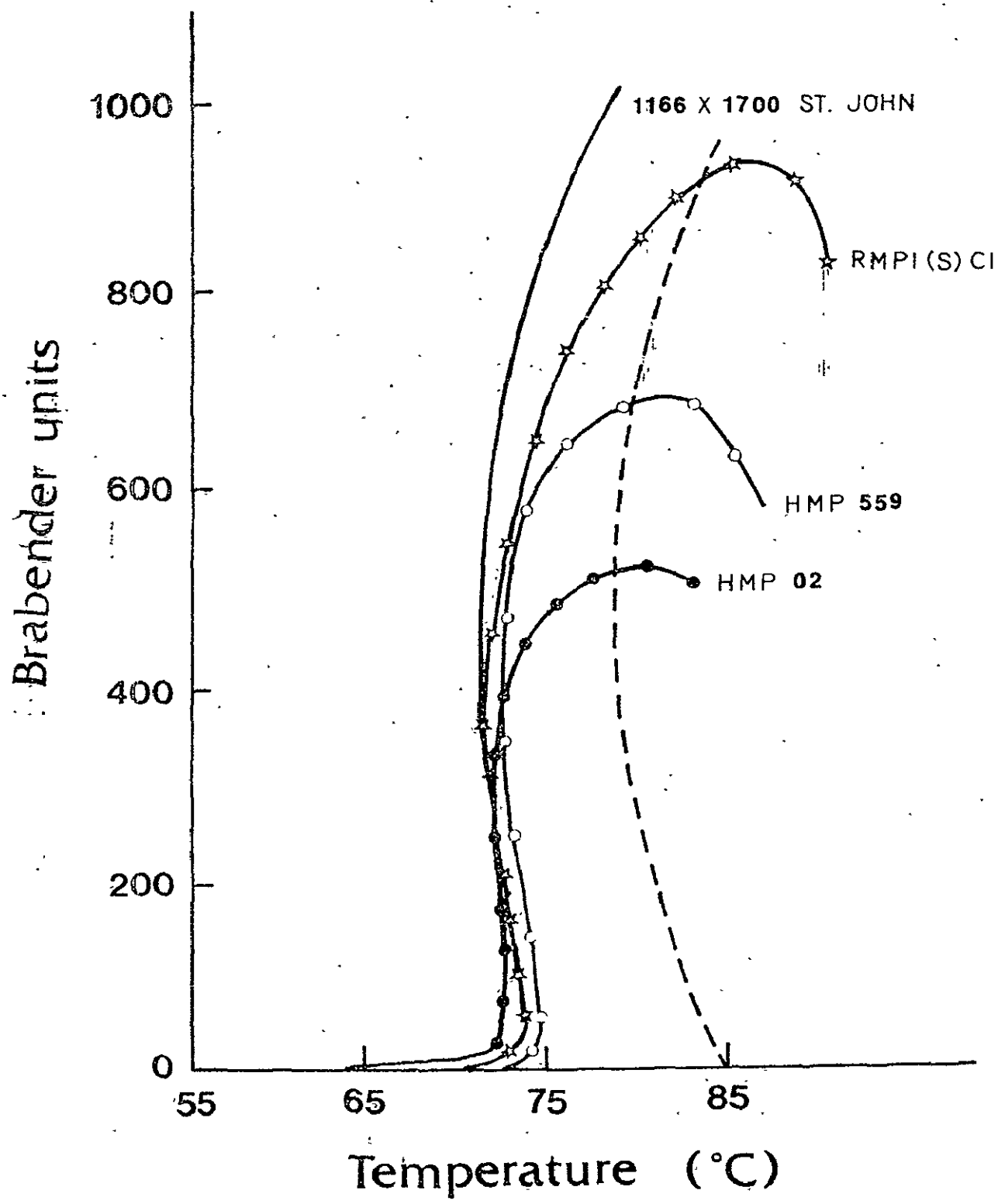
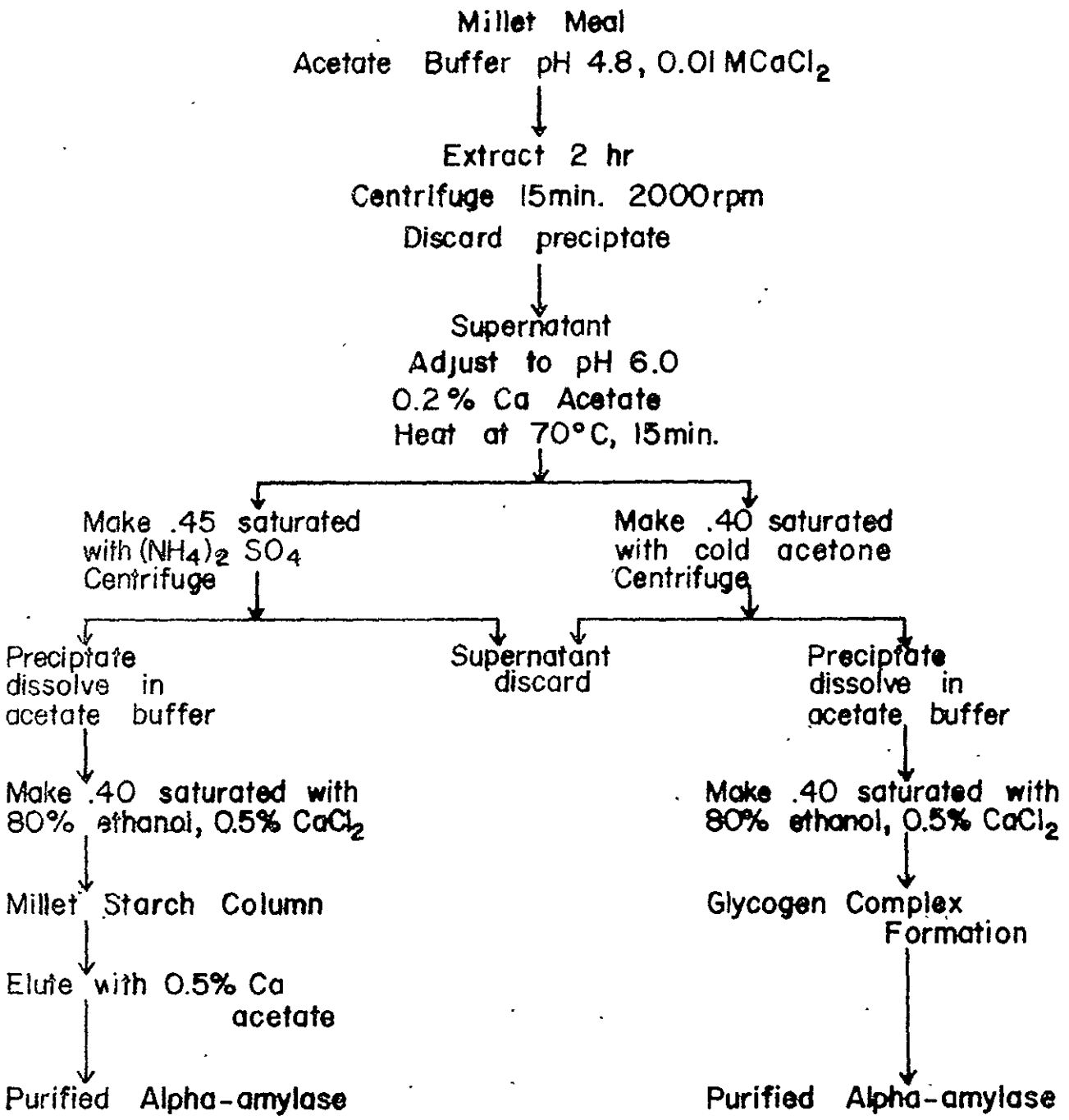


Figure 1. Amylograms of millet meals.

Figure 2

Alpha Amylase Isolation



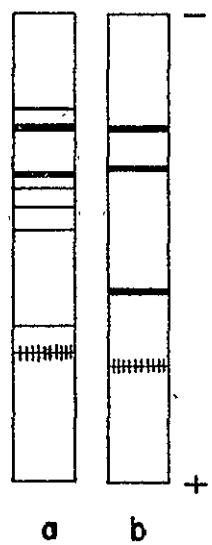


Figure 3. Polyacrylamide gel electrophoresis of alpha-amylase purified by the starch column (a) and by glycogen complex (b).

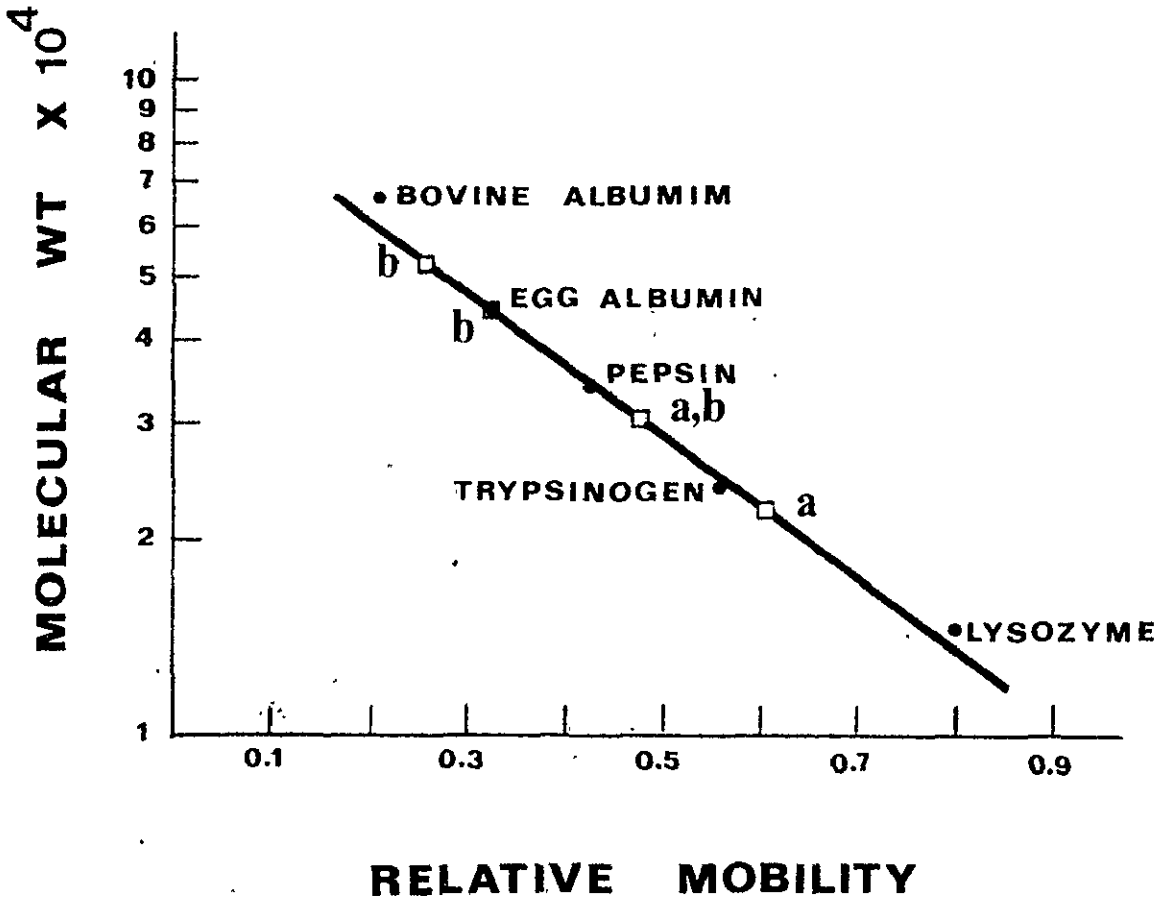


Figure 4. SDS gel molecular weight determinations of alpha-amylase purified by starch column procedures (a) and by glycogen complex formation (b).

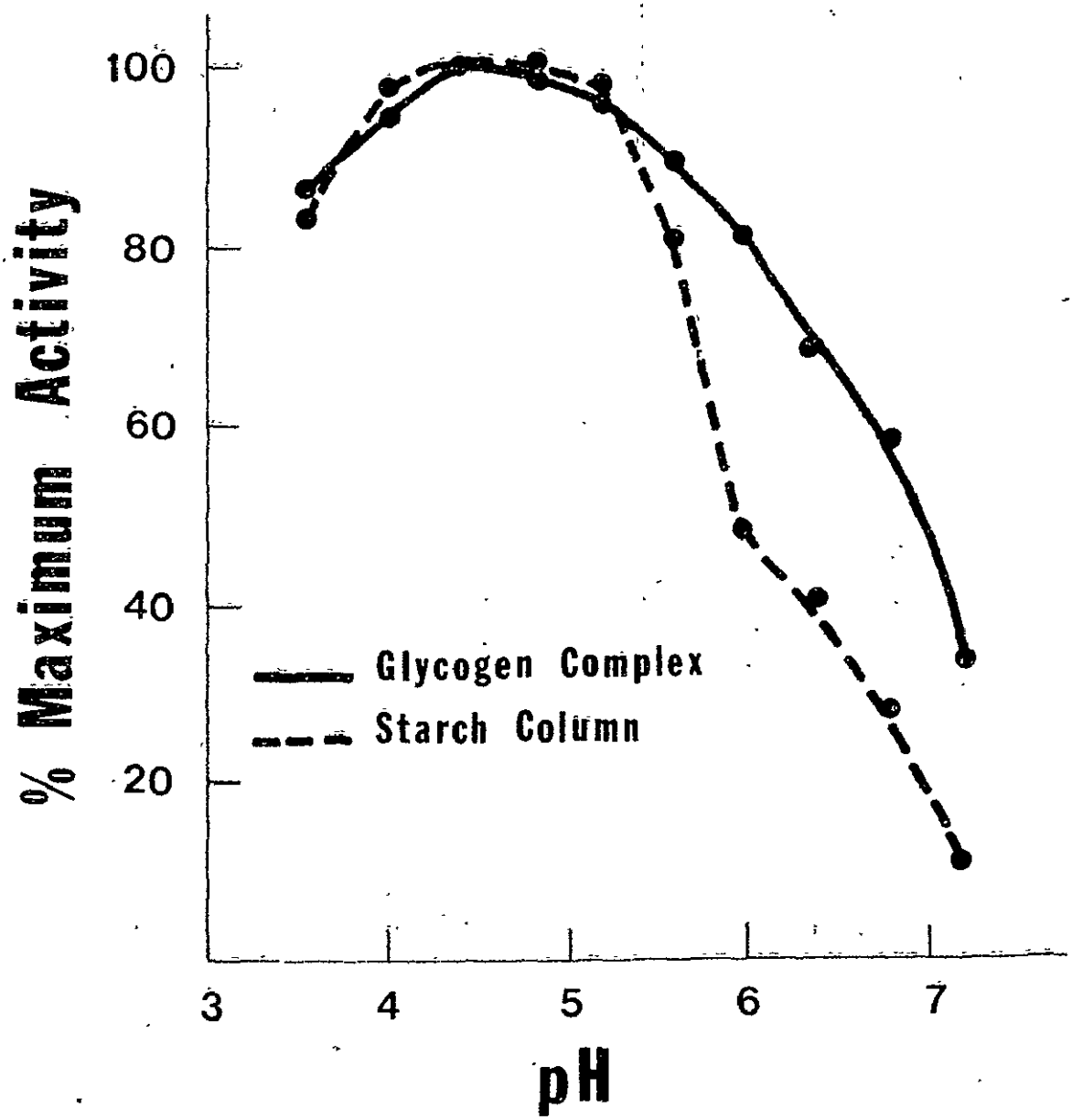


Figure 5. pH optima for alpha-amylase purified by the starch column procedure (---) and by glycogen complex formation (—).

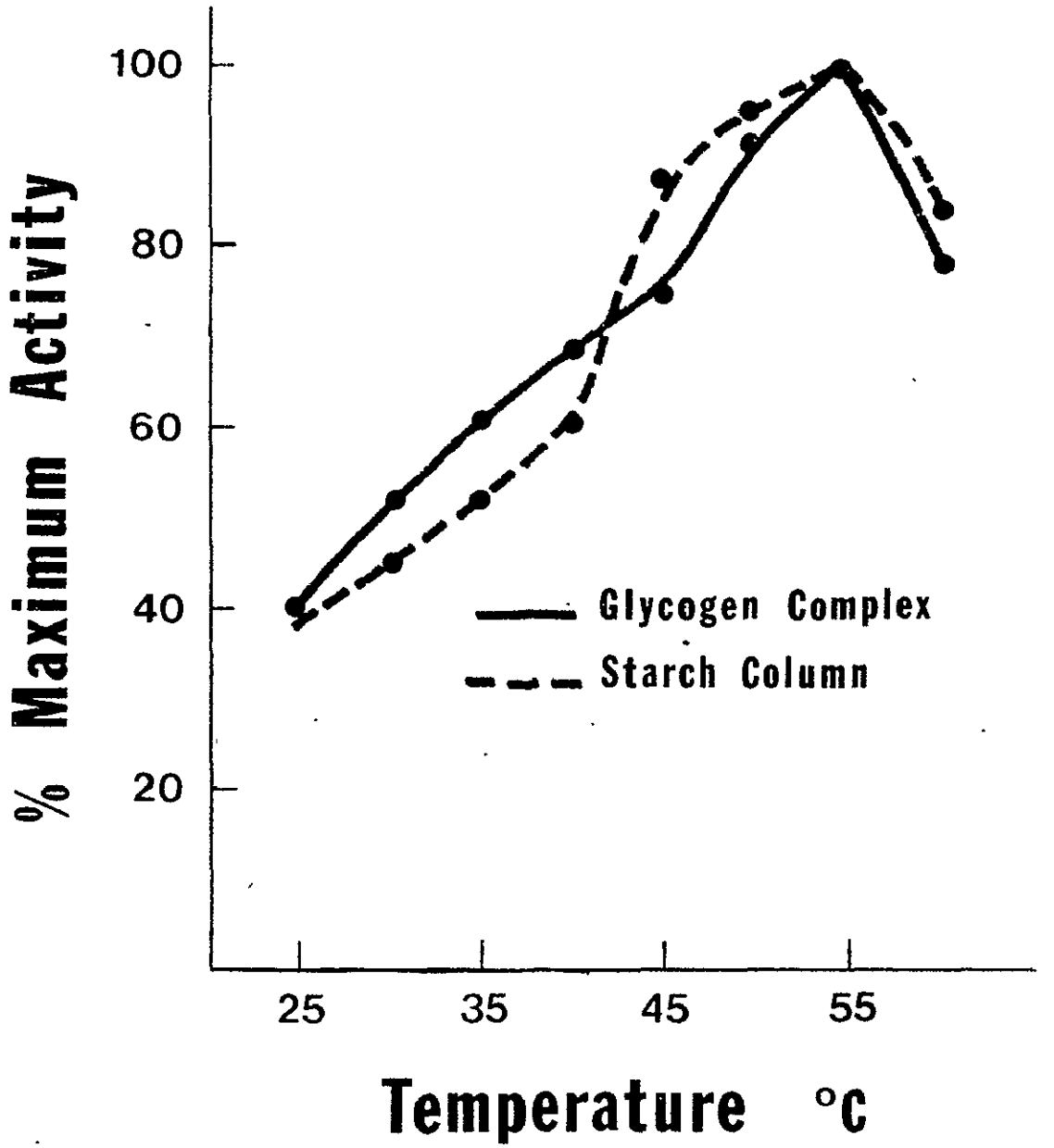


Figure 6. Temperature optima for alpha-amylase purified by the starch column procedure (---) and by glycogen complex formation (—).

LITERATURE CITED

American Association of Cereal Chemists. 1972. Methods 56.81B and 22-10. Cereal laboratory method (7th ed.). The Association: St. Paul, MN.

Badi, S. M., Hoseney, R. C., and Finney, P. L. 1976. Pearl millet. II. Partial characterization of starch and use of millet flour in breadmaking. Cereal Chem. 53:718.

Beleia, A., Varriano-Marston, E., and Hoseney, R. C. 1980. Characterization of starch from pearl millets. Cereal Chem. 57:300.

Davis, B. J. 1964. Disc electrophoresis II. Method and application to human serum proteins. Ann. N.Y. Acad. Sci. 121:404.

Dube, S. K., and Nordin, P. 1961. Isolation and properties of sorghum alpha-amylase. Arch. Biochem. and Biophys. 94:121.

Greenwood, C. T., and Milne, E. A. 1968a. Studies on starch degrading enzymes. Part VIII. A comparison of alpha-amylases from different sources: Their properties and action pattern. Die Starke 20:139.

Greenwood, C. T., and Milne, E. A. 1968b. Properties and action pattern of the alpha-amylase from barley, oats, rye and wheat. Starke 20:101.

Kulp, K. 1975. Carbohydrases. In: "Enzymes in Food Processing." Reed, G., ed., p. 54. Academic Press, New York.

Levitzki, A., Heller, J., and Schramm. 1964. Specific precipitation of enzyme by its substrate: The alpha-amylase-macrodextrin complex. Biochem. Biophys. Acta. 81:101.

Lowry, O. H., Rosebrough, N. J., and Farr, A. L. 1951. Protein measurement with the Folin Phenol reagent. J. Biol. Chem. 193:265.

Loyter, A., and Schramm, M. 1962. The glycogen-amylase complex as means of obtaining highly purified alpha-amylases. Biochem. Biophys. Acta. 65:200.

MacGregor, A. W. 1977. Isolation purification and electrophoretic properties of an alpha-amylase from malted barley. J. Inst. Brew. 83:100.

MacGregor, A. W. 1978. Alpha-amylase I from malted barley - Physical properties and action pattern on amylose. Cereal Chem. 55:754.

MacGregor, A. W., Thompson, R. G., and Meredith, W. O. S. 1974. Alpha-amylase from immature barley: Purification and properties. J. Inst. Brew. 80:181.

Miller, G. L. 1959. Protein determination for large numbers of samples. Analytical Chem. 31:964.

Nelson, N. 1944. A photometric adaptation of the Somogyi method for the determination of glucose. J. Biol. Chem. 153:375.

Novellie, L. 1962. Kaffircorn malting and brewing studies. XI. Effect of malting conditions on the diastatic power of kaffircorn malt. J. Sci. Food Agric. 13:115.

Purdy, L. H., Loegering, W. Q., Konzak, C. F., Peterson, C. J., and Allans, R. E. 1968. A proposed standard method for illustrating pedigrees of small grain varieties. Crop Sci. 8:405.

Reisner, A. H., Nemes, P., and Bucholtz, C. 1975. The use of coomassie brilliant blue G250 perchloric acid solution for staining in electrophoresis and isoelectric focusing on polyacrylamide gels. Anal. Biochem. 64:509.

Robyt, J. F., and Whelan, W. J. 1968. Amylases and their actions on starch. In: "Starch and its derivatives." Radley, J. A., Fourth Edition. Chapman and Hall LTD. Chap. 13.

Schwimmer, S. and Balls, A. K. 1949. Isolation and properties of crystalline alpha-amylase from germinated barley. J. Biol. Chem. 179, 1063.

Tkachuk, R., and Kruger, J. E. 1974. Wheat amylases II. Physical characterization. Cereal Chem. 51:508.

Vogel, S., and Graham, M. 1978. Sorghum and millet: Food production and use. Intern. Dev. Research Center 123 ed.

Walker, G. J., and Hope, P. M. 1963. The action of some alpha-amylases on starch granules. Biochem. J. 86:452.

Weber, K., and Osborn, M. 1969. The reliability of molecular weight determinations by dodecyl sulfate-polyacrylamide gel electrophoresis. J. Biol. Chem. 244:4406.

Wrigley, C. 1968. Gel electrofocusing - a technique for analyzing multiple protein samples by isoelectric focusing. Instr. J. 15:17.

PEARL MILLET AMYLASES. II. ACTIVITY TOWARDS INTACT GRANULES AND HEATED STARCH

Adelaide Beleia and E. Varriano-Marston

ABSTRACT

The effects of pearl millet amylases on intact granules and heated starch suspensions were studied. Amylases in crude millet extracts showed higher amylolytic action on wheat starch than on millet starch, both in the amylograph determinations and in studies on hydrolysis of raw starches. Products formed by the hydrolysis of raw and gelatinized starch, as well as millet starch fractions, by purified millet alpha-amylase were studied by paper chromatography. The action pattern of millet alpha-amylase was similar to other cereal alpha-amylases with the rate of appearance of hydrolysis products being dependent on the particular starch substrate.

INTRODUCTION

Pearl millet populations and hybrids, in general, contain an active amylase system, with purified alpha-amylase showing characteristics similar to those reported for amylases from immature cereal grains (Beleia and Varriano-Marston, 1981). Although pearl millet starch has been extensively studied (Badi et al., 1976; Beleia et al., 1980), no information has been published on its susceptibility to amylolytic attack. We report here the effects of pearl millet amylases on millet starch and starch fractions.

MATERIALS AND METHODS

Materials

A random mating bulk population of pearl millet (HMP 02), grown at Hays Branch Experiment Station in 1978, was used as the source of crude amylases and of purified alpha-amylase.

Commercial wheat starch was obtained from Midwest Solvents. Pearl millet starch was isolated from the grain according to Beleia et al. (1980). Starch samples contained less than 0.5% starch damage as determined by the AACC method (1972).

Alpha-Amylase Isolation

Alpha-amylase was isolated and purified from pearl millet by solvent fractionation and glycogen complex formation. Details of the purification procedure and enzyme properties have been presented (Beleia and Varriano Marston, 1981).

Starch Amylograms

We determined effects of crude enzyme extracts from pearl millet (HMP 02) on wheat and millet starch amylograms. Ground millet (3 to 60 g) was extracted with phosphate-citrate buffer (pH 5.3) for 1 hr and centrifuged at 4000 rpm for 15 min. Phosphate-citrate buffer was used to extract the amylase from the grain because that is the standard buffer used for determining diastatic activity in flours (AACC, 1972). The precipitate was discarded and the supernatant diluted with buffer to 460 ml. The resulting solution then was used to determine the effect of amylases on wheat starch (11% d.b., w/v) or millet starch (9% d.b., w/v) amylograms. Total enzyme concentration in the buffer-extract was estimated by the Phadebas method (Barnes and Blakeney, 1974). Phadebas tablets were calibrated against purified enzyme in milli Enzyme Units. One Unit of amylase activity was expressed as μmoles of apparent maltose produced per ml of digest per min. The starch suspension was heated from 30°C to 95°C in a Brabender Amylograph with a 700-cm gm head and operating at 75 rpm.

Paper Chromatography

The nature and sequence of products formed from various substrates by the action of purified alpha-amylase were determined by qualitative paper chromatography. The substrates studied were gelatinized and raw millet starch, and amylose and amylopectin prepared from millet starch by the method of Montgomery and Senti (1958). All substrates except raw millet starch were used at 0.5% concentration; raw starch was used at a concentration of 50 mg/0.5 ml of solution. For studies on starch fractions and gelatinized starch, we used an enzyme concentration of 430 mU/mg of substrate. Higher enzyme concentrations (2150 mU) were used for studies on raw millet starch. All samples were incubated at 35°C and sampled as hydrolysis progressed. A few drops of toluene were added to prevent microbial growth. Chromatograms were developed by the method of Robyt and French (1963). Carbohydrate standards were produced by acid hydrolysis of wheat starch and subsequent separation on a charcoal column.

Starch Hydrolysis

The hydrolysis of raw wheat and millet starch by a dialyzed crude extract of millet was followed by incubating 250 mg raw starch with 7 ml of millet extract (20 g meal + 50 ml 0.01M acetate buffer, pH 4.8, 0.01M $CaCl_2$) at 35°C. After designated times, the suspension was centrifuged (2500 rpm, 10 min), and total carbohydrate in the supernatant was determined by the phenol-sulfuric acid method (Dubois et al., 1956).

Scanning Electron Microscopy

Starch granules hydrolyzed by millet amylases were examined by scanning electron microscopy. Granules were separated from the amylase solution by centrifugation, rinsed three times with distilled water, and dehydrated with ethanol. The dried starch was sprinkled on double-sided adhesive tape which was attached to specimen stubs. Samples were coated with gold-palladium, and micrographs were taken on an Etec U-1 Scanning Electron Microscope at an accelerating voltage of 10 KV.

RESULTS AND DISCUSSION

Action of Millet Alpha-amylase on Heated Starch Pastes

Supplementing wheat flours with millet meal reduces the viscosity of flour pastes (Badi et al., 1976). To obtain a better understanding of what levels of alpha-amylase were required to significantly reduce the viscosity, we ran amylograms containing isolated wheat or millet starch and alpha-amylase. Millet meal was extracted with phosphate-citrate buffer, and the crude extract was used to run amylographs with wheat and pearl millet starches. An estimate of the total alpha-amylase activity in the extracts was determined by the Phadebas method (Barnes and Blakeney, 1974). Amylograms of millet starch showed a higher peak viscosity (1440 B.U.) than wheat starch (900 B.U.) at the same concentration, i.e., 11% (d.b.), so the concentration of millet starch was reduced to 9% (d.b.) to give a peak viscosity in the same range as that of the wheat starch.

The peak viscosity of the control wheat starch (900 B.U.) was reduced to 580 B.U., 300 B.U., and 250 B.U., respectively, by adding 2.4 U, 5.6 U, and 7.2 U of pearl millet alpha-amylase (Fig. 1). Pasting temperature was lowered and the shape of the curve broadened as amylase concentration increased. Those same alterations in amylograph curves were observed by Anker and Geddes (1944) when takadiastase was added to wheat starch. Since the amount of soluble starch is the major factor producing the amylograph consistency (Miller et al., 1973), a decrease in the pasting temperature results because the solubles are degraded by amylolytic attack.

Higher levels of alpha-amylase were needed to reduce the viscosity of millet starch pastes than were needed to reduce the viscosity of wheat starch pastes, indicating that millet starch was less susceptible to amylolytic degradation (Fig. 2). Because millet starch has a higher gelatinization temperature than wheat starch (Beleia et al., 1980), alpha-amylase had less time to degrade the millet starch before heat inactivation. The peak viscosity of the control millet starch (900 B.U.) was reduced to 850 B.U. by adding 16 U of millet alpha-amylase, while 48 U of millet alpha-amylase reduced the peak viscosity to only 420 B.U. (Fig. 2). Both pasting temperature and temperature at maximum viscosity were reduced, but shapes of the millet starch amylograms did not broaden as they did with wheat starch.

Hydrolysis of Raw Starch by Millet Alpha-Amylase

Although the amylograph may provide information related to changes in starch while millet is cooked, it supplies little information on the events that occur at room temperatures or at temperatures below 70°C, so we studied rates of hydrolysis of raw pearl millet and wheat starches by alpha-amylase at 35°C.

Percentages of raw wheat and millet starch hydrolyzed by amylases in a crude extract during a 32-hr reaction period are shown in Figure 3. Wheat starch was 30% hydrolyzed at the end of the time period, compared with only 19% of millet starch. These data confirm the amylograph results (Fig. 1 & 2) indicating that millet starch is less susceptible than wheat starch to

millet amylolytic attack.

Scanning electron micrographs (Figs. 4a-c) clearly showed the erosion of the granule surface by the amylases of the crude extract. Large wheat starch granules (Figs. 4a and b) and spherical millet starch granules (Fig. 4c) were preferentially attacked. Degradation of many of the large wheat starch granules was confined to the interior of the granule, leaving only an outer shell similar in structure to a mushroom cap (Fig. 4b).

Millet starch hydrolyzed by alpha-amylases in a heat-treated, crude millet extract showed no erosion at the surface of the granules, but pitting of the granules was apparent (Fig. 4d). Millet starch granules hydrolyzed by purified alpha-amylase (Fig. 4e and f) also showed signs of attack similar to the starch that was hydrolyzed by amylases in the heat-treated extract (Fig. 4d). Formation of deep pin holes into the granule surface appears to be a characteristic alpha-amylase mode of attack. Purified alpha-amylase attacked a higher proportion of millet polygonal starch granules than the other alpha-amylase preparations probably because of the higher enzyme concentration in that digest.

Hydrolysis Products of Alpha-Amylase Action

Paper chromatography was used to study the products formed by the hydrolysis of millet starch by purified alpha-amylase. Alpha-amylase purified from pearl millet produced the same general pattern of action on starch and its fractions as do other cereal alpha-amylases.

The products of millet amylose and amylopectin hydrolysis were essentially the same (Fig. 5). For both substrates, maltooctaose fragments were present after the first five min of hydrolysis, but disappeared after 15 min.[1]. From 3 to 12 hr, however, olygosaccharides with four to six glucose residues disappeared faster from amylose hydrolyzates than from amylopectin hydrolyzats. This suggests that the initial products of amylose hydrolyzates. This suggests that the initial products of amylose hydrolysis are more susceptible to further degradation by alpha-amylase than are products from amylopectin hydrolysis. The concentration of maltose in the hydrolyzates of both amylose and amylopectin increased throughout the reaction time. Such accumulation of maltose is characteristic of cereal alpha-amylase action patterns (Greenwood and Milne, 1968a).

Hydrolysis products of gelatinized millet starch after 30 min of digestion were glucose to maltoheptaose (Fig. 6). As the reaction progressed, higher molecular weight maltodextrins disappeared and after 72 hr only glucose and maltose remained. Maeda et al. (1978), using alpha-amylase purified from malted barley to hydrolyze soluble starch, found products ranging from glucose to maltoheptaose after one min of reaction, but after 30 min, only carbohydrate fragments containing one to three glucose units remained. Their much faster hydrolysis of soluble starch, compared with ours, probably stemmed from a higher enzyme concentration rather than to differences in enzyme source, because their hydrolysis products were essentially the same as those observed for pearl millet amylase action.

[1] The white streak, having the same Rf as glucose, is an artifact produced during chromatogram development.

Hydrolysis of raw millet starch by alpha-amylase (Fig. 6b) produced glucose, maltose, and maltotriose the first 5 hr of reaction. After 8 hr, maltotetrose could be detected, and at 72 hr traces of maltopentaose were present. Nordin and Kim (1959) found only low molecular weight sugars (glucose to maltotriose) in the hydrolyzates of raw sorghum starch by sorghum alpha-amylase after a 3 -day digestion period at 30°C. On the other hand, Maeda et al. (1978) found maltohexose, maltoheptaose, and higher molecular weight maltodextrins in 24 hr hydrolyzates of raw barley starch by malted barley alpha-amylase.

ACKNOWLEDGEMENT

We thank John Krchma, Entomology Department, for taking the SEM pictures.

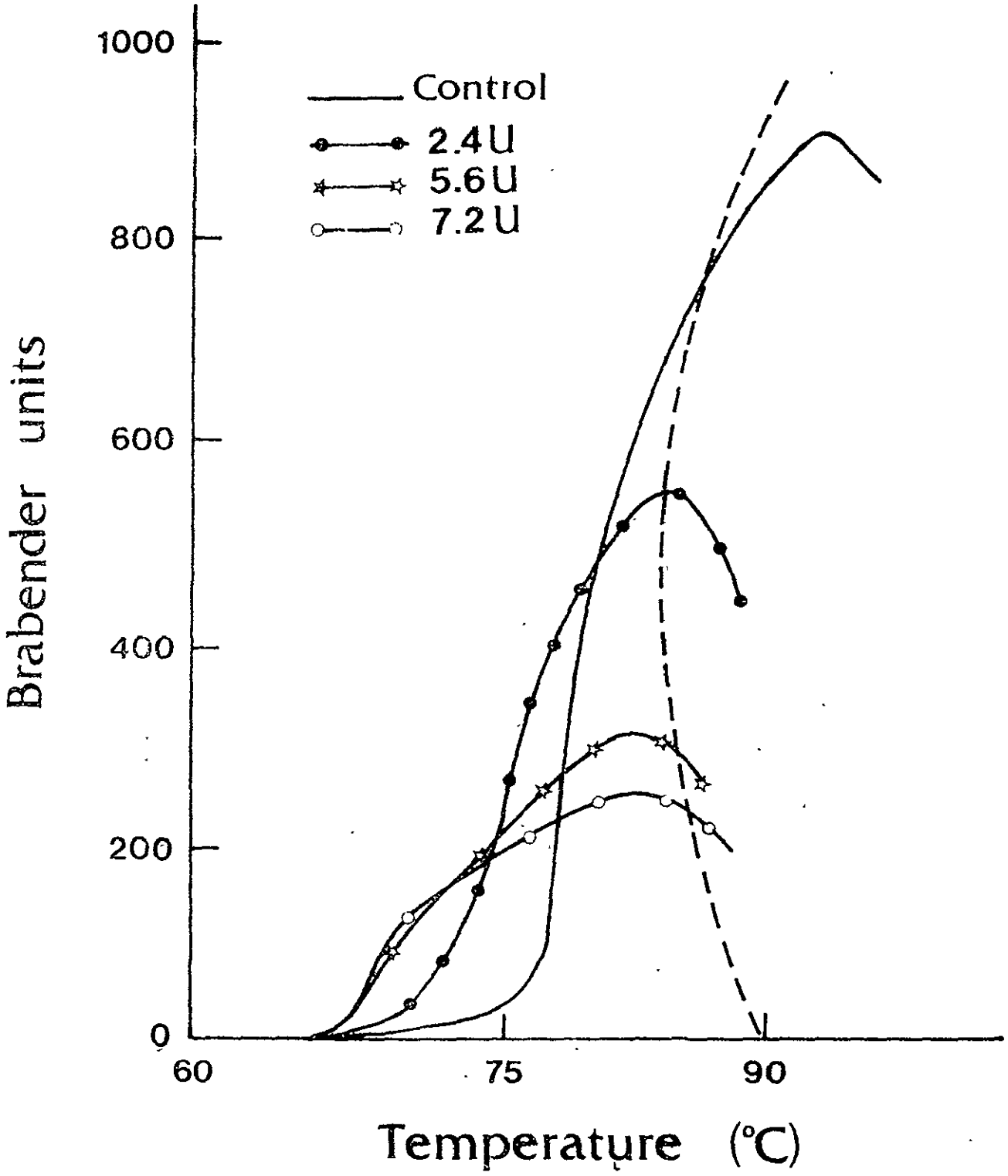


Figure 1. Amylograms of wheat starch and a buffer extract of millet meal.

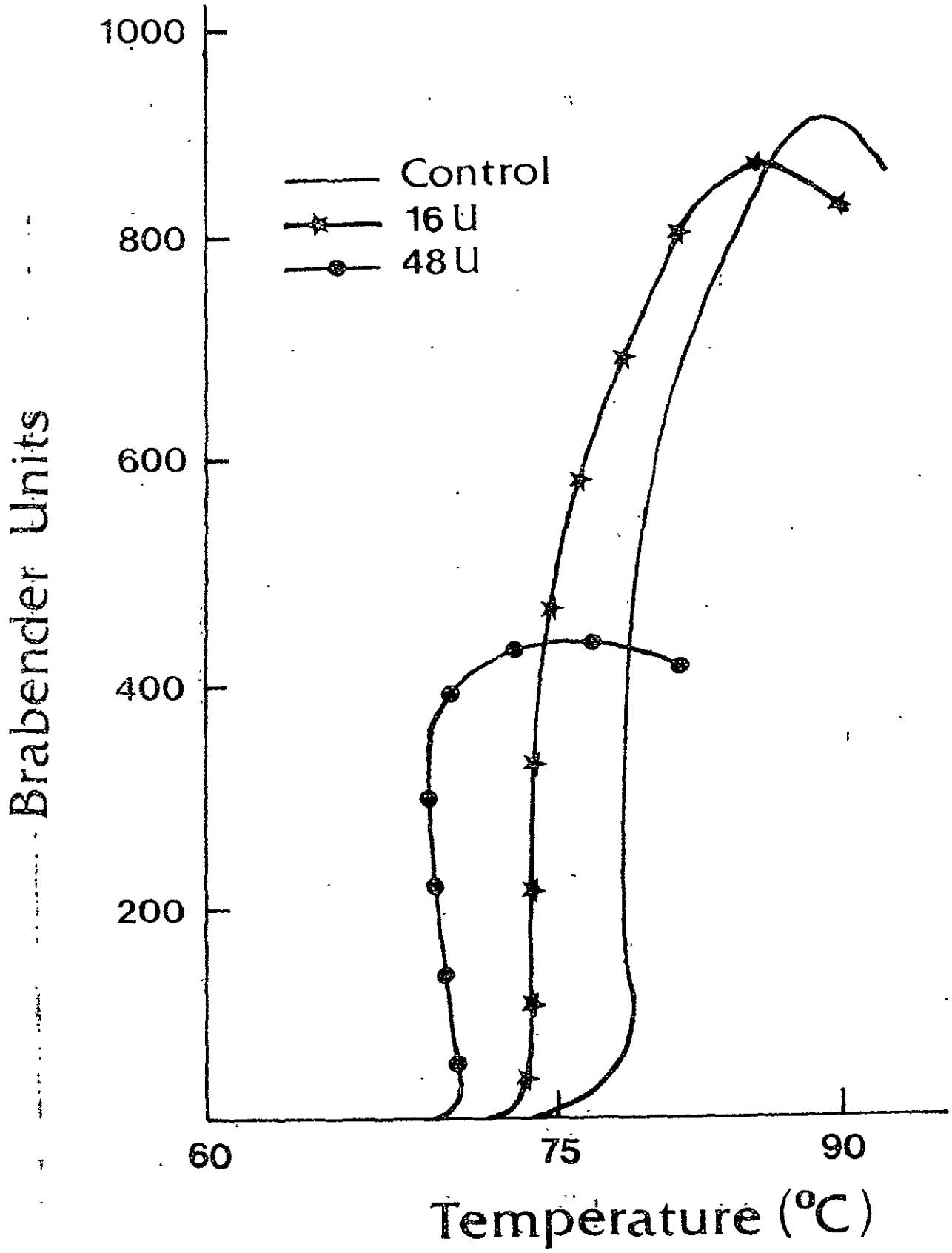


Figure 2. Amylograms of millet starch and a buffer extract of millet meal.

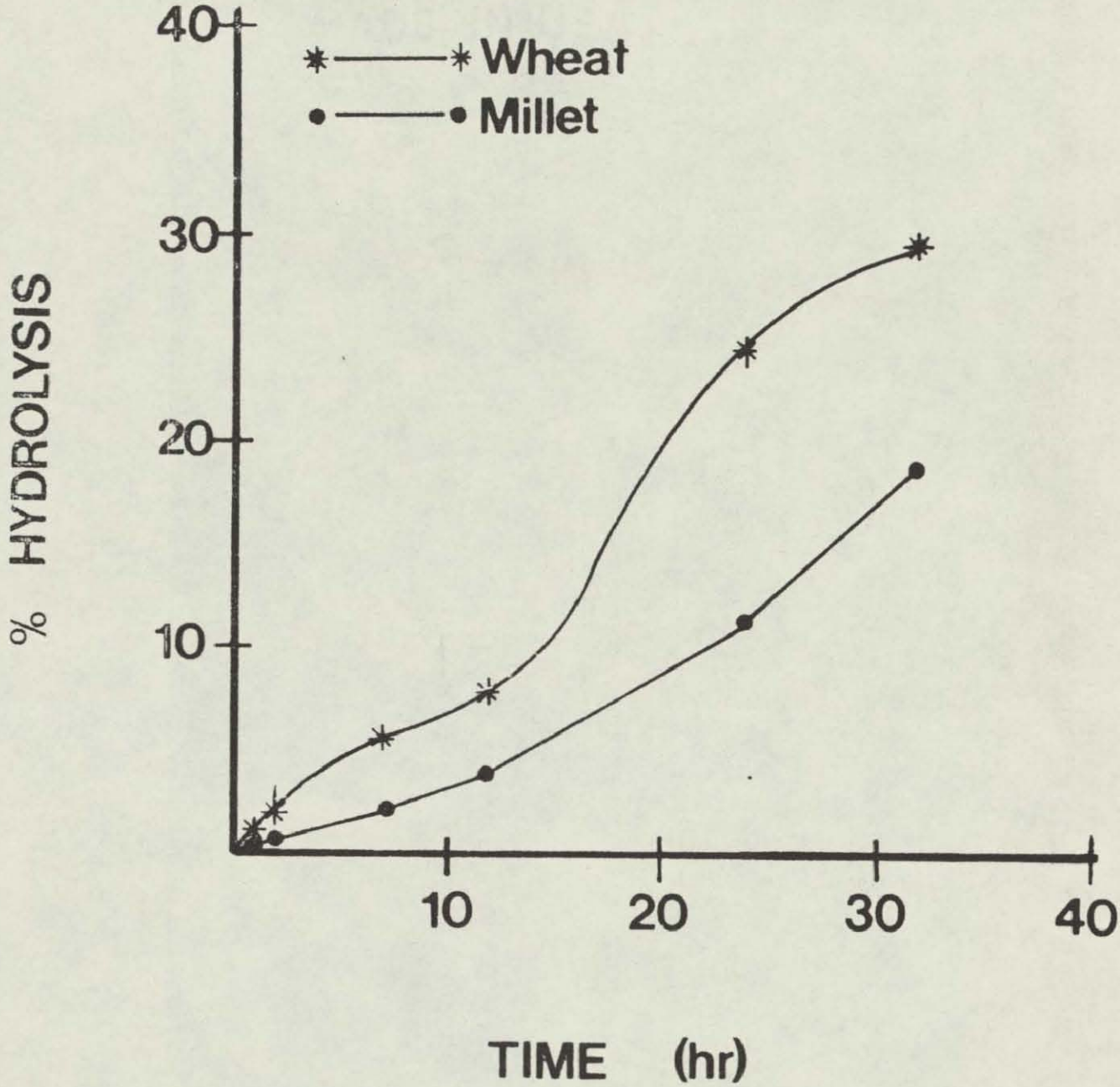


Figure 3. Percent hydrolysis of wheat and millet starch granules by amylases in a crude extract of millet meal.

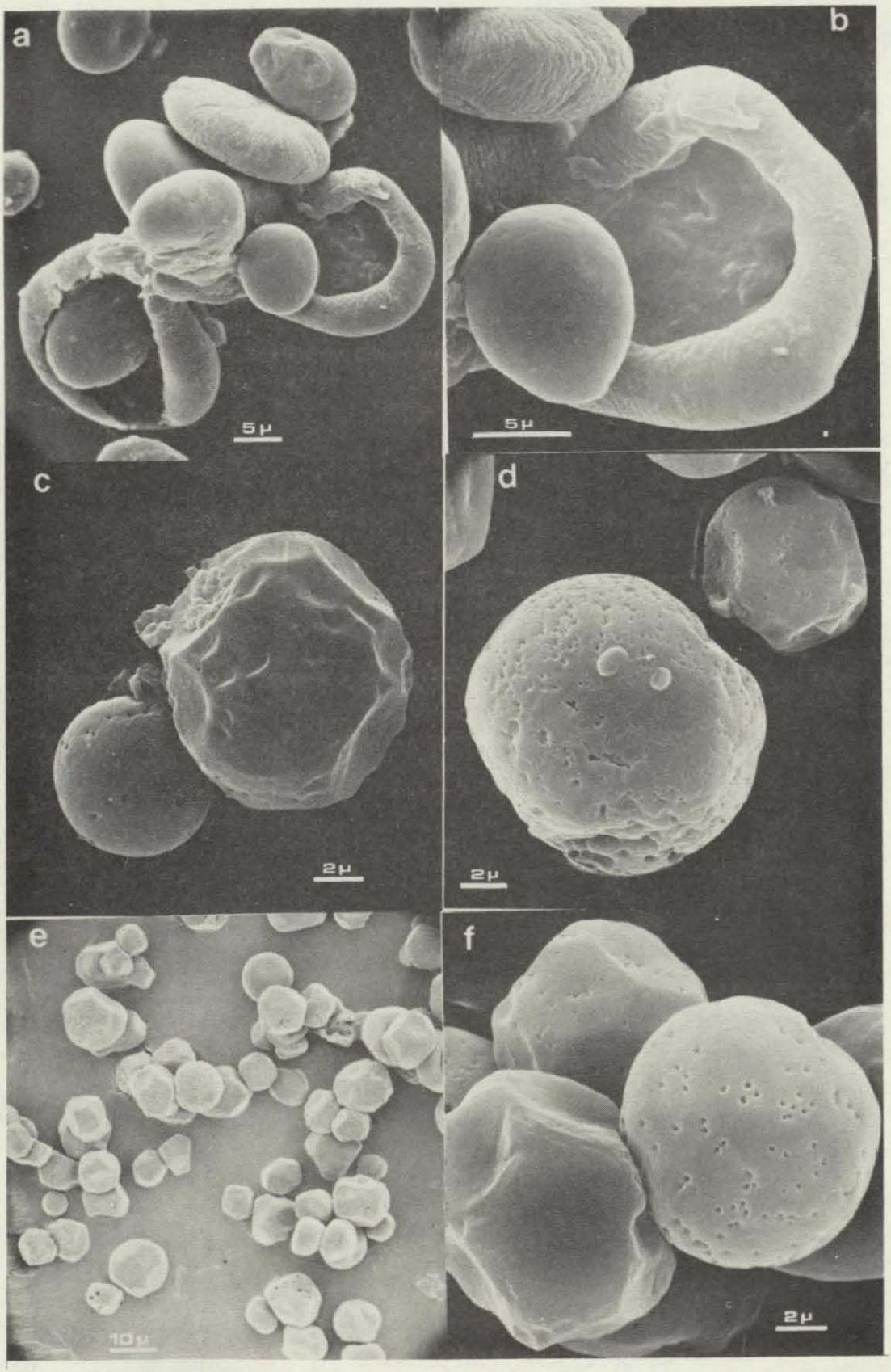


Figure 4. Scanning electron micrographs of wheat starch granules hydrolyzed by amylases in a crude (unheated) extract of millet meal (a, b); millet starch granules hydrolyzed by amylases in a crude (unheated) extract of millet meal (c); millet starch hydrolyzed by amylases in a heat treated extract of millet (d); and millet starch hydrolyzed by purified (glycogen complex) alpha-amylase (e, f).

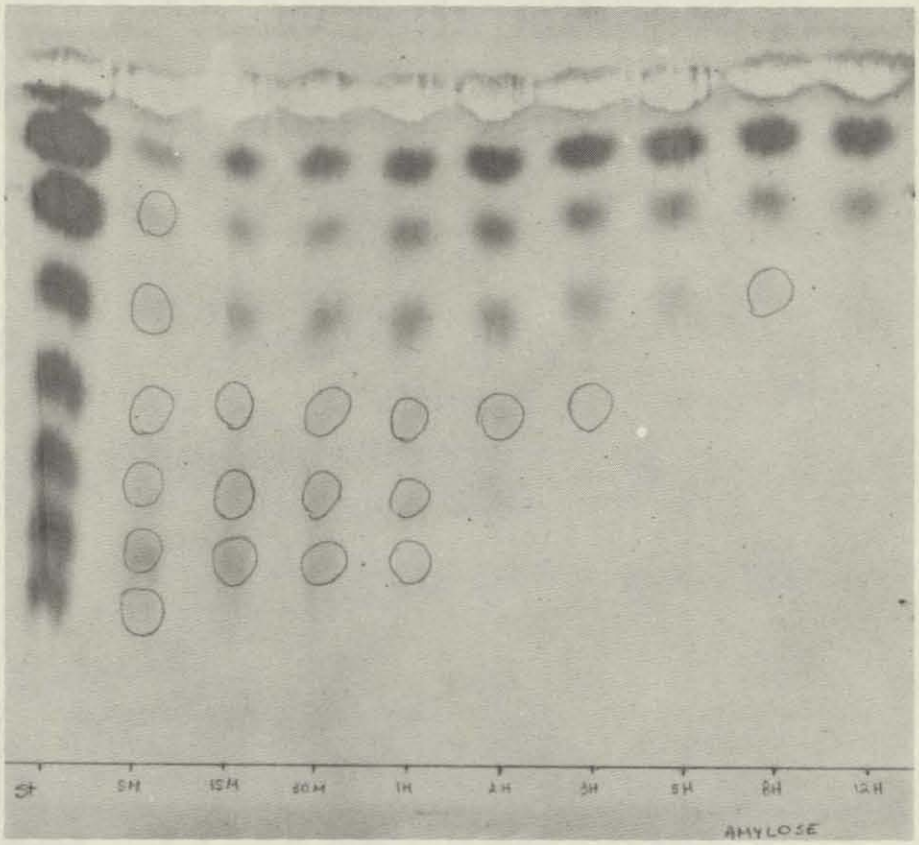


Figure 5. Chromatograms of products formed by the hydrolysis of millet amylose by alpha-amylases purified by glycogen complex formation (430 mU mg amylose). The standards (S) consist of carbohydrate fragments containing 1 to 8 glucose units.

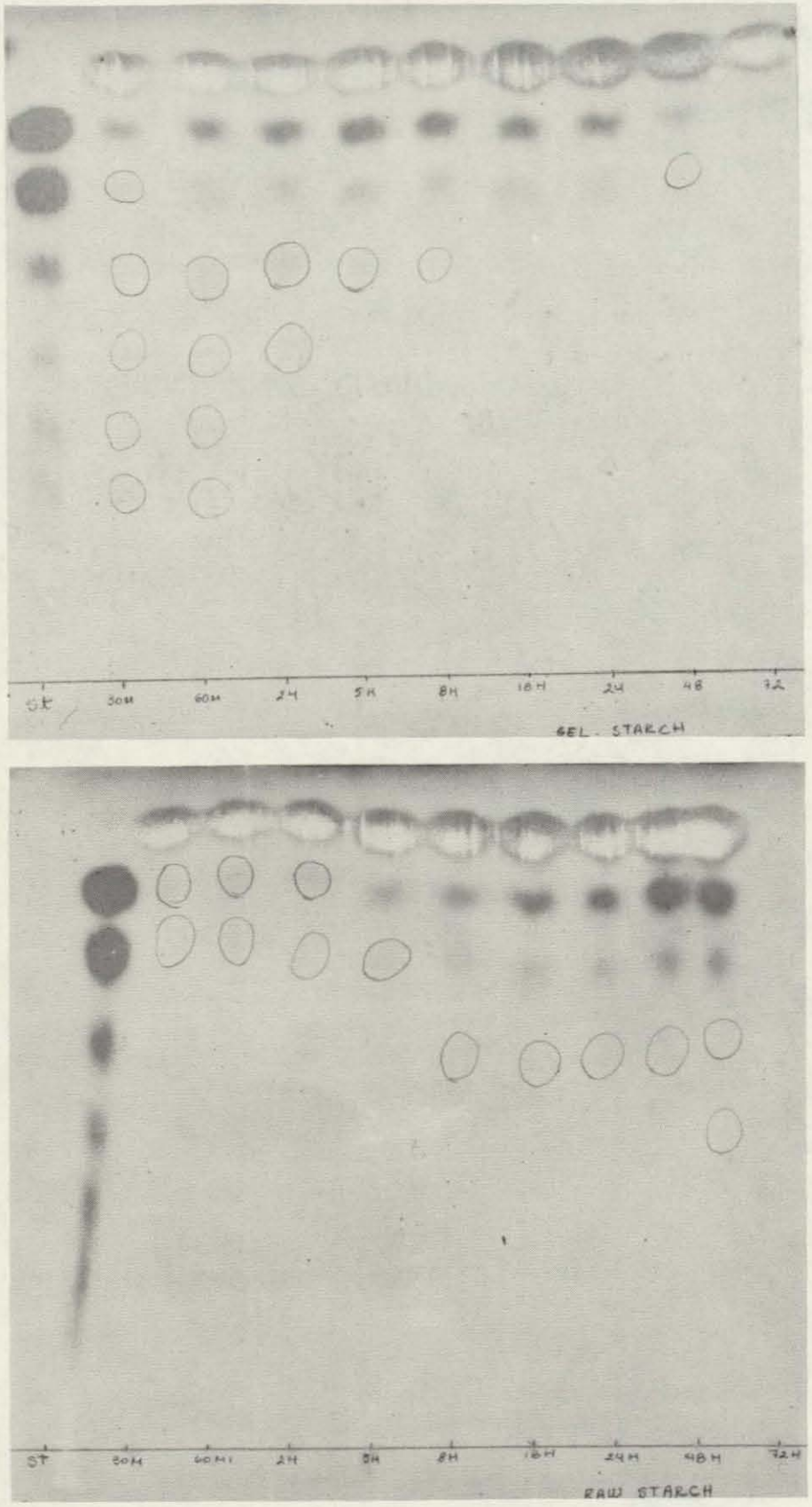


Figure 6. Chromatograms of products formed by the hydrolysis of gelatinized millet starch (a) and raw millet starch (b) by alpha-amylase purified by glycogen complex formation. Enzyme concentrations of 430 mU/mg gelatinized starch and 2150 mU/mg raw starch were used. The standards (S) consist of carbohydrate fragments containing 1 to 7 glucose residues.

FIGURE CAPTIONS

Figure 1. Amylograms of wheat starch and a buffer extract of millet meal.

Figure 2. Amylograms of millet starch and a buffer extract of millet meal.

Figure 3. Percent hydrolysis of wheat and millet starch granules by amylases in a crude extract of millet meal.

Figure 4. Scanning electron micrographs of wheat starch granules hydrolyzed by amylases in a crude (unheated) extract of millet meal (a, b); millet starch granules hydrolyzed by amylases in a crude (unheated) extract of millet meal (c); millet starch hydrolyzed by amylases in a heat treated extract of millet (d); and millet starch hydrolyzed by purified (glycogen complex) alpha-amylase (e, f).

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LITERATURE CITED

American Association of Cereal Chemists. 1972. Approved Methods of the AACC. Method 76-30A, approved May 1969, Method 22-10, approved May 1960. The Association: St. Paul, MN.

Anker, C. A., and Gedder, W. F. 1944. Gelatinization studies upon wheat and other starches with the amylograph. Cereal Chem. 21:335.

Badi, S. M., Hoseney, R. C., and Finney, P. L. 1976. Pearl millet. II. Partial characterization of starch and use of millet flour in breadmaking. Cereal Chem. 53:718.

Barnes, C. W., and Blakeney, A. B. 1974. Determination of cereal alpha-amylases using a commercially available dye-labeled substrate. Stärke 26:193.

Beleia, Adelaide, Varriano-Marston, E., and Hoseney, R. C. 1980. Characterization of starches from pearl millets. Cereal Chem. 57:300.

Beleia, A., and Varriano-Marston, E. 1981. Pearl millet amylases. I. Properties of partially purified alpha-amylase. Cereal Chem. Accepted.

Dubois, M., Gilles, K. A., Hamilton, J. F., Rebers, P. A., and Smith, F. 1956. Colorimetric method for determination of sugars and related substances. Anal. Chem. 28:350.

Greenwood, C. T., and Milne, E. A. 1968. Studies on starch degrading enzymes. Part VIII. A comparison of alpha-amylases from different sources: their properties and action pattern. Die Stärke 20:139.

Maeda, I., Kiribuchi, S., and Nakamura, M. 1978. Digestion of barley starch granules by the combined action of alpha- and beta-amylases purifed from barley and barley malt. Agric. Biol. Chem. 42:259.

Miller, B. S., Derby, R. I., and Trimbo, H. B. 1973. A pictorial explanation for the increase in viscosity of a heated wheat starch-water suspension. Cereal Chem. 50:271.

Montgomery, E.M., and Senti, F. R. 1958. Separation of amylose from amylopectin by an extraction-sedimentation procedure. J. Polymer Sci. 28:1.

Nordin, P., and Kim, Y. S. 1960. The reaction of amylases with starch granules. J. Amer. Chem. Soc. 82:4604.

Robyt., J., and French, D. 1963. Action pattern and specificity of an amylase from *Bacillus subtilis*. Arch. Biochem. Biophys. 100:451.

ANALYSIS OF PEARL MILLET FOR PROANTHOCYANIDINS, TANNINS AND OTHER PHENOLICS

Larry Butler, R. C. Hoseney, and E. Varriano-Marston

Six samples of pearl millet were sent to Dr. Butler, Department of Biochemistry, Purdue University. Dr. Butler has developed a battery of tests to characterize the phenolics in sorghum and agreed to submit the pearl millet samples to those tests. The results were quite clear, there were no significant amounts of tannins or proanthocyanidins in the pearl millet samples, the only assay which did not give zero numbers was the Prussian Blue assay for reducing equivalents (total phenols). The Prussian Blue results (Table 1) are uniformly comparable to those for RS 610, a standard low-tannin variety of sorghum, and far smaller than those for BR-64, a standard high-tannin sorghum.

Table 1. Assays for reducing power (eq / g) of pearl millet (Prussian Blue).

Sample	Whole grain	Extract	
		methanol	H+/methanol
Senegal (H)[a]	0.40	0.30	0.45
HMP 02 (H)	0.15	0.17	0.27
HMP 559	0.24	0.24	0.31
1166 x 1700 (T)	0.33	0.27	0.38
2090 x 7101 (S)	0.35	0.30	0.32
2118 x 7024 (H)	0.25	0.24	0.38
BR-64 (High tannin sorghum)	1.64	4.37	1.14
RS 610 (Low tannin sorghum)	0.32	0.37	0.27

[a]Grown in Hays (H), Tribune (T) or St. John (S), Kansas in 1979.

PRELIMINARY PEARL MILLET ROTI METHOD

B. Mason and R. C. Hoseney

INTRODUCTION

In India, pearl millet (*Pennisetum americanum*) grain is consumed primarily by the rural population of Fajasthan, Mahasta, and Mysore states. It is eaten in the form of an unleavened, pan-baked bread called a chapati or a roti (Upretty and Austin, 1972). The latter term is preferred because it distinguishes the pearl millet product from the customary wheat chapati and will be employed in this paper. No published methods for preparing experimental roties were found, although several such methods have been reported for chapaties (Murty and Austin, 1963; Sinha, 1964; Chaudry, 1968; Archer, 1970; and Rashid, 1974). Pearl millet does not have the gluten forming properties of wheat flour accordingly the chapati dough behaves differently from the roti dough. In short, the roti dough traps gas less readily and tears more easily when handled. It is the purpose of this paper to report preliminary efforts to adapt the chapati making methods cited above, along with those learned through personal communication, for the reproducible preparation of pearl millet roties.

Chapati Preparation in the Home

Indigenously, chapaties are made from stone ground wheat flour from which the larger bran particles have been removed to yield an extraction rate of 85 to 100 percent (Rashid, 1974). The flour is mixed with water and sometimes fat and salt to produce a dough of the proper consistency (quite slack relative to a bread dough). The dough is then rested under a cover or a moist cloth. Following the rest period the dough is divided and each piece is rolled between the palms of the hands to form a round dough ball. The dough balls are rolled or patted into a disc before being baked and puffed on a greaseless iron plate or in a mud-walled oven. The time required for cooking which of course depends upon the temperature of the plante and the size of the chapati was 3 minutes for one study by Indian researchers who used a 220 to 240°C grill (Rao et al., 1964). Puffing of wheat chapaties may be spontaneous on a hot surface but it is also encouraged in the home by tamping the baking dough's upper surface with a moistened cloth or by flaming the baked chapati. Chapaties are generally eaten soon after preparation.

Quality Parameters in Chapaties and Roties

Since a roti is an ersatz chapati a consideration of desirable chapati quality is helpful in defining what a roti would be. Aziz (1960) observed that a chapati should be flexible with a soft and silky surface. The mouthfeel should be smooth with the chapati easily chewable. The chapati should resist staling. Ahmad (1960) also noted that the thickness and texture of

the chapati should be uniform across its diameter. Sinha (1964) pointed out that a chapati should not be leathery, tough, brittle, or gritty and that the chapati should be well puffed on both sides and well baked inside. These qualities can be approximated in a roti although the latter product must be thicker to compensate for decreased dough strength.

In the present study the following roti characteristics were sought: 1) minimal thickness; 2) puffing throughout roti; 3) centering of cleft between upper and lower surfaces; 4) flexibility; 5) tan to golden brown surface color; 6) uniformity of texture and color across roti; 7) adequate internal cooking; 8) chewy rather than gummy or brittle texture; and 9) appetizing aroma and taste. The ultimate reference in this study was the subjective evaluation by two Indian food technologists who grew up near Hyderabad, ate roties in their family homes, and now study and work at Kansas State University. The procedure reported below was found to produce a roti comparable to roties these gentlemen (P. R. Reddy and H. S. Sharma) ate at home.

Factors Affecting Chapati Quality

Several factors have been reported to affect chapati quality. Aziz and Bhatti (1962) reported that finer flour granulations were preferable and suggested that this might be due to improved water absorption. Ahmad (1960) noted that the level of water absorption was critical but that there was not a good objective approach for the determination of optimum water absorption. The methods employed for the determination of water absorption in breadmaking are not directly applicable because of the increased slackness of the chapati dough. High diastic activity wheat varieties are sometimes considered desirable (Singh and Bailey, 1940). Knight (1965) considered the advantages of dough resting and suggested that improved hydration of starch and protein afforded optimum dough development and a more pliable chapati.

Evaluation of Chapati Quality

Most of the chapati studies to date have based product evaluation on taste panels (Murty et al., 1963; Chaudry, 1968; and Archer, 1970). Rashid (1974) employed the Instrom Universal Testing Machine to measure textural properties of chapaties. Three tests were used; pull-break, hole punching, and compression. In the present study product quality was estimated as per the desired characteristics outlined above under "Quality Parameters in Chapaties and Roties".

Proposed Roti Method

The following represents the roti method found to be most staisfactory. The procedure is followed by descriptive and explanatory notes regarding certain steps.

1. Mix 50 g millet flour with 38 ml boiling water using a spoon. When the mixture is adequately cool, work the dough by hand to achieve a uniform consistency.

2. Roll the dough into a ball and place the ball in a zip-lock plastic bag for 60 minutes at room temperature.

3. Remove the dough ball from the bag and place it on a tray covered with dusting flour and dust the top of the dough itself.

4. Pat the ball into a flat disc with intermittant dustings, flips, and thickening of the disc's periphery. Continue until the disc is 15 cm in diameter.

5. Invert the disc and dust and pat the underside of the molded roti.

6. Transfer the unbaked roti to a 200°C, ungreased grill.

7. Bake on side 1 for 90 seconds. During the last 15 of the first 90 seconds apply about 4 ml of water uniformily over the roti's exposed surface and rub the water into the dough.

8. Flip the roti and bake for 90 seconds on side 2.

9. Flip the roti and bake again for 90 seconds on side 1.

10. Flip the roti and bake again for 90 seconds on side 2.

11. Transfer the roti to a tripod ring stand with side 1 down. Flame the entire surface of side 1 over a period of about 10 seconds using a bunsen burner.

12. Invert the roti and flame side 2. This time begin at the center and spiral outward as the flamed area puffs.

Descriptive and Explanatory Notes Regarding Roti Method

Each note is proceded by the number of the step to which it refers.

1. Boiling water was found to improve the cohesiveness of the dough and therefore increase the ease with which roti dough is formed and handled. The flour used included the high ash and low ash flour streams from a Brabender Quadrumat Junior Experimental Mill and corresponded to an extraction rate of 60%.

2. Resting improved the 'smoothness' of the roties' texture as well as the uniformity of the color and texture. A 60 minute rest was decidedly better than a 30 minute rest.

4. During flattening of the dough ball it may become apparent that the dough's consistency is too dry or too sticky. Additional water mixed in thoroughly will prevent excessive cracking of the dry dough. Additional amounts of flour will render a wet dough easier to handle without tearing.

   The elimination of cracks around the roti's perimeter is critical to puffing as these fissures along with surface scars constitute the main causes of steam pressure loss.

   Thickening is achieved by pushing the outer edge toward the center of the disc and sealing any cracks present with a downward pressure on the dough at the points of fissure.

   Doughs containing 50 g flour will be about 4 mm thick when 15 cm wide.

5. To prevent excessive drying and brittleness the roti surfaces must be well dusted prior to baking. To invert the fully molded roti gently slide a spatula between the dough and the tray to free the disc. Invert the tray and allow the disc to fall onto the free hand. It is important to seal all cracks in the roti prior to baking. But even if no cracks are present a brittle roti surface will fracture under the pressure of trapped steam and no puffing will occur.

6. A 200°C grill allowed thorough cooking of the roti without burning or drying of the surface. Inasmuch as published chapati studies (Rao et al., 1964) also employed some higher temperatures for baking, greater grill temperatures should be tested as well.

7. The water applied in this way appeared to aid in the formation of the internal cleft and in the puffing phenomenon.

11. The brief flaming of side 1 (which has the lesser gas holding ability) appeared to help center the cleft within the roti.

12. Flaming is done over a fire in the homes where roties are eaten.

SUMMARY

The experiments reported above were preliminary efforts toward adapting laboratory chapati methods to the preparation of roties for pearl millet flour quality evaluation and other analytical purposes. Subsequent studies are needed to further clarify the optimum procedure for laboratory use. Studies employing higher grill temperature, added salt, added fat, higher extraction flour, and more precise control of flour-water absorption and dough rheology will be especially beneficial.

REFERENCES

Ahmad, H. 1960. Rheology of wheat flour. Pakistan J. Sci. 12:287.

Archer, J. L. 1970. Performance of protein supplemented flours in chapatis. M. S. Thesis, Kansas State University, Manhattan, KS.

Aziz, M. A. 1960. Cereals and Pulses. A resume of 50 years research work at the Punjab Agricultural College and Research Institute, Lyallpur, Pakistan, Department of Agricultural, Lahore, West Pakistan.

Aziz, M. A. and Bhatti, H. M. 1962. Quality considerations for chapatis (unleavened pancakes). Agricultural (Pakistan) 13:157.

Chaudry, M. S. 1968. Preparation and evaluation of attas and chappatis from U.S. wheats. Ph.D. Thesis, Kansas State University, Manhattan, KS.

Knight, J. W. 1965. The Chemistry of Wheat Starch and Gluten and their Conversion Products, Leonard Hill Publishers, London.

Murty, G. S. and Austin, A. 1963. Study on the quality characteristics of Indian wheats with reference to chapati making. Food Science (Mysore) 12:61.

Rao, G. K., Malathi, M. A., and Vijayaraghavan, P. K. 1964. Preservation and packaging of Indian foods. I. Preservation of chapatis. Food Technology (India) 18:108.

Rashid, J. 1974. Triticale as a cereal for chupatty making. M.S. Thesis, University of Strathcylde, Glasgow, Scotland.

Sinha, A. C. 1964. Quality of chapatis from Indian and imported wheats. Bull. Grain Technol. (India) 2:53.

Singh, R. and Bailey, C. H. 1940. A biochemical and technological study of Punjab wheat varieties. Cereal Chem. 17:169.

Upretty, D. L. and Austin, A. 1972. Varietal differences in the nutrient composition of improved bajra (pearl millet) hybrids. Bull. Grain Technol. (India) 10:249.

DEVELOPMENT OF PEARL MILLET BASED GRUELS AND STEAMED CAKES DESIGNED FOR INFANT AND PRESCHOOL CHILDREN FEEDING IN CAMEROON

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Ms. Ngo Som was a Ph.D. student in the Department of Foods and Nutrition at Kansas State University. Her home is Cameroon. She was not paid on the project but received support in the form of ingredients, analytical results, etc. Her complete Ph.D. dissertation would be available to interested parties from Dissertation Abstracts.

The study was designed to develop acceptable gruels and steamed cakes for infants and preschool children. The food was to be based on pearl millet and to use other ingredients commonly available in Cameroon.

As the result of preliminary work, the formula given in Table 1 was adopted. The preparation of the gruel was as follows:

1. To millet flour add water and lemon juice stirring well.
2. Add goundnut flour, salt, sugar, ginger, and stir to a smooth paste.
3. Blend egg and oil for 30 sec. at medium speed and stir into the millet-groundnut mixture.
4. Cook the mixture over medium heat until the temperature reaches 85°C, stirring constantly to avoid lumps.
5. The formula given produces about 500 ml of gruel.

Procedure for steamed cakes:

1. To millet flour add half of the water and lemon juice and mix into a smooth paste.
2. Add and mix groundnut flour, salt, sugar, and ginger.
3. Blend eggs, oil, and other half of water for 30 sec. at medium speed.
4. Add the blended liquid to the paste, a small amount at a time with mixing at each addition.
5. After the last addition, hand mix for an additional 3 min.
6. Transfer the mixture into 3-100 ml custard cups.
7. Place custard cups into a custard pan with racks.
8. Steam for 40 min. in oven at 190°C.
9. Let cool at room temperature for 5 min., invert cups to release cakes.

Pearl millet flour (PMF) of 75% extraction and a food-grade groundnut flour (GNF) were used. Lemon juice, egg, oil, sugar, salt, and ginger, all available in Cameroon, were added. Protein contents, essential amino acid patterns, and chemical scores were estimated from proximate and amino acid analyses of the pearl millet and groundnut flours. Selected gruels and steamed cakes were freeze-dried and their protein content, essential amino acid patterns, and chemical scores determined. Gruels and steamed cakes were evaluated for color, aroma and flavor (blandness), texture (grittiness), consistency (thickness), and moistness by five taste panelists. The flavor profile of selected gruels and steamed cakes was analyzed by six trained judges. Percent reflectance, Hunter L-values, and pH of gruel and steamed cakes pastes were measured.

Supplementation of pearl millet flour with groundnut flour increased protein content and chemical scores. The addition of eggs increased the protein quantity and improved the protein quality in gruels and steamed cakes. Color scores, % reflectance and Hunter L-values indicated that the addition of lemon juice to gruels and steamed cakes significantly improved their color (from dark grey to creamy light). Flavor and aroma scores showed no significant (α = .0.5) differences in blandness for steamed cakes or gruels. Steamed cakes or gruels supplemented with 20 and 30% GNF were significantly less smooth than those made from 100% PMF. Gruels treated with lemon juice were significantly thinner than those with no lemon juice added. There were no significant differences in moistness among the steamed cakes. Flavor profile analysis showed the gruels made from 70% PMF + 30% GNF were fruity, cereal-like, nutty and sweet. Steamed cakes of the same composition had cereal-like, sweet, and nutty flavors.

It can be concluded from this investigation that gruels and steamed cakes made from 70% PMF + 30% GNF can be easily prepared at home. They are palatable and nutritious. The gruels and steamed cakes are creamy in color, and have a nutty, fruity flavor and sweet taste. Two servings of gruels or steamed cakes provide 30.5g and 36.7g protein, respectively, per day. Those values are higher than the 1973 FAO requirements for infants and preschool children.

Table 1. Formula adopted for gruel and steam cake.

Ingredient	Gruel g.	Steam cake g.
Pearl Millet Flour	70	70
Groundnut Flour	30	30
Sugar	100	50
Oil	20	40
Lemon juice	10	15
Whole egg	100	100
Water	800	135
Salt	4	3
Ginger	2	2
Banana	200	-

HARDNESS OF PEARL MILLET AND GRAIN SORGHUM

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ABSTRACT

The hardness of various populations of pearl millet and cultivars of grain sorghum was determined by particle size analysis after milling the grains on attrition and roller mills. Sudan grown millets were in general, softer than Kansas grown populations. However, the degree of kernel vitreosity did not parallel the hardness of the grain as determined by particle size analysis. Futhermore, tempering either millet or sorghum before milling did not significantly change the particle size distribution compared to nontempered samples.

INTRODUCTION

Grain hardness has always been a major concern of the miller because it determines grinding time and energy expenditures as well as the performance and appearance of the final product. Grain hardness also is a concern of people in developing countries where much of the milling is done by hand using wooden or stone mortars or hand operated stone mills (Vogel and Graham, 1979).

Although a substantial number of reports have dealt with measuring wheat hardness (for review see Obuchowski and Bushuk, 1980), only limited data are available on hardness of grain sorghums and pearl millets (Rooney and Sullins, 1969, 1970; Maxon et al., 1971). Our objective was cultivars of grain sorghum by characterizing the particle sizes after milling the grain in attrition and roller mills.

MATERIALS AND METHODS

Materials

The proximate composition and pedigree of the millet and sorghum samples studied were described in a previous report (de Francisco et al., 1981). One other pearl millet that was studied, HMP557A had a proximate composition of 10.4% protein, 9.8% moisture, 1.6% ash, and 5.7% fat, and it was grown in Minneola, Kansas in 1979.

Grain Cleaning

The millet samples were cleaned in a laboratory rice cascating aspirator to remove light weight debris. Adhering glumes were removed in a Satake rice polisher and broken and undersized kernels were removed by passing the grain over an 8 in. dia. Tyler Rotap sieve with 2362 μ openings. Glumes on sorghum kernels were removed by hand.

Moisture Determination

Moisture contents of millet and sorghum were determined by the AACC method (1972).

Milling and Sieving Studies

Grain samples (50 g) were milled in a Hobart coffee grinder attrition mill, Model 275 (Hobart MFG. Co., Troy, Ohio), at the finest setting. The milled product was then collected and placed on a stack of 8 in. dia. Tyler Rotap sieves (Table 1) for one min. to separate the different particle sizes.

The separated particles were combined into two fractions. One fraction, called the fines, consisted of the overs of the 295, 208, 147 μ sieves and the pan fraction. The other fraction, the coarse particles, included the overs of the 1191, 833, 589, 417 μ sieves. Those two fractions were milled separately in a Ross laboratory mill equipped with smooth rolls at gaps of 80 and 100μ, respectively. Sieve analysis was then performed on the Tyler Rotap sifter as described above.

Tempering of Millet and Sorghum

Sudan yellow and Serere millets were conditioned for 15 hours to 15, 18 and 21% moisture content. The Motomco moisture meter was used to check the final moistures. Additional tempering of Serere to 18 and 21% moisture content was done for 15 hours with 0.5% sodium metabisulfite, a starch-protein bond weakening agent described by Badi et al. (1978).

Scanning Electron Photomicrographs

Samples of the fine fractions (< 417μ) were dusted on double-sticky tape mounted on alumnium stubs. Coarse fractions (> 417μ) were mounted on stubs with conductive silver paste. Samples were coated with a 150-Å thick, gold-palladium layer viewed and photographed in an ETEC U-1 autoscan electron microscope at an accelerating voltage of 20 kV.

RESULTS AND DISCUSSION

Millet

Visual observations on hand-dissected kernels of pearl millet (Fig. 1) show that the populations are different in their proportion of trans-

lucent and opague endosperm. Serere 3A, RMPI(S)CI, and Sudan green have a higher proportion of translucent endosperm than do HMP550 or Sudan yellow. It has generally been assumed that opaque endosperm is synonomous with soft endosperm. To test that assumption, we used a series of milling and sieving operations to study the relationship between vitreosity (and opacity) of millet samples and physical hardness as determined by particle size distribution.

Grinding pearl millet samples in the Hobart mill did not differentiate the samples based on particle size (Fig. 2). If the opaque endosperm was soft, it should have broken into smaller particle sizes during Hobart milling. Similar grinding of soft wheat gave a finer particle size distribution (Fig. 3). Further grinding of millet fine particles (<417μ), persumably originating from the opaque endosperm, in a Ross laboratory mill equipped with smooth rolls, did not change the particle size distribution of the fine fraction. Thus, that fine fraction is characterized by strong bonds between starch granules and protein matrix (Fig. 4) which is typical of hard endosperm particles.

Milling the coarse fractions (>417μ) with Ross smooth rolls shifted the particle size distribution to finer sizes (Fig. 5). That reduction in particle size is not a reflection of grain softness but simply that larger particles are easier to reduce.

In general, the millet samples could be divided into two groups according to their particle size distribution after Ross milling (Fig. 5). Group I (relatively large particle sizes) included all the millets grown in Kansas. Millets obtained from Sudan form the second group and gave smaller particle size distributions than the Kansas grown millets. Those results show that the large endosperm particles of the millets obtained from Sudan were softer and therefore more easily disrupted during milling than were the large particles from millets grown in Kansas. Millets obtained from Sudan, while softer than the other millets, were still much harder (i.e. gave larger particle sizes) than a soft wheat (Fig. 3).

Sorghum

To determine if grain sorghums showed the same milling characteristics as pearl millets, three experimental sorghum lines, SRAI W6, SRAI W4, and Dwarf White (PI400226(, were ground in the Hobart mill. They all gave similar particle size distributions (Fig. 6). Milling the coarse fractions (>417μ) from the Hobart mill on the Ross smooth rolls gave similar particle size distributions for SRAI W6 and W4, but the Dwarf White had a greater amount of smaller particle sizes. Those results indicate that Dwarf White is softer than the other grain sorghums, which is contrary to what might be assumed from the higher proportion of translucent endosperm shown in Figure 7.

Tempering Studies on Millet and Sorghum

Millet. We tempered Serere 3A and Sudan yellow millets to moisture contents of 15, 18, and 21% to determine the effect of tempering on the

size of particles produced. The samples were ground in the Hobart mill and sieved as previously described. Tempering and subsequent milling in the Hobart mill did not significantly change the particle sizes compared to the nontempered samples (Figs. 8a & 9a). When the coarse fractions (>410μ) were passed through the Ross smooth rolls and sifted, the particle size distribution showed that tempering produced larger particle sizes (Figs. 8b & 9b). For both millet samples, as the tempering level (moisture content) was increased the particle size of the products increased. Thus tempering appears to make the particles resistant to reduction. This is contrary to reports for wheat showing that tempering causes the endosperm to break into finer particles (Butcher and Stenvert, 1973).

In wheat, it has been shown that the factor responsible for grain hardness is the strength of the protein-starch bond (Simmonds et al., 1973; Simmonds, 1974). This bond is weakened by water and thus may be responsible for the softening effect during wheat tempering.

As shown above, tempering with water did not soften millet, i.e. it did not decrease the particle size distribution (Fig. 8b). Therefore, Serere 3A was tempered to 21% moisture with 0.5% sodium metabisulfite, a starch-protein bond weakening agent (Badi et al., 1978), and then ground in the Hobart mill and shifted. The particle distribution after grinding in the Hobart mill was the same as we had observed with the water temper (Fig. 8a). Similarly, when the coarse fraction (>417μ) was passed through Ross smooth rolls, it did not alter the particle size distribution from that of the water temper (Fig. 8b). Therefore, sodium metabisulfite shows no advantage in particle size reduction over tempering with water.

Sorghum. Tempering all three sorghums to 18% moisture and grinding in the Hobart mill increased the number of particles having a size treater than 1191μ (compare Fig. 6a & 10a) again suggesting that the tempering process made the larger particles more resilient and thus more resistant to breakage. When the coarse fraction (>417μ) of tempered sorghums was passed through the Ross smooth rolls, the resulting distribution was shifted to larger particles sizes (compare 5b and 8b), this was particularly evident for Dwarf white. Thus, grain sorghum responds to tempering in a manner similarly to pearl millet.

Table 1. Tyler Rotap Sieve Stack Used for Particle Size Distribution

U.S.A. Equivalent	Opening (Microns)
16	1191
20	833
30	589
40	417
50	295
70	208
100	147
pan	<147

Table 2. Moisture Contents of Pearl Millets and Grain Sroghums

Sample	% Moisture
Pearl Millets	
HMP 1700	10.4
HMP 557A	9
HMP 550	9.6
RMPI(S)CI	10.3
Serere 3A	8.9
Sudan Yellow	6.7
Sudan Green	7.0
Grain Sorghum	
SRAI W4	14.4
SRAI W6	8.2
Dwarf White	12.6

Figure 1. Pearl millet kernels showing distribution of opaque and translucent endosperm in various populations: (a) Serere 3A, (b) HMP 550, (c) Sudan Green, (d) Sudan Yellow, and (e) RMP 1(S)C1.

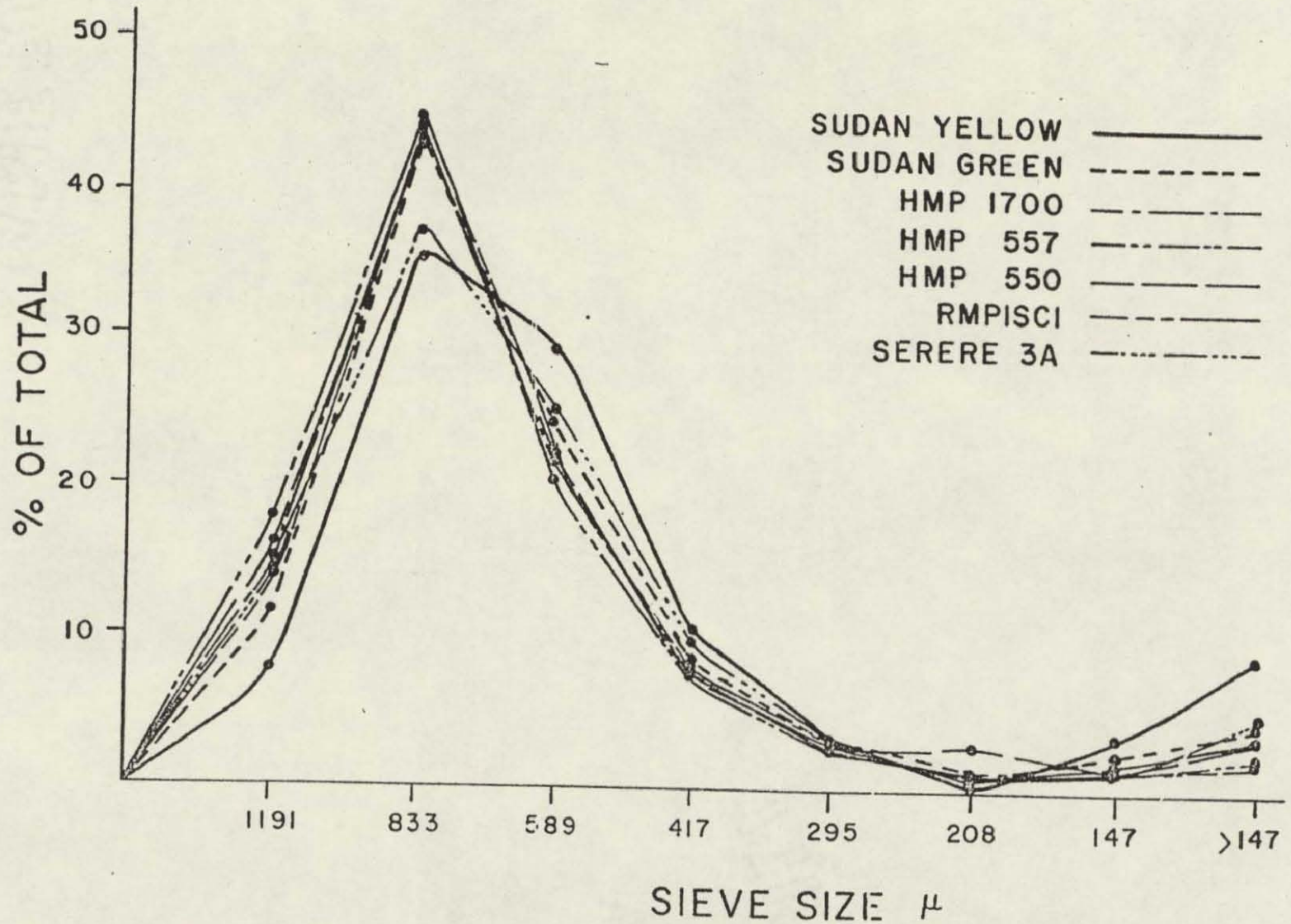

Figure 2. Particle size distrubution of pearl millets ground in a Hobart mill.

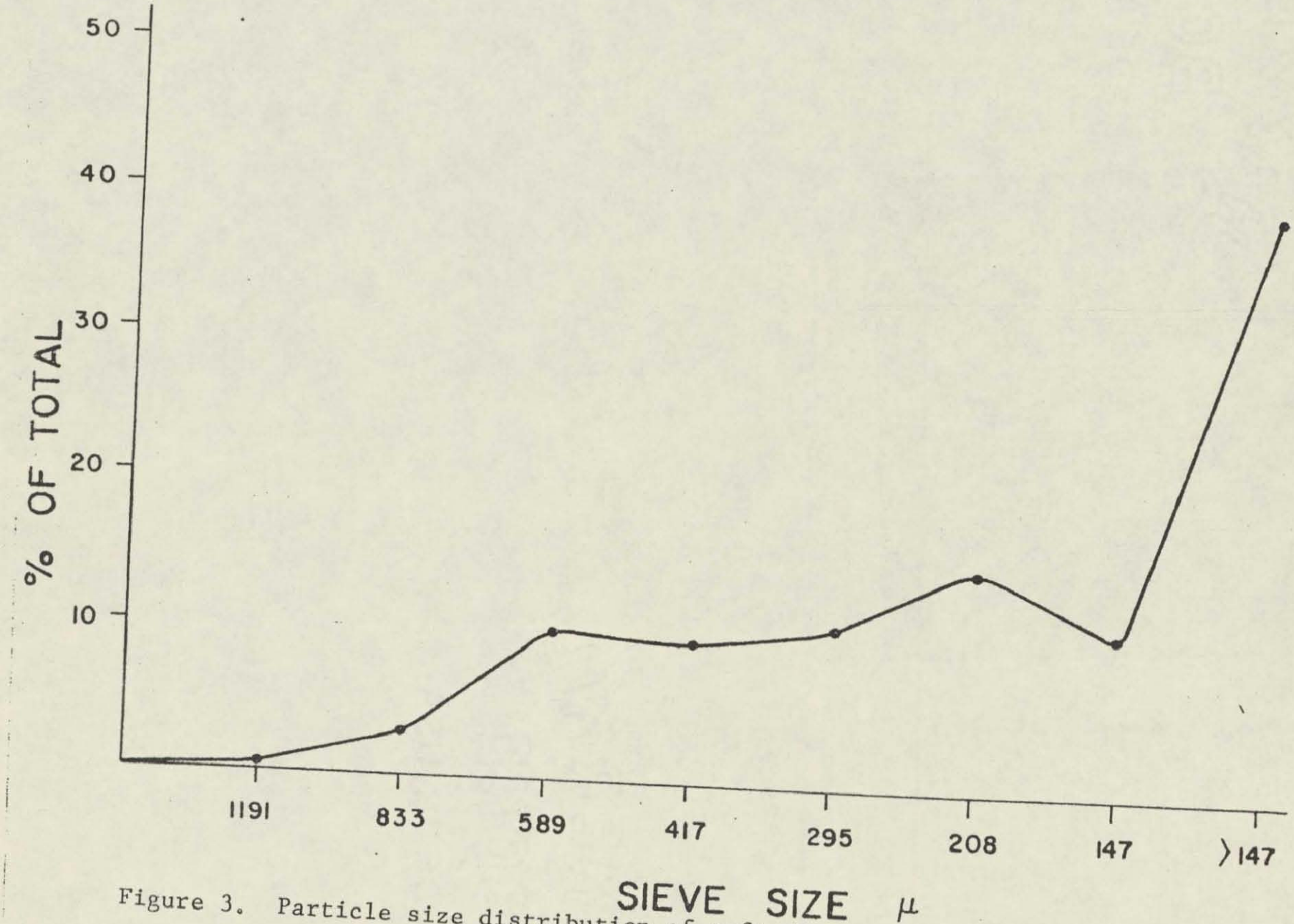

Figure 3. Particle size distribution of soft wheat ground in a Hobart mill.

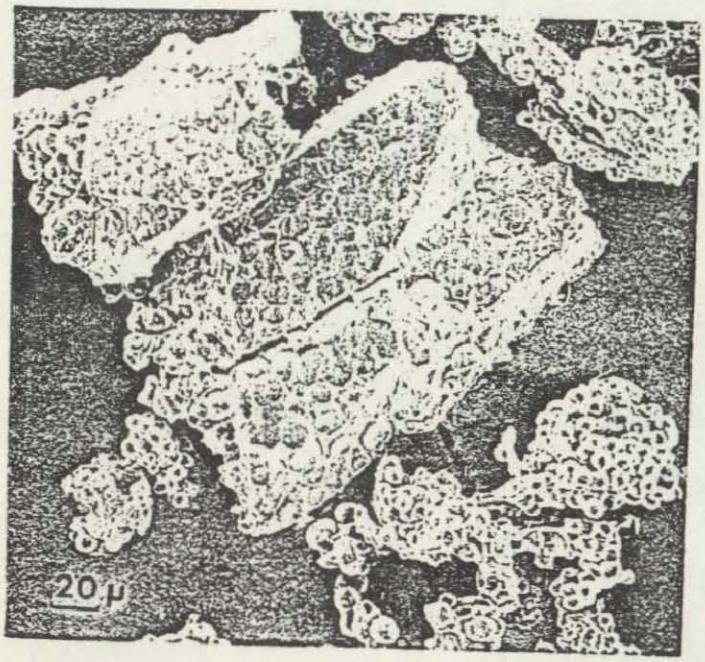

Figure 4. SEM of millet particles after roller milling the fine fraction (<417μ) obtained from the Hobart mill.

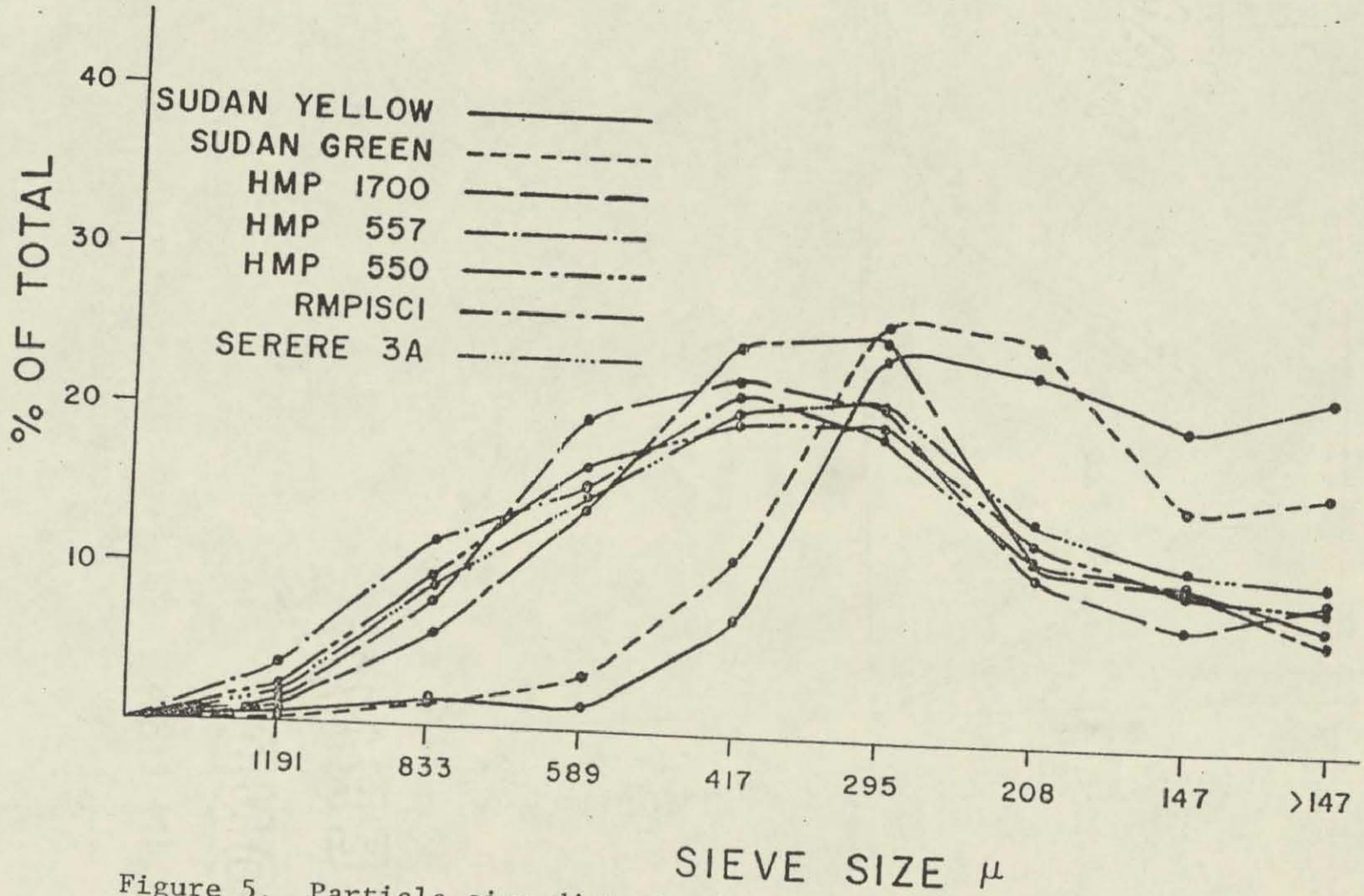

Figure 5. Particle size distribution of millet after smooth-roll-milling the coarse fraction (>417 μ) obtained from the Hobart mill.

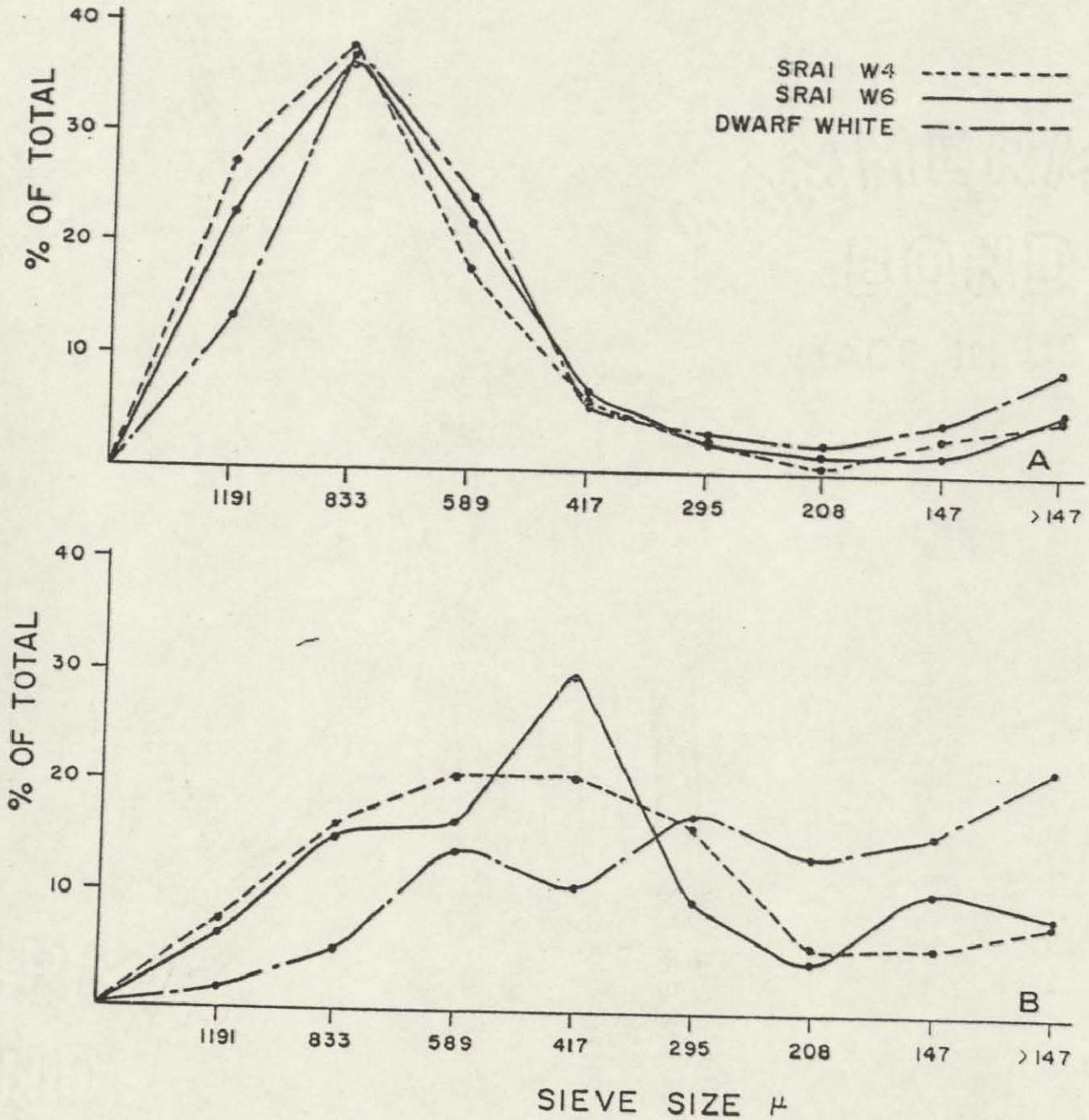

Figure 6. Particle size distribution of sorghums ground in a Hobart mill (a). The distribution of the coarse fraction (>417 μ) after passing through smooth rolls is shown in (b).

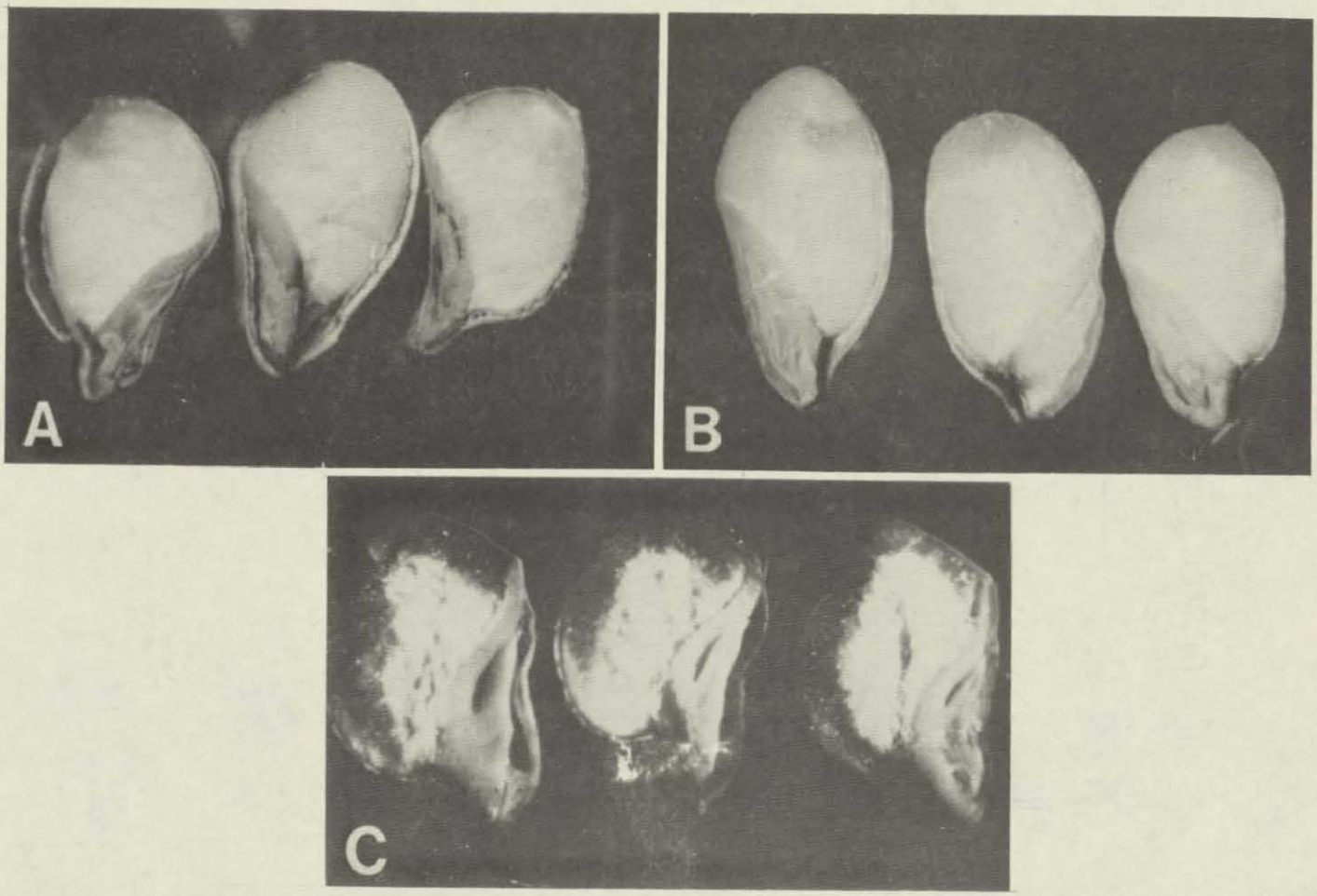

Figure 7. Grain sorghum kernels showing distribution of opaque and translucent endosperm in various cultivars: (a) SRAI W6, (b) SRAI W4, and (c) Dwarf White.

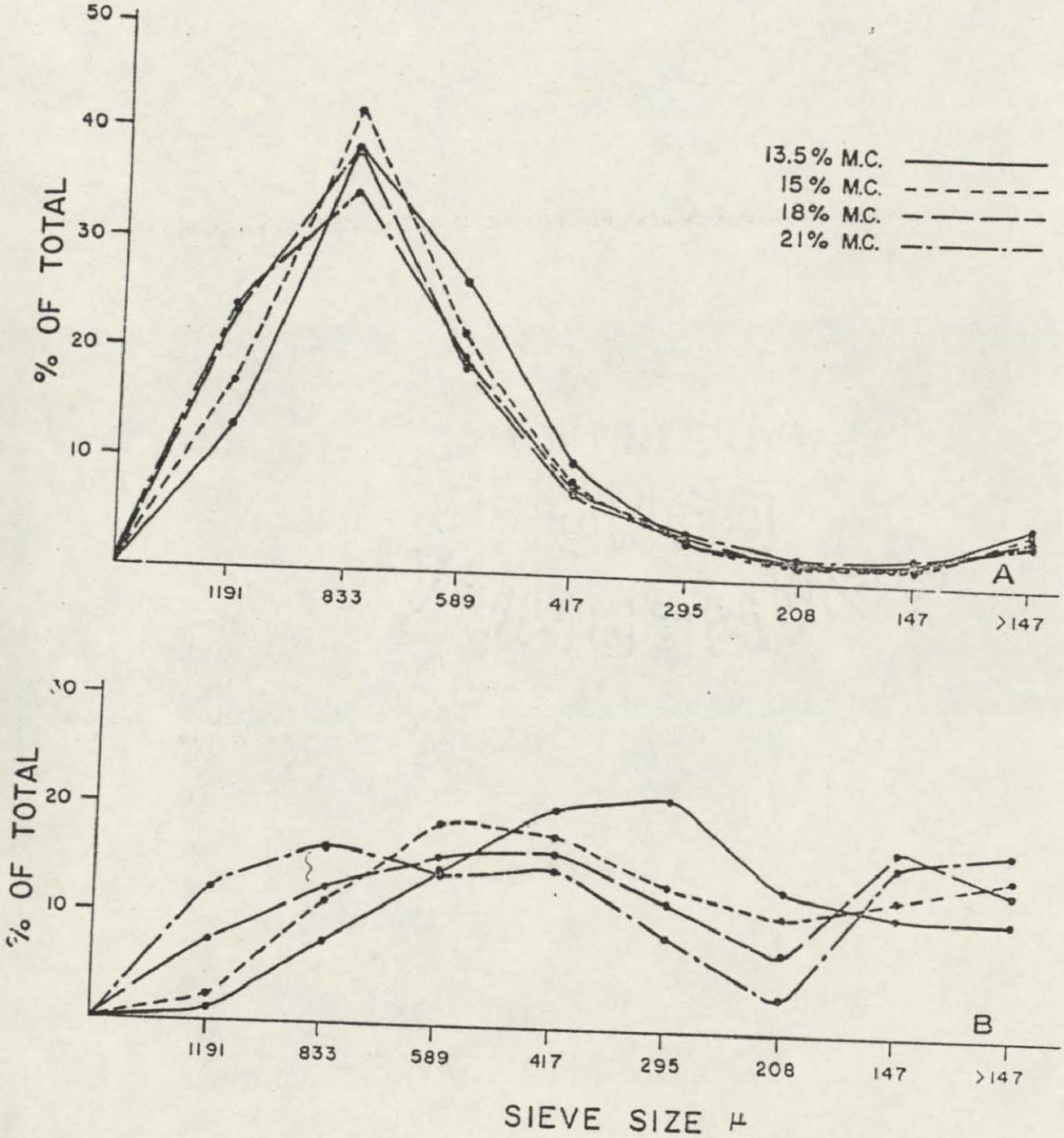

Figure 8. Particle size distribution of tempered Serere 3A millet ground in a Hobart mill (a). The distribution of the coarse fraction (>417 μ) after passing through smooth rolls is shown in (b).

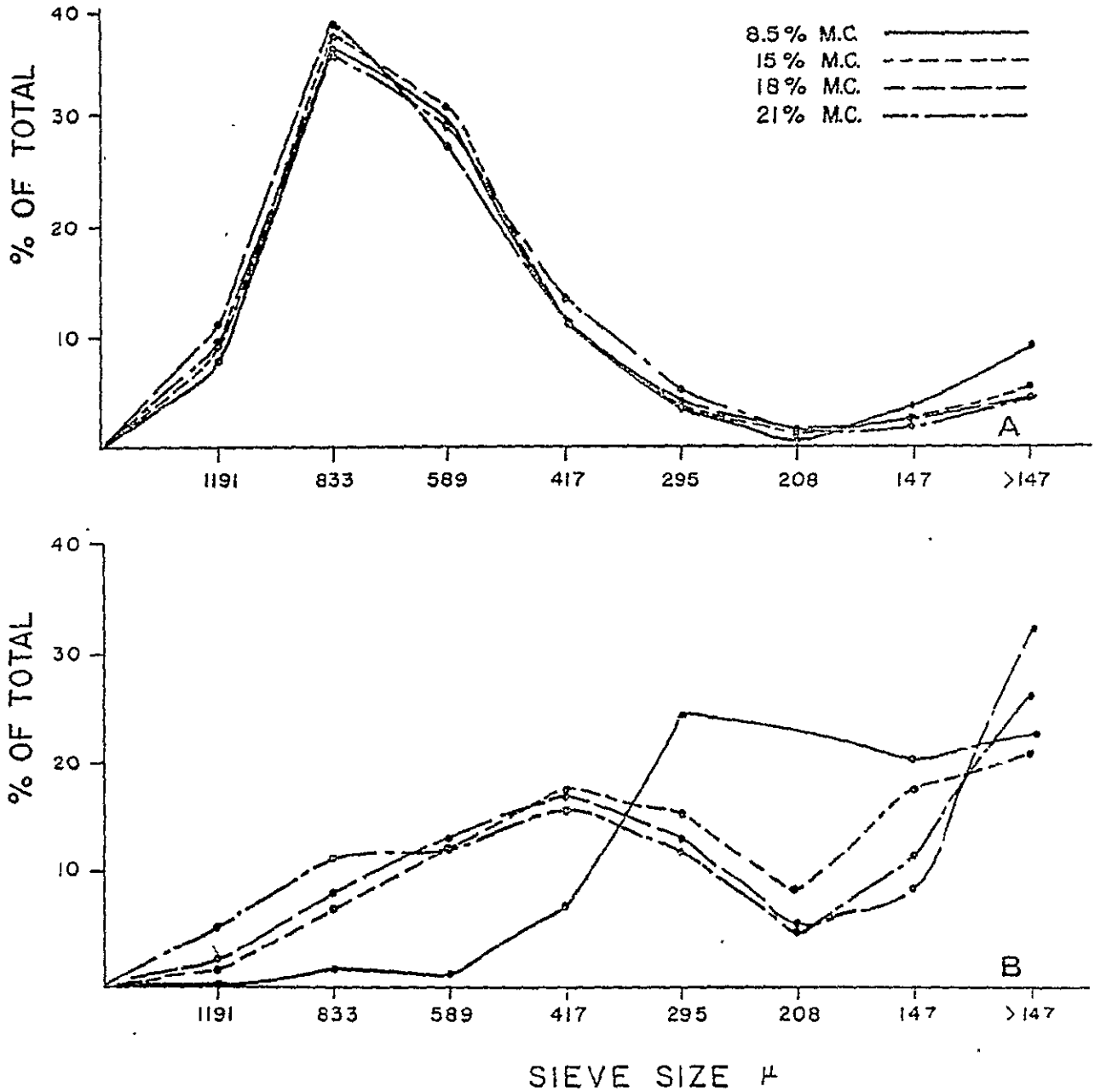

Figure 9. Particle size distribution of tempered Sudan Yellow millet ground in a Hobart mill (a). The distribution of the coarse fraction (>417 μ) after passing through smoothe rolls is shown in (b).

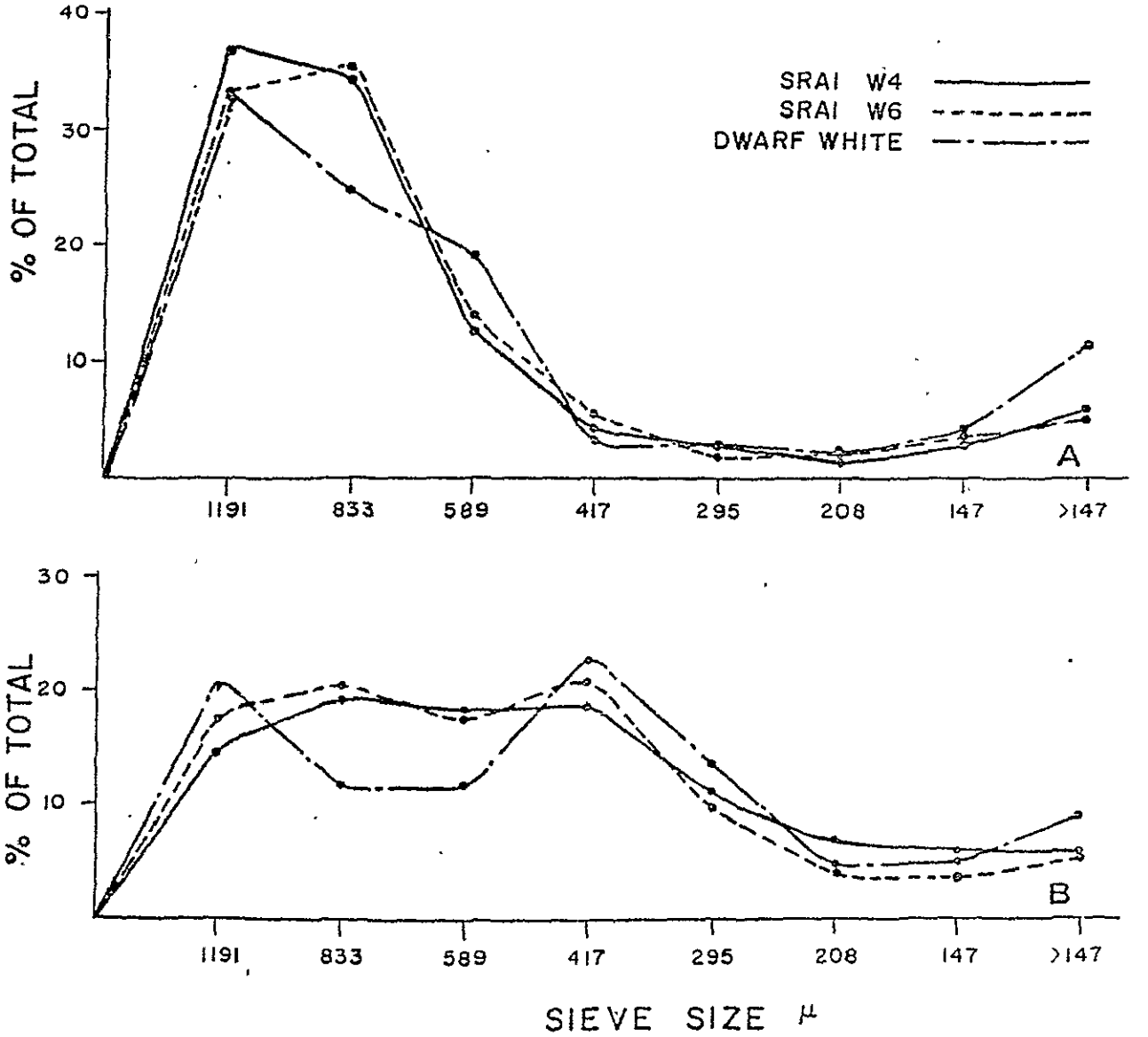

Figure 10. Particle size distribution of tempered sorghum ground in a Hobart mill (a). The distribution of thecoarse fraction (>417 μ)after passing through smooth rolls is shown in (b).

LITERATURE CITED

American Association of Cereal Chemists. 1967. Approved Methods of the AACC '7th ed.). Method 44-15A. The Association: St. Paul, Mn.

Badi, S. M., Hoseney, R. C., and Eustace, W. D. 1978. Corn flour: Reduction of particle size. Cereal Chem. 55:489.

Butcher, J. and Stenvert, N. L. 1973. Conditioning studies on Austrailian Wheat. I. The effect of conditioning on milling behavior. J. Sci. Fd. Agric. 24.1055.

de Francisco, A., Shepherd, A. D., Hoseney, R. C., and Varriano-Marston, E. 1981. Decortication of pearl millet and grain sorghum in a laboratory abrasive mill. Cereal Chem. (in preparation).

Maxon, E. D., Fryar, W. B., Rooney, L. W., and Krishnaprasad, M. N. 1971. Milling properties of sorghum grain with different proportions of corneous to floury endosperm. Cereal Chem. 48:478.

Obrichowski, W. and Bushuk, W. 1980. Wheat hardness: Comparison of methods and its evaluation. Cereal Chem. 57:421.

Rooney, L. W. and Sullins, R. D. 1969. A laboratory method for milling small samples of sorghum grain. Cereal Chem. 46:486.

Rooney, L. W. and Sullins, R. D. 1970. Chemical, physical and morphological properties of diploid and tetraploid Sorghum bicolor (L.) Moench kernels. Crop Science 10:97.

Simmonds, D. H., Barlow, K. K., and Wrigley, C. W. 1973. The biochemical basis of grain harness in wheat. Cereal Chem. 50:553.

Simmonds, D. H. 1974. Chemical basis of hardness and vitreosity in the wheat kernel. Bakers Dig. 48:16.

Vogel, S. and Graham, M. 1979. Sorghum and millet: Food production and use. International Development Research Center, Ottawa, Canada.

DECORTICATION OF PEARL MILLET AND GRAIN SORGHUM IN A LABORATORY ABRASIVE MILL

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INTRODUCTION

One important factor in determining grain quality is its milling characteristics. For millet and sorghum their decorticating behavior drastically influences the palatability and cooking quality of the grains (Desikachar, 1977; Kapasi-Kakama, 1977).

The equipment used to study the decortication of sorghum and millet include barley pearlers or similar machines (Hahn, 1969; Rooney et al., 1972; Stringfellow and Peplinski, 1966; Anderson et al., 1969), rice hullers and polishers (Raghavendra and Desikachar 1964; Virakthamath et al., 1971; Anderson and Burbridge, 1971), wire brush-type mills (Weinecke and Montgomery, 1975; Rooney and Sullins, 1969) and peelers (Shoup et al., 1970). Very few laboratory decotricating mills for small grains have been described. Hogan et al. (1965) described the original laboratory decorticating mill, and Barber (1972) modified it. It consisted of a transential abrasive device effective in dehulling but deficient in the ease of collection of the decorticate and decorticated bran.

Reichert and Youngs (1975) compared different dehulling methods and concluded that the abrasive technique was the most favorable for the dehulling of sorghum and pearl millet. Recently a laboratory decorticating mill for small seeds was developed by Shepherd (1979). It is an abrasive-type mill that is an efficient decorticator and provides convenient methods to determine the responses of different random mating populations of pearl millet (*Pennisetum americanum* (L.) Leeke) and cultivars of grain sorghum (*Sorghum bicolor* (L.) Moench) to decortication on shepherd's Udy Cyclone modified mill. We wanted to determine if decortication behavior could be used to differentiate millet and sorghum samples.

MATERIALS AND METHODS

Materials

The proximate compositions of the pearl millet samples studied are shown in Table 1. The pedigrees of the millet cultivars grown in Kansas were as follows: HMP 1700 (PI263540/Tift 23 DB_1/2/Tift 239 DB_2/2*Serere 3A), HMP 550 (Tift 23 DB_1/*2PI185642), RMP I(S)[1] (Parentage from Serere 3A, Serere 17 and Tift 239 DB_2), and Serere 3A, developed by Serere Exp. Stn., Uganda, Africa. The pedigree of the Sudanese yellow and green millets was unknown. Those two samples were selected from the marketplace in Khartoum, Sudan, and represented "good" (green) and "poor" (yellow) quality grains as judged by the Villagers based on flavor characteristics and price differential in the marketplace (Badi, 1979).

Sorghum cultivars, SRAI W6 and SRAI W4, were developed at the Seed Research Association, Scott City, Kansas, and the Dwarf White sample originated in Sudan but was grown in Kansas. Proximate analyses of those samples also are shown in Table 1.

Grain Cleaning

Light weight debris was removed from pearl millet samples with an aspirator, and the grains were passed over a 5 1/2/64 X 3/4 in. slotted sieve to remove undersized seeds. The sorghum samples were cleaned and sized over a 8/64 in. round perforation-dimpled screen. After cleaning the grains, the overs were hand cleaned to remove broken kernels and seeds with adhering glumes. The latter were deglumed in the decorticating mill which contained a rubber liner in place of the abrading surface. Deglumed seeds were combined with the hand-cleaned overs for decortication.

Decortication

Decortication was performed with a Udy Cyclone modified mill (Shepherd, 1979). The grain was fed into a chamber where air from an impeller conveyed the kernels against a cylindrical abrasive surface. Particles of sufficiently small size left the grinding compartment through a screen and were carried by an air stream to a cyclone connected to a glass receiver. To empty the grinding chamber, the screen was removed, and the motion of the impeller was reversed. This debranned sample was collected in a clean glass receiver.

For pearl millet decortication, the Udy Cyclone mill was fitted with 4 blades so that the distance from blade tip to blade tip was 4.25", a mesh grit impaction surface, and a screen perforated with round holes 1 mm in diameter. It was operated at 1800 rpm for both Kansas and Sudanese millets. The latter were also decorticated with an 80 mesh grit at 1500 rpm.

For sorghum decortication studies, the mill was fitted with four blades, a 60 mesh grit impaction surface and a 3/32 round hole perforated screen. It was operated at 1800 rpm.

Preliminary decorticatons were performed on 10 g samples of millet in order to determine the optimum times for obtaining 5, 10, 15, and 20% bran removal. The bran or decorticate fractions were collected and weighed every 20 sc. From the cumulative run, the optimum decortication times were selected and fresh samples were run at each time interval.

Dye Studies

The decorticated grains were stained with a mixture of 0.05% methylene blue and 0.15% Eosin-Y in 70% ethanol to differentiate the tissues of the pericarp which was a modification of the method of Scheuring and Rooney (1979).

Fractionation of Decorticated Sorghum

The sorghum endosperm material whole or broken (decorticated grain) as well as the materials removed from the surface of the grain (decorticate) were fractionated and grouped according to their particle size as is shown in Figure 1. This fractionation technique allowed us to obtain a more precise estimate of the amount of "pure" bran removed from the kernels (uncontamination by endosperm fragments) as well as the percentage of broken kernels resulting from decortication.

RESULTS AND DISCUSSION

Decortication

The amount of bran removed from pearl millets during decortication varied considerably among populations (Fig. 2). The Serere 3A and RMPI(S) CI required more time than the other samples to obtain the same degree of decortication. Conversely, the millets obtained from Sudan were much easier to decorticate than the millets grown in Kansas, except for HMP 550. We found that Sudan Green took longer to decorticate than Sudan Yellow (Fig. 3) when using less severe decortication conditions.

The Udy Cyclone mill has been reported (Shepherd, 1979) to be useful in differentiating sorghum cultivars. Using that mill we found the Dwarf White sample required the shortest time for decortication followed by SRAI W6 andW4 (Fig. 4). Sorghum was more readily decorticated than was millet.

Structural Studies

Microscope studies were conducted to determine why sorghum was more easily decorticated than millet. Scanning electron micrographs of half-kernels of decorticated pearl millet and grain sorghum show that the germ was retained in both (Fig. 5). The pericarp from millet was removed in small flakes (Fig. 6a) which readily passed a 1 mm screen.

Conversely, the pericarp of sorghum was removed in large flakes during decortication (Fig. 6b). The structural point of detachment of the pericarp for millet was at the junction between the endosperm and the aleurone layer (Fig. 7a & c). The structural point of detachment for sorghum pericarp was in the starch-containing mesocarp (Fig. 7b & d). Millet mesocarp cells are devoid of starch granules, as reported by Sullins and Rooney (1977). Based on the SEM data, we concluded that the process of decortication of grain sorghum and pearl millet follow different patterns due to inherent structural dissimilarities.

Fractionation of the Decorticate

To explain differences in the amount of decorticate obtained with different sorghum cultivars, we classified the decorticate into bran, brokens and intact decorticated grains according to the fractionation scheme shown in Figure 1. A large variation in the percentage of brokens was found. The data showed that Dwarf White, the cultivar with the most decorticate, had a higher percentage of brokens than did the other samples (Table 2). Therefore, differences in decortication behavior of sorghum cultivars are related to "softness" of the endosperm, with Dwarf Whie having a softer endosperm than the other sorghums. The amount of bran removed ranged from 10.1% to 14.2% (Table 2) in the three cultivars studied. This is a surprising amount of variation and may indicate genetic variation in the amount of starch in the mesocarp or in the thickness of the outer pericarp layers.

Table 1. Proximate composition of pearl millets and grain sorghums

Sample	Protein %	Moisture %	Ash %	Fat %
Pearl Millets				
HMP 1700[a]	14.7	10.4	1.6	6.9
HMP 550[a]	13.6	9.6	1.8	7.1
RMPI(S)CI[b]	11.1	14.2	1.4	6.8
Serere 3A[c]	13.5	9.5	1.6	6.2
Sudan Yellow[d]	14.5	7.4	2.0	7.8
Sudan Green[d]	12.0	7.8	1.5	5.9
Grain Sorghum[e]				
SRAI W4	9.3	17.0	1.5	3.5
SRAI W6	9.8	16.6	1.2	2.8
Dwarf White	13.5	14.4	1.8	3.2

[a]Grown in Hays, Kansas, 1977
[b]Grown in Manhattan, Kansas, 1976
[c]Grown in Hays, Kansas, 1975
[d]Grown in Sudan
[e]Grown in Scott City, Kansas

Table 2. Fractionation of Decorticated Sorghums

Cultivars	Recovered Products (%)		
	Bran (Fines & Flakes)	Brokens (Small & Large)	Whole Grain
SRAI W4	10.1 ± 0.05	5.0 ± 0.03	83.6 ± 0.03
SRAI W6	13.0 ± 0.5	7.3 ± 0.005	80.8 ± 0.15
Dwarf White	14.2 ± 0.04	43.0 ± 0.02	41.2 ± 0.2

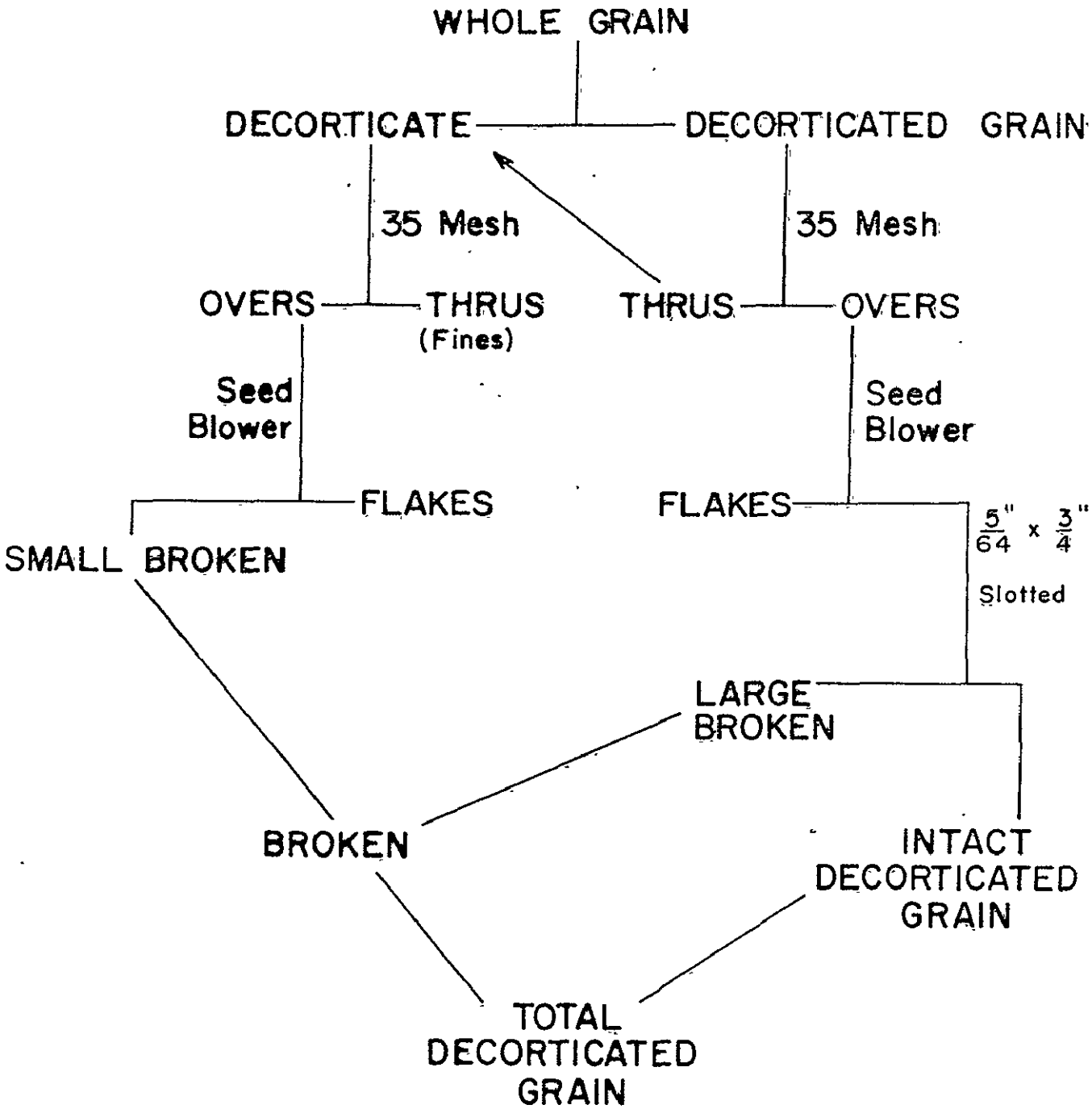


Figure 1. Fractionation scheme for decorticated sorghum.

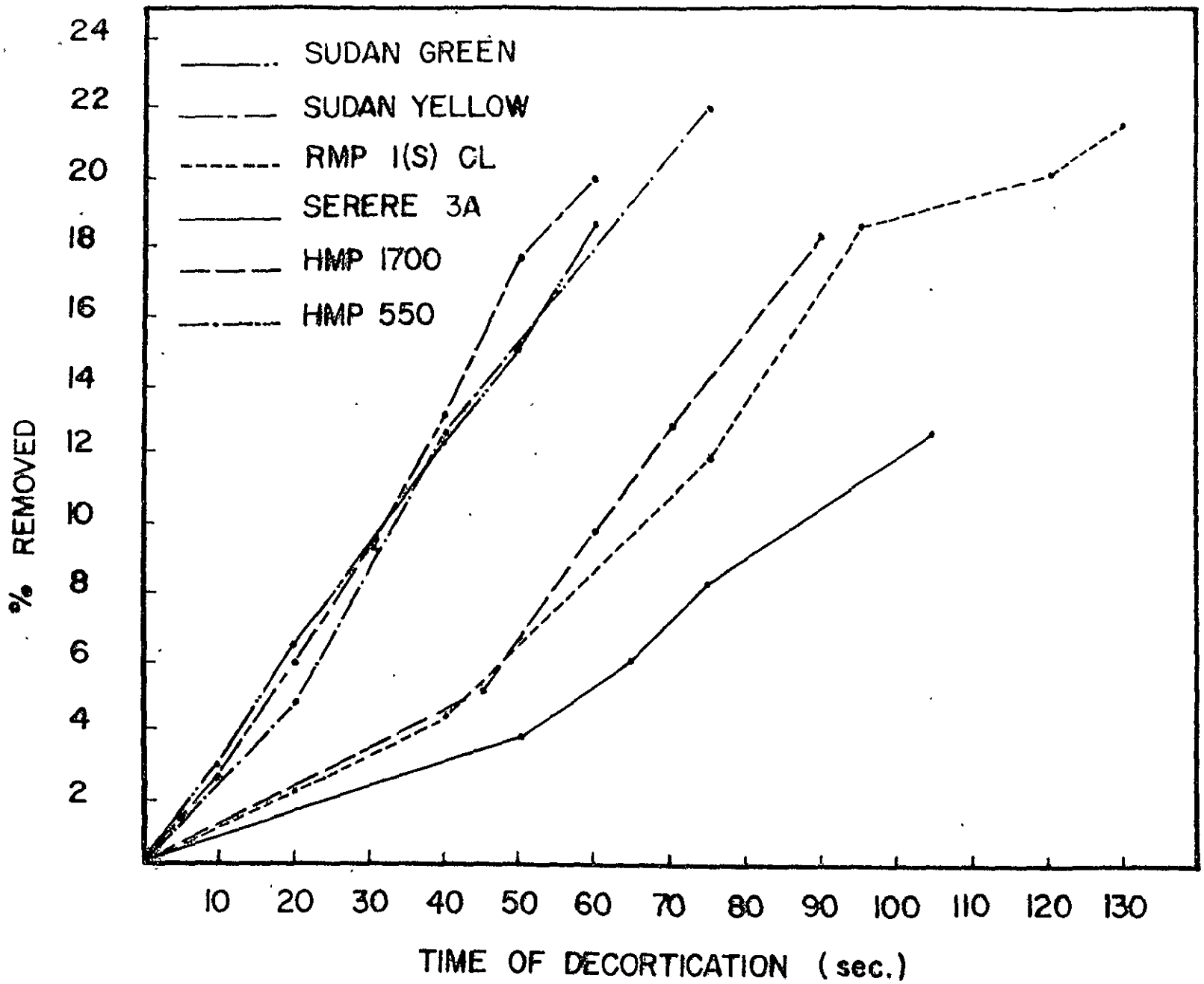


Figure 2. Decortication of pearl millets at 1800 rpm.

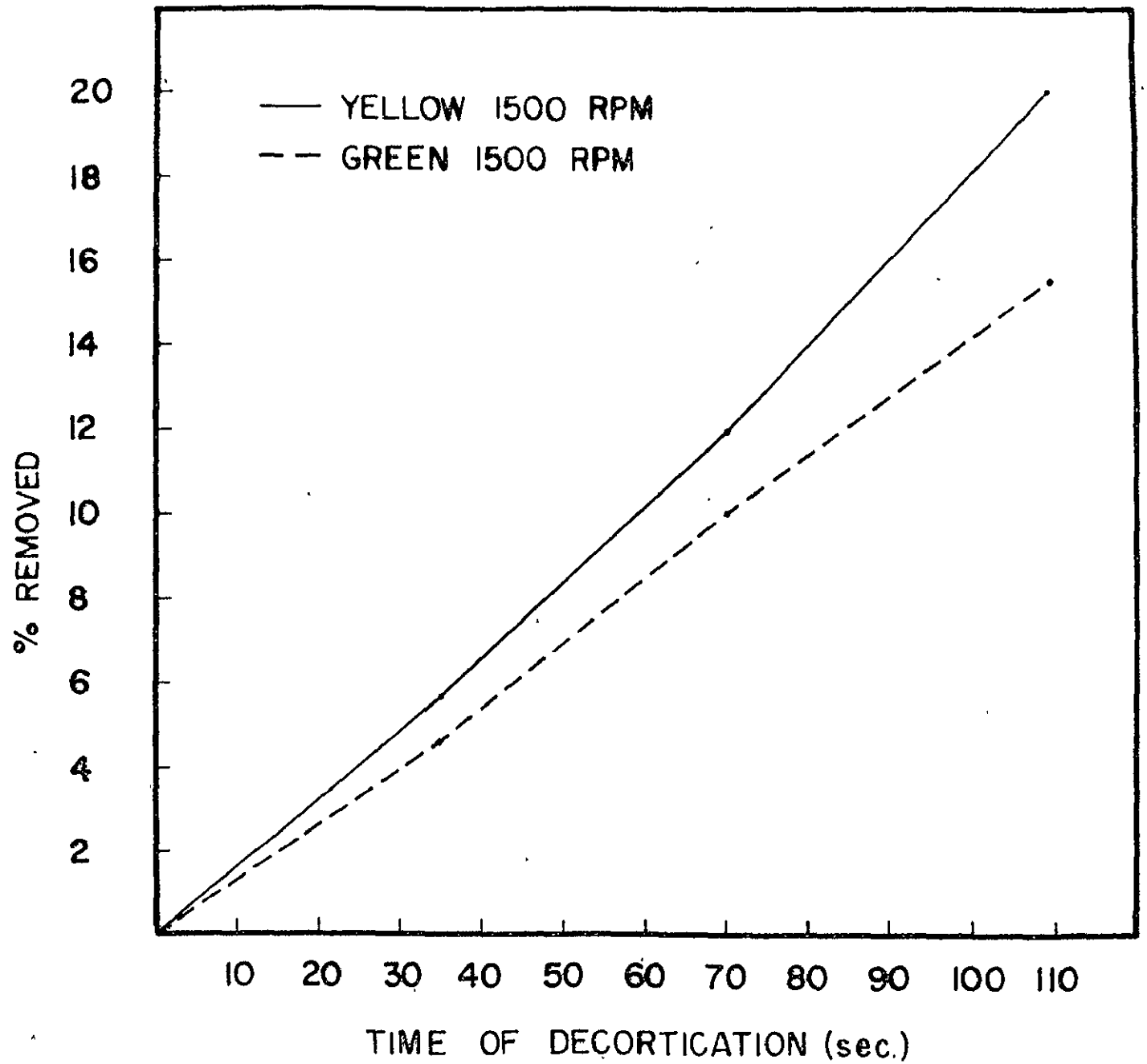


Figure 3. Decortication of Sudanese millets using an 80 mesh grit and 1500 rpm.

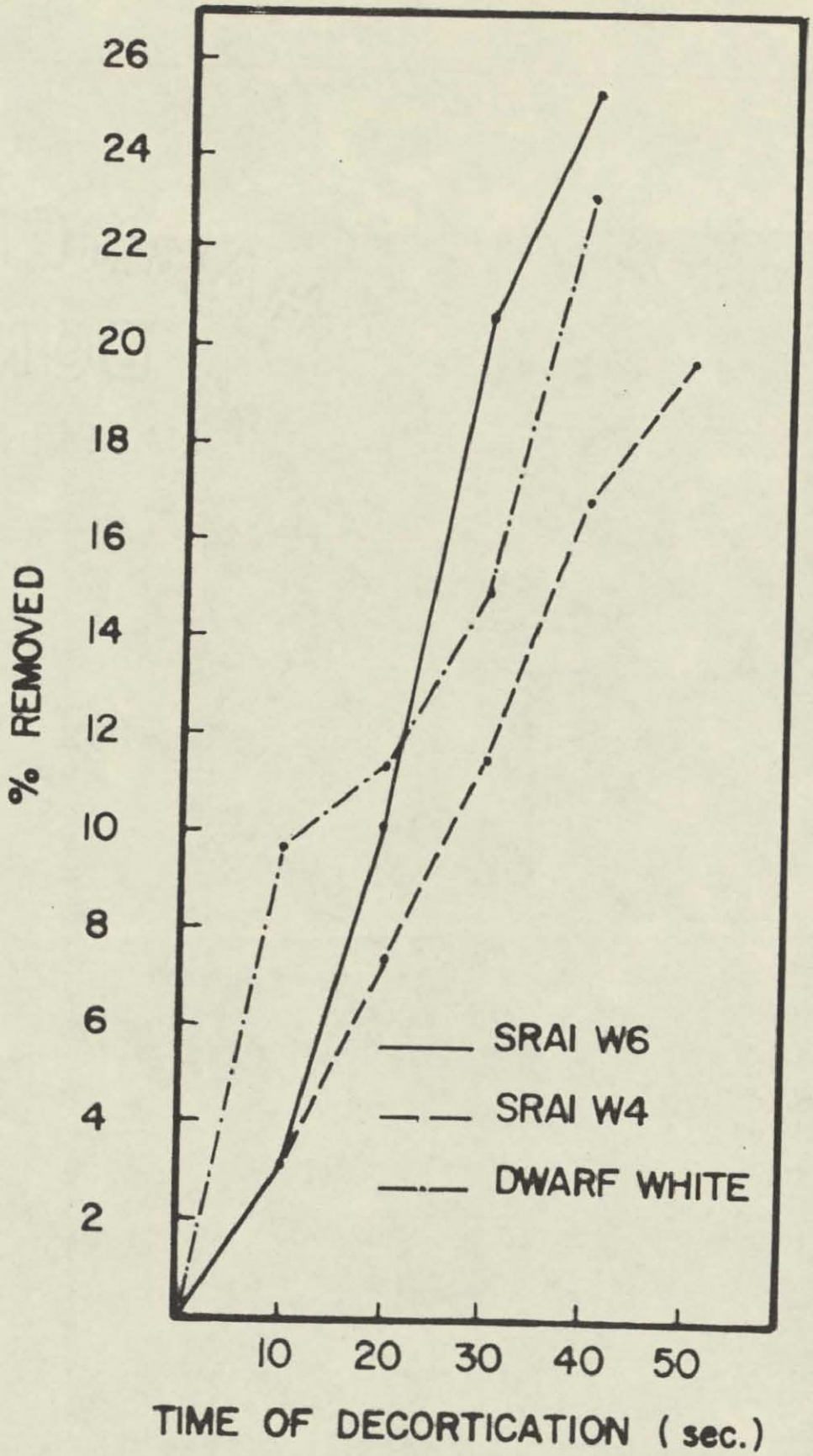


Figure 4. Decortication of sorghum at 1800 rpm.

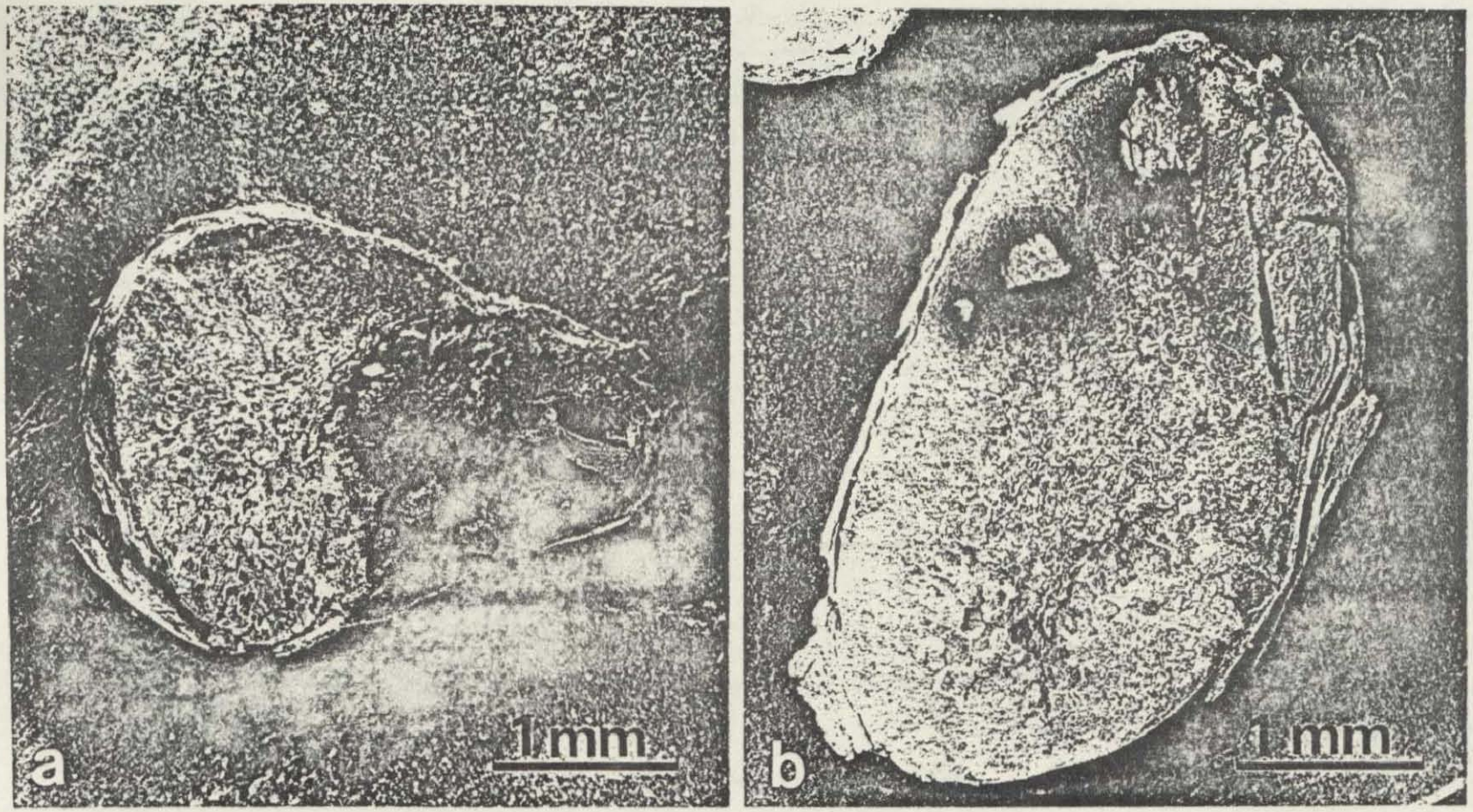


Figure 5. Millet (a) and sorghum (b) decorticated to 12% and 15%, respectively.

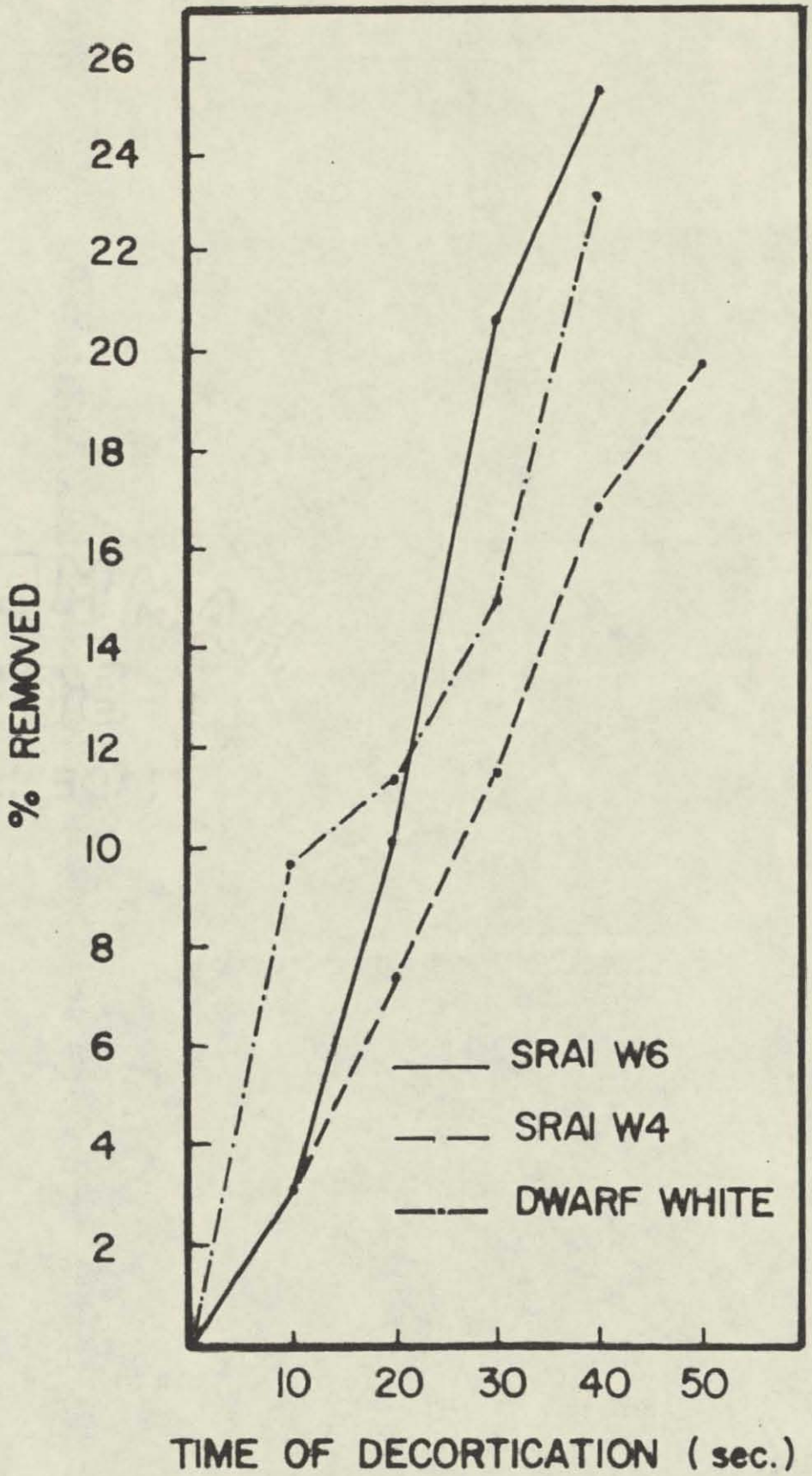


Figure 4. Decortication of sorghum at 1800 rpm.

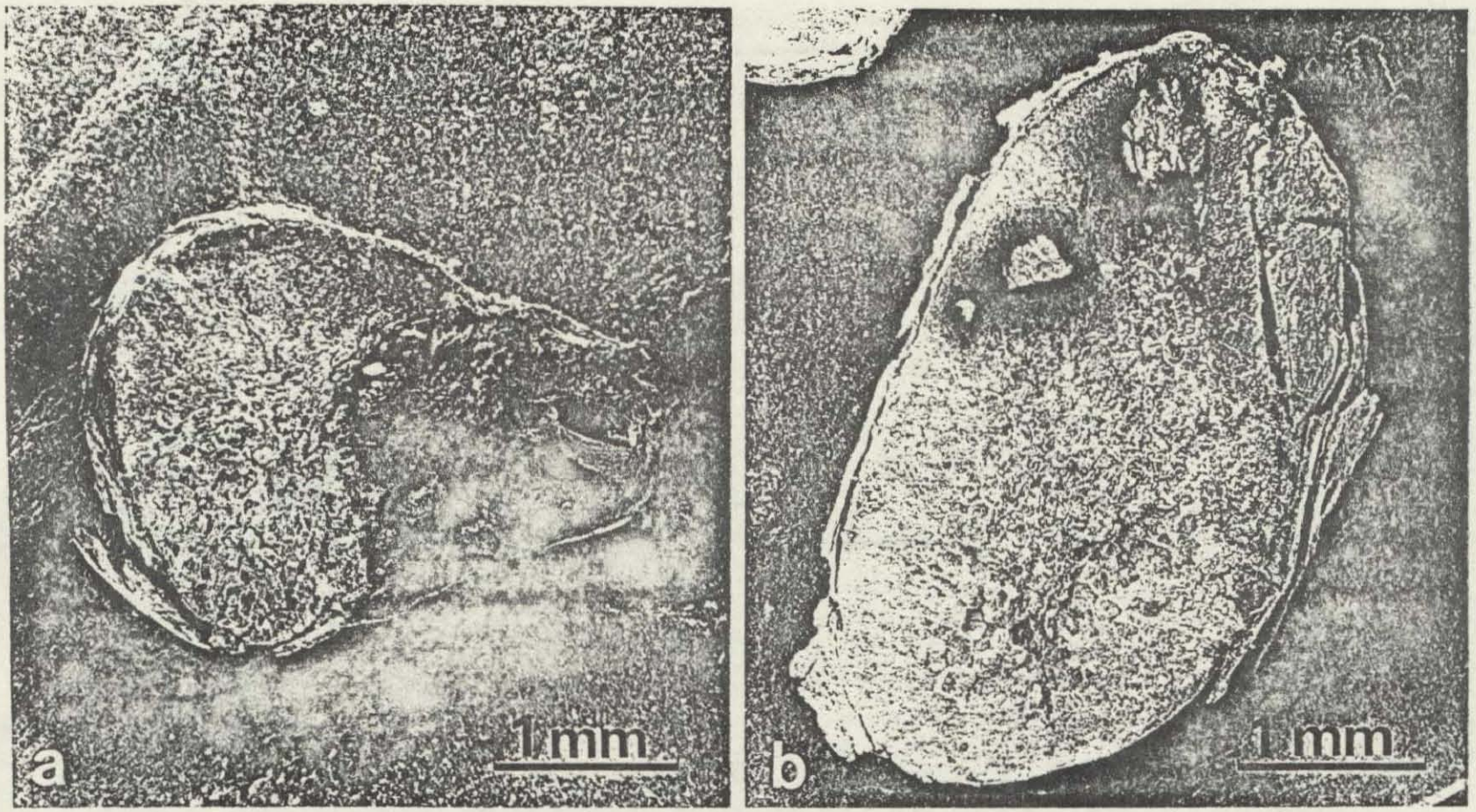


Figure 5. Millet (a) and sorghum (b) decorticated to 12% and 15%, respectively.

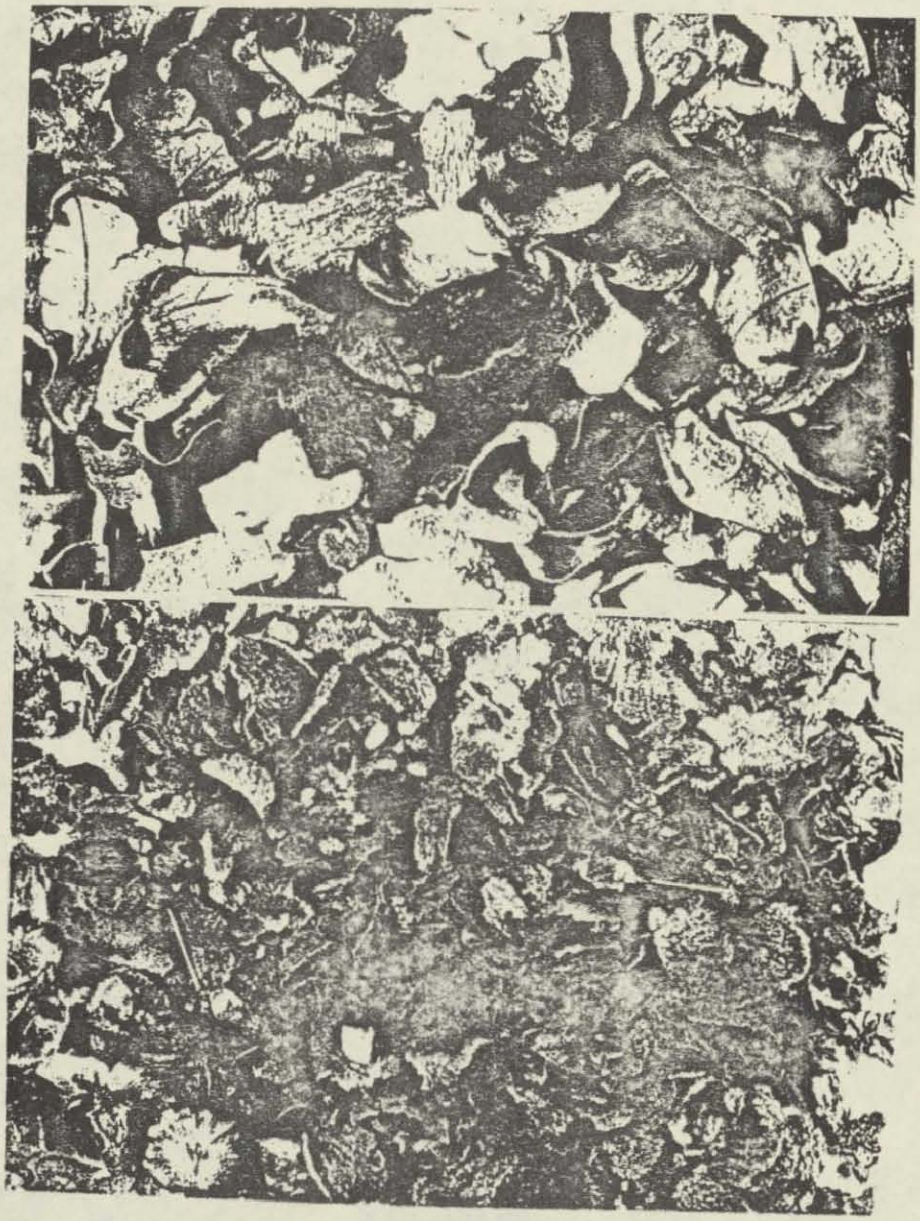


Figure 6. Flakes from decorticated sorghum (top) and millet (bottom).

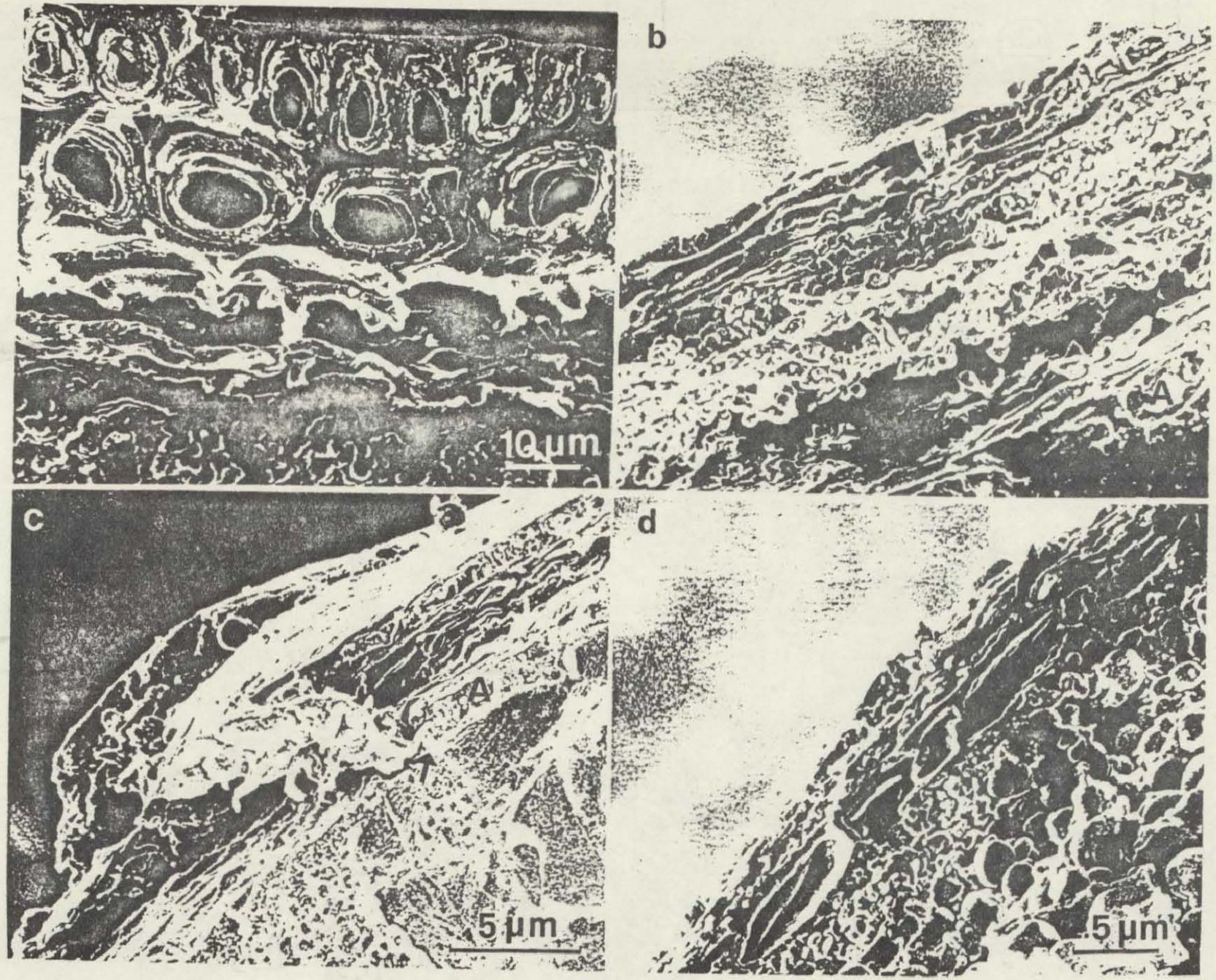


Figure 7. SEM micrographs of intact and decorticated grains: (a, c) millet and (b, d) sorghum.

LITERATURE CITED

Anderson, R. A. and Burbridge, L. H. 1971. Integrated process for dry milling grain sorghum. Northwest Miller. 278:24.

Anderson, R. A., Montgomery, R. R., and Burbridge, L. W. 1969. Low fat endosperm fractions from grain sorghum. Cereal Sci. Today. 14:366.

Badi, S. M. 1979. Food Research Center, Khartoum, Sudan, Africa. Personal communication.

Barber, S. 1972. Milled rice and changes during aging. II. Distribution of chemical constituents within the milled rice kernel, p. 215. In: "Rice: Chemistry and Technology." Am. Assoc. Cereal Chem. St. Paul, MN (Houston, D. F., ed.).

Blakely, M. E., Rooney, L. W., Sullins, R. D., and Miller, F. R. 1979. Microscopy of the Pericarp and the Tests of Different Genotypes of Sorghum. Crop Science. 19:837.

Desikachar, H. S. R. 1977. Processing of sorghum and millets for versatile food uses in India. In "Proceedings of a symposium on Sorghum and Millets for Human Food." (Dendy, D. A. V., ed.) p.41. Tropical Products Institute, London.

Hahn, R. R. 1969. Dry milling of grain sorghum. Cereal Sci. Today. 14:234.

Hogan, J. T., Normand, F. L., and Deohald, H. J. 1964. Method for removal of successive surface layers from brown and milled rice. Rice J. 67:27.

Kapasi-Kakama, J. 1977. Some characteristics which influence the yield and quality of pearled sorghum grain. In: "Proceedings of a Symposium on Sorghum and MIllets for Human Food." (Dendy, D. A. V., ed.) p. 21. Tropical Products Institute, London.

Raghavendra Rao, S. N. and Desikachar, H. S. R. 1964. Pearling as a method of refining jowar and wheat and its effect on their chemical composition. J. Sci. Technol. 1:40.

Reichert, R. D. and Youngs, C. G. 1975. Dehulling cereal grains and grain legumes for developing countries. 3. Quantitative comparison between attrition and abrasive type mills. Cereal Chem. 53:829.

Rooney, L. W. and Sullins, R. D. 1969. A laboratory method for milling small samples of sorghum grain. Cereal Chem. 46:486.

Rooney, L. W., Fryar, W. B., and Cater, C. M. 1972. Protein and amino acid contents of successive layers removed by abrasive milling of sorghum grain. Cereal Chem. 49:399.

Scheuring, J. F. and Rooney, L. W. 1979. A staining procedure to determine the degree of bran removal in pearled sorghum. Cereal Chem. 56:545.

Shepherd, Allan D. 1979. Laboratory abrasive decorticating mill for small grains. Cereal Chem. 56:517.

Shoup, F. K., Deyoe, C. W., Farrell, E. P., Hammond, D. L., and Miller, G. D. 1970. Sorghum grain dry milling. Food Technol. 24:88.

Stringfellow, A. C. and Peplinski, A. J. 1966. Air classification of sorghum flours from varieties representing different hardnesses. Cereal Sci. Today. 11:438.

Sullins, R. D. and Rooney, L. W. 1977. Pericarp and endosperm structure of pearl millet (*Pennisetum typhoides*). In: "Proceedings of a Symposium on Sorghum and Millets for Human Food." (Dendy, D. A. V., ed.) p. 79. Tropical Products Institute, London.

Viraktamath, C. S., Raghavendra, G., and Desikachar, H. S. R. 1971. Use of rice milling machinery for commercial pearling of grain sorghum (Jowar) and culinary uses for pearled sorghum products. J. Food Sci. Technol. 8:11.

Weinecke, L. A. and Montgomery, R. R. 1965. Experimental units now suitable for scale-up to mill size production. Amer. Miller. 93:8.

EFFECTS OF PEARL MILLET AND SORGHUM DIETS ON GROWTH RATES AND CHOLESTEROL LEVELS IN GUINEA PIGS

Carol Klopfenstein

Sorghum and pearl millet are major dietary staples in some parts of the world, but the nutritive value of these grains has not been extensively studied. Recently several health problems have been associated with the consumption of sorghum (Belavady, 1975; MacLean and Graham, 1980). It has long been suspected that a high incidence of pellagra results from the consumption of diets high in sorghum (Gopalan, 1968). Several have suggested that sorghum's high leucine: isoleucine ratio interferes with normal niacin metabolism (Gopalan, 1968; Belavady, 1975).

For some population groups having diets high in lightly processed cereals, serum cholesterol levels are low and coronary heart disease is rare (Trowell, 1972, 1975; Connor et al., 1978; Phillips et al., 1978). Laboratory work investigating the causes of that phenomenon has been sparse. While some attention has been given to wheat, wheat bran, and various oats fractions, virtually no data are available on the effects of sorghum or pearl millet diets on cholesterol levels. In our preliminary study (2nd Annual Report) guinea pigs fed sorghum diets high in ascorbic acid appeared to have lower serum cholesterol levels than those fed wheat, rolled oats, or pearl millet diets. Liver cholesterol was significantly lower ($P \leq 0.05$) for animals fed sorghum diets.

The experiment described here was designed to determine (1) the effect of pearl millet and sorghum diets on guinea pig growth, (2) what anatomical portion of the sorghum kernel was responsible for the cholesterol-lowering effect, and (3) if ascorbic acid in the diet was a related factor.

MATERIALS AND METHODS

Experimental diets were fed to male albino English Shorthair guinea pigs ranging in weight from 280 to 386 grams. The control diet consisted of vitamin-free casein (20%), skim milk powder (20%), sucrose (29%), soybean oil (9.9%), cellulose (19%), and cholesterol (0.1%). Potassium acetate (2.5 lbs.), magnesium oxide (0.5 lbs.), vitamin diet fortification mix (2.2 lbs.), and Briggs N salt mix (6 lbs.) were added to 100 lbs. of that diet. Vitamin and mineral mixes were obtained from ICN Nutritional Biochemicals, Cleveland, OH.

The sorghum diet formulation was the same as the control diet except that 58% ground whole sorghum (DeKalb C46+) replaced the skim milk powder and sucrose. Cellulose was reduced to 10%.

The sorghum bran diet contained bran obtained by decorticating the grain in a Satake mill. The first 20% of the grain removed was used and substituted for 11.5% of the cellulose in the control diet. The decorticated grain, which consisted of the endosperm and germ, was ground (corrugated rolls set at 0.013") and then used to replace the sugar and skim milk powder of the control diet to make up the sorghum endosperm diet.

The sorghum + ascorbic acid diet had the same formulation as the sorghum diet except the ascorbic acid level was tripled to provide an intake of approximately 60 mg ascorbic acid per day/per animal.

The pearl millet diet was the same as the control diet except that 58% ground whole millet (HMP1700, 1979) replaced the skim milk powder and sucrose. Cellulose was reduced to 10%.

The feeds were mixed and pelleted as described previously (2nd Annual Report). Animals were individually housed and given feed and water ad libitum. Daily growth records were kept. Blood samples were taken from a toenail vein at 62, 87, and 95 days; serum total cholesterol and cholesterolester-cholesterol ratios were determined. Liver samples were taken after 95 days and lipids were extracted (2nd Annual Report). Serum and liver cholesterol concentrations were measured using the reagent of Rosenthal et al. (1957). Cholesterol ester - cholesterol ratios were determined by spotting an ether:absolute ethanol (80:20) extract of the serum on Brinkman thin layer plates precoated with silica gel 60. The plats were developed in hexane:ether: acetic acid (80:20:1), dried, and then dipped in a solution of 3% cupric acetate in 8% phosphoric acid for 3 secs. and heated at 130°C for 30 min. (Bitman et al., 1980). After cooling, cholesterol and cholesterol ester were measured densitometrically at 400 nm.

RESULTS AND DISCUSSION

Growth Rate

During the first 37 days of the experiment, animals eating the sorghum bran diet (which contained skim milk powder and casein instead of sorghum endosperm) grew significantly ($P \leq 0.05$) faster than those in any other group except for animals on the pearl millet diet (Table 1). Animals receiving the other grain diets grew at the same rate as the control group (casein base). Of animals receiving the experimental grain diets, those eating sorghum bran and pearl millet grew faster ($P \leq 0.05$) than those eating sorghum + ascorbic acid, sorghum or sorghum endosperm.

After about day 40 of the experiment, animals eating the sorghum, particularly the sorghum endosperm diets, began to grow slowly and some lose weight. We thought these animals might be becoming pellagranenic, so nicotinic acid was orally administered to animals in those groups. A concentration of 1 mg of the vitamin per day caused a marked improvement

in their appearance. Previously lethargic animals became active and the condition of their coats was better. Animals appearing to be near death began to slowly grow again (Table 2). Although niacin had no significant effect on growth rates, the general health of the animals was markedly improved. Niacin deficiency may have accentuated or initiated unidentified problems.

While those animals discussed above were doing poorly on sorghum or sorghum endosperm diets, animals eating a diet essentially identical to the sorghum diet, but containing three times more ascorbic acid, continued to grow and remain healthy and active. Animals receiving higher levels of ascorbic acid grew significantly ($P \leq 0.05$) faster than those on sorghum and sorghum endosperm diets, even after the later diets had been supplemented with niacin (Table 3). As in our previously reported experiment (2nd Annual Report), growth rates of animals on the ascorbic acid supplemented diet were not significantly different ($P \leq 0.05$) from those on the millet diet. Growth rates for the sorghum bran diet also were not different from those for pearl millet and sorghum + ascorbic acid (Table 3). Pearl millet diets produced the highest growth rate for days 37 through 51.

Because of the dramatic effect ascorbic acid had on the health and growth of sorghum-fed animals, we supplemented the other diets for 13 days with 40 additional mg/day of ascorbic acid (equivalant to about 8.4 growth rates of animals on any of the diets.

Liver Weight - Animal Weight Ratios

As in our earlier work (2nd Annual Report), livers of animals fed grain diets appeared to be proportionately heavier than those of control (casein-fed) animals. In the present experiment, liver weights were significantly higher for animals fed pearl millet ($P \leq 0.05$), sorghum ($P \leq 0.01$), and sorghum endosperm ($P \leq 0.05$) diets. Sorghum bran and ascorbic acid supplemented sorghum diets gave the same liver weight/ animal weight ratios as did the control diet ($P \leq 0.05$, Table 4).

Serum Cholesterol

Serum total cholesterol analyses were performed three times during the experiment: after 62, 87 and 95 days. Those values were found to be in the normal range (Ginter, 1977) even though the animals received 0.1% dietary cholesterol. At each sampling date serum cholesterol was lower in animals eating the ascorbic acid-supplemented sorghum diet than for animals in any other group. In the 62-day samples serum cholesterol values were significantly lower ($P \leq 0.10$) in the sorghum + ascorbic acid-fed animals than in animals fed sorghum, sorghum endosperm or sorghum bran diets (Table 5). In our earlier experiment (2nd Annual Report), the mean

serum cholesterol level was also lower for the ascorbic acid supplemented sorghum diet than for other grain diets or the control diet, but the difference was not significant ($P \leq 0.10$). The unsupplemented sorghum diet produced significantly higher ($P \leq 0.10$) serum cholesterol values than the control diet. The pearl millet diet gave intermediate serum cholesterol values (Table 5).

Liver Cholesterol

After 95 days on the diets, the animals' liver cholesterol values were exceptionally high, being approximately twice those of animals which were fed similar diets for only 43 days (2nd Annual Report) the the difference was not significant.

Cholesterol Ester - Cholesterol Ratios

Oral supplementation of 40 mg ascorbic acid per day for 13 days to all animals, except those already receiving the ascorbic acid supplemented diet, resulted in higher cholesterol ester - cholesterol ratios (Fig. 1). When supplementation of ascorbic acid was discontinued, ratios dropped.

Disc Electrophoresis for Lipoproteins

When serum was electrophoresed using Redi-Disc lipoprotein gels (Ames Co., Elkhart, Indiana), the chylomicron fraction was always low. The gel pattern resembled the common IIb phenotype for human blood. A narrow pre-β-lipoprotein band, a wide, more diffuse β-lipoprotein band and a sharp, dark α-lipoprotin band were noted for all animals. Few differences were noted among experimental groups before or after supplementation with ascorbic acid or after its subsequent removal.

Sepraphore Strip Electrophoresis for High Density Lipoprotein Cholesterol (HDLC)

The HDL cholesterol electrophoresis system (Gelman Sciences, Inc., Ann Arbor, Michigan) proved unsatisfactory for separating and measuring the HDLC in guinea pig serum. Using this method, human blood serum normally shows 2 to 3 red/pink bands: these being (from point of application) low density lipoprotein cholesterol (LDLC), very low density lipoprotein cholesterol (VLDLC) and high density lipoprotein cholesterol (HDLC). Often the second band (VLDLC) is very faint or absent. When barbitone acetate or tris-buffer, pH 8.6, was used, guinea pig serum produced only one pink band in the alpha-, or HDLC, position, directly aligned with the HDLC band of human serum. When strips were then stained with Coomassie Blue protein stain, these HDLC bands were located immediately behind the albumin and directly in front of a dark alpha-protein band.

Summary

The pearl millet diet produced strong, healthy animals with the best average growth rate of any of the diets after 41 days of feeding. After about 40 days of the experiment, animals eating sorghum and sorghum endosperm diets were growing poorly, were lethargic, and had poor coats. We

assumed that the animals had pellagra an administered 1 mg nicotinic acid/ day for 11 to 16 days. The nicotinic acid alleviated most of the symptoms but did not significantly improve growth rate. Animals on the ascorbic acid-supplemented sorghum diets did not exhibit the symptoms described above and remained healthy throughout the experiment. This study confirmed our earlier work showing that ascorbic acid-supplemented sorghum diets exert a cholesterol-lowering effect in guinea pig serum and liver. No differences in serum lipoproteins were noted among the groups.

Table 1. Weight Gained/Day for First 37 Days

Diet	Mean (g/day)	Grouping+
Sorghum Bran (4)*	6.5	A
Pearl Millet (5)	5.4	AB
Control (6)	4.2	BC
Sorghum + Ascorbic Acid (3)	2.8	C
Sorghum (5)	2.3	C
Sorghum Endosperm (4)	2.2	C

*Number of animals in group
+Analysis of variance procedure, Duncan's multiple range test, alpha level ≤ 0.05. Means with the same letter are not significantly different.

Table 2. Effect of Niacin Supplementation

Diet	Grams Gained/Day		
	10 days before niacin	During niacin*	10 days after niacin
Sorghum	2.5 ± 1.0	3.0 ± 1.0	2.9 ± 0.4
Sorghum Endosperm	0.2 ± 1.8	1.8 ± 0.8	1.8 ± 1.5

*Sorghum animals received 1 mg nicotinic acid/day for 11-13 days, Sorghum Endosperm animals received 1 mg/day for 16 days.

Table 3. Weight Gained/Day for Days 37-51

Diet	Mean ± S.D. (g/day)
Pearl Millet	5.8 ± 1.2
Sorghum + Ascorbic Acid	4.4 ± 1.1
Sorghum Bran	3.4 ± 1.8
Control	2.3 ± 2.1
Sorghum Endosperm + Niacin	2.1 ± 1.1
Sorghum + Niacin	0.6 ± 2.0

Table 4. Liver Weight/100 Grams of Animal Weight

Diet	Mean (g/100g)	Grouping+
Pearl Millet (4)*	4.55	A
Sorghum (5)	4.49	A
Sorghum Endosperm (4)	4.22	AB
Sorghum Bran (4)	4.10	ABC
Sorghum + Ascorbic Acid (3)	3.94	BC
Control (5)	3.65	C

*Number of animals in group.
+Analysis of variance procedure, Duncan's multiple range test, alpha level ≤ 0.05. Means with the same letter are not significantly different.

Table 5. Serum Cholesterol After 62 Days

Diet	Mean (mg/dl)	Grouping+
Sorghum (4)*	93.8	A
Sorghum Endosperm (3)	89.2	AB
Sorghum Bran (4)	86.9	AB
Pearl Millet (3)	77.1	ABC
Control (5)	72.4	BC
Sorghum + Ascorbic Acid (3)	62.9	C

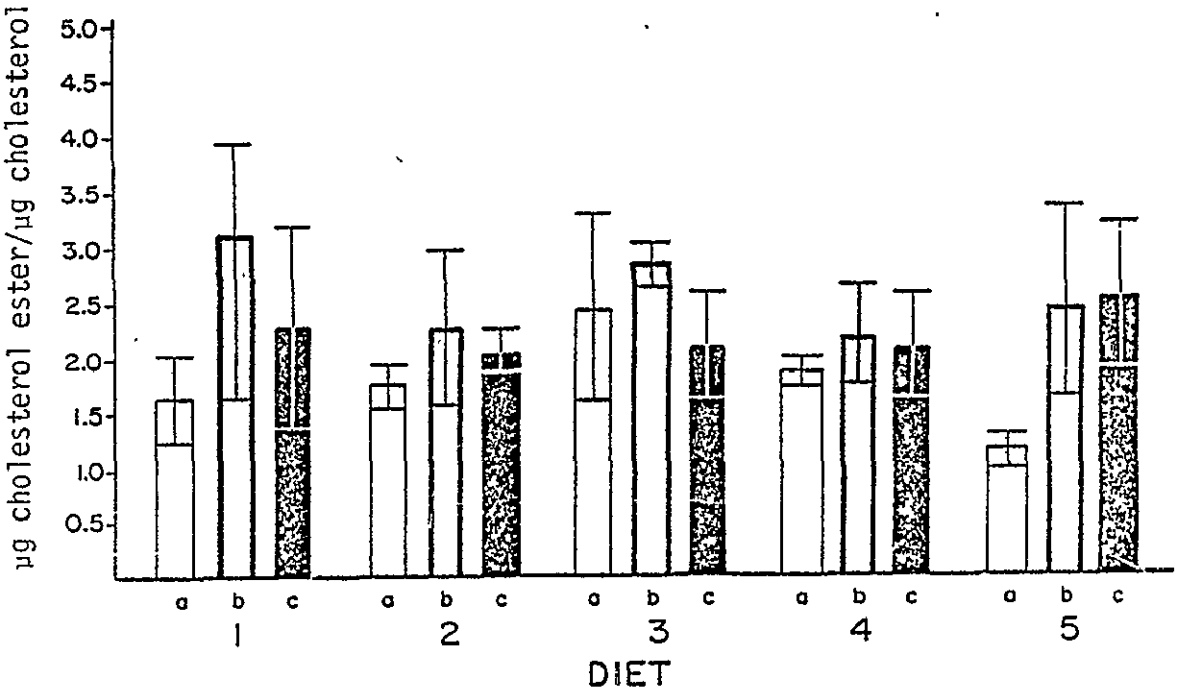
*Number of animals in group.
+Analysis of variance procedure, Duncan's multiple range test, alpha level ≤ 0.10. Means with the same letter are not significantly different.

Table 6. Liver Cholesterol

Diet	Mean (mg/100g)	Grouping+
Sorghum (5)*	1478.0	A
Pearl Millet (4)	1302.5	AB
Sorghum + Ascorbic Acid (3)	1203.3	ABC
Sorghum Bran (3)	1116.7	ABC
Sorghum Endosperm (4)	947.5	BC
Control	745.0	C

*Number of animals in group.
+Analysis of variance procedure, Duncan's multiple range test, alpha level ≤ 0.05. Means with the same letter are not significantly different.

Fig. 1. Effect of ascorbic acid on cholesterol ester-cholesterol ratio.



Diet 1. Control
2. Sorghum
3. Sorghum bran
4. Sorghum endosperm
5. Pearl millet

a = pre-ascorbic acid (day 67-75)

b = high ascorbic acid (day 75-88)

c = post-ascorbic acid (day 88-94)

REFERENCES

Belavady, B. 1975. Nutritive value of maize (*Zea mays*) and sorghum (*Sorghum vulgare*). J. Scient. Ind. Res. 34:294-304.

Bitman, J., D. L. Wood, and J. M. Ruth. 1980. A two-stage, one-dimensional thin layer chromatographic method for separation of lipid classes. JAOCS 57:abs. 384.

Connor, W. E., M. T. Cerqueira, R. W. Connor, R. B. Wallace, M. R. Malinow, and H. R. Casdorph. 1978. The plasma lipids, lipoproteins and diet of the Tarahumara Indians of Mexico. Am. J. Clin. Nutr. 31:1131-1142.

Gopalan, C. 1968. Leucine and pellagra. Nutr. Reviews 26:323.

MacLean, W. C. Jr. and G. G. Graham. 1980. Evaluation of the protein quality and digestibility of sorghum in the diet of infants: supplementary report. Progress Report--March 19, 1980. Research Contract AID/ta-C-1286.

Phillips, R. L., F. R. Lemon, W. L. Beeson, and J. W. Kuzma. 1978. Coronary heart disease mortality among Seventh-Day Adventists with differing dietary habits: a preliminary report. Am. J. Clin. Nutr. 31:S191-S198.

Rosenthal, H. L., M. L. Pfluke, and S. Buscaglia. 1957. A stable iron reagent for determination of cholesterol. J. Lab and Clin. Med. 50:318-322.

Second Annual Report, AID Contract/ta-C-1458. 1979. Improvement of pearl millet. Second annual report: 144-149.

Trowell, H. 1972. Ischemic heart disease and dietary fiber. Am. J. Clin. Nutr. 25:926-932.

Trowell, H. 1975. Ischemic heart disease, atheroma and fibrinolysis. Ch. 15, Refined Carbohydrate Foods and Disease. Burkitt, D. P., and H. Trowell, eds. Academic Press, London. pp. 195-226.

NOTE ON RATE OF WATER PENETRATION INTO SORGHUM DURING TEMPERING

A. A. Abdelrahman and E. P. Farrell

Grain is often "tempered" prior to grinding. Tempering involves adding water, followed by a rest period (Gillespie, 1948; Cleve, 1954). For wheat, tempering toughens the bran, allowing a cleaner separation of bran and endosperm (Briggs, 1925), and increases the friability of the endosperm particles (Butcher and Stenvert, 1973).

The effects of tempering on milling are not completely understood, but adding moisture to grain causes the germ to swell and to pull away from the endosperm (Martin, 1970; Sorenson and Person, 1970). The factors affecting proper conditioning of the grain prior to milling are the amount and distribution of water in the kernel (Bradbury et al., 1960; Anon, 1957) which, in turn, are affected by the amount of water added to the grain, the water temperature, and the time allowed for water to penetrate the kernel (Kuprits, 1965).

The rate at which water penetrates grain affects the time needed for tempering, and this must be considered in the mixing of different grain lots (Baker, 1935; Blessin et al., 1962). Fraser and Haley (1932) found that the amount and rate of water absorption by wheat was affected by wheat variety, tempering time and temperature, and kernel size. Scouring the grain increased water absorption; the percentage of protein in wheat had a minor effect on water absorption.

In contrast, Butcher and Stenvert (1973) found that the concentration and distribution of protein within the wheat kernel greatly affected the rate at which moisture penetrated the grain. High concentrations of protein below the aleurone layer retarded the movement of moisture into the grain, but the grain's hardness was not related to the rate at which moisture penetrated the kernel.

Little work has been done on the uptake of water by grain sorghum. Recording weight gains during tempering, Fan et al. (1963) found that the initial weight gain was rapid but decreased gradually with time. They reported that the diffusivities of water in corn and sorghum were of the same order of magnitude as those in wheat. Others have found that hard sorghum absorbs moisture more slowly than does soft sorghum (Weinecke et al., 1965) and that waxy sorghum cultivars absorb more water than do nonwaxy cultivars (Mustafa, 1969).

Our objective was to study the rate at which water penetrates sorghum kernels during tempering by using autoradiography and an electrical conductance moisture meter.

MATERIALS AND METHODS

Materials

A commercial, low-tannin sorghum, grown in Kansas in 1978, was used. After the grain had been cleaned on the Carter Dockage Tester and scoured with an experimental scourer, the light debris was removed with a Kice Aspirator. The cleaned grain had a test weight of 59.8 lbs/bushel and a 1,000 kernel weight of 24.9 g. One sample contained 9.1% protein (N x 6.25), 3.3% fat, 1.5% ash, and an initial moisture content of 12.5%. Another sample had an initial moisture of 10.8%.

Water Penetration into Sorghum Kernels

Water penetration was studied with a Tag-Heppenstall electrical conductance moisture tester. With the electrical moisture tester the resistance of the grain to passage of an electrical current decreases as the moisture content increases. By measuring the decrease in apparent moisture in the outer layers of the grain at regular time periods, the rate of entry of the water into the kernel is determined. Sorghum (3,000 g) was tempered to different moisture levels (15, 16, 17, & 18%). The amount of water required to attain each level was mixed with the grain in a rotating steel drum long enough to allow water on the surface to be absorbed, and then each sample was kept in a closed alumnium can. A small sample from each can was tested in the moisture meter at various times after the initial introduction of water to the grain.

An autoradiographic technique (Jackson and Varriano-Marston, 1980) also was used to determine the rate and pattern of moisture uptake. Sound kernels (30) were placed in glass vials, and 0.2 ml of tritiated water (50 mCi/ml) was added to each vial. The vials were shaken and then stored at 25°C for 1 to 3 hr. After a designated time, sorghum kernels were washed with distilled water, cut with a razor blade, mounted in pithwood, and frozen in liquid nitrogen. Half-kernels were taped to pre-frozen strips of NMB film and then exposed for 24 hr at -78°C. Following exposure, kernels were removed from the film, and the film was developed in D-19.

RESULTS AND DISCUSSION

The rates at which water penetrated sorghum kernels as determined by the moisture meter are presented in Figures 1 and 2. Since nearly all added water was initially on the surface of the kernels, the initial reading indicated a much higher moisture percentage than that of the tempered kernels. Initial moisture content of the grain had an effect on the rate that water penetrated the grain during the first 2 hr of tempering. Grain with an initial moisture content of 10.8% (Fig. 1) absorbed more water than did grain having an initial moisture content of 12.5% (Fig. 2).

As time progressed, the moisture on the surface was absorbed into the kernels. Initially water penetrated rapidly; after 3 hr most of the water had adsorbed into the kernel. Water uptake, thereafter, was slow and was not affected by initial grain moisture content.

Autoradiographic data agreed with data obtained on the conductance meter. The extent to which tritiated water had penetrated individual kernels after 1 hr and 3 hr is shown in Figure 3. After 1 hr the water was confined to the outside layers of the kernel, but after 3 hr water was distributed throughout the entire kernel. The autoradiograms suggest that the structures of the pericarp do not delay water penetration into the grain; i.e., the rate of penetration through the bran is the same as through the germ. Similar results were reported for wheat by Jones (1949). Comparing our data with similar autoradiographic studies on wheat kernels (Jackson and Varriano-Marston, 1980) indicates that water penetrates sorghum more rapidly than it does wheat.

LITERATURE CITED

Anon. 1957. The objects of conditioning. Milling. 128:306

Baker, R. H. 1935. What the miller should know. Am. Mill. 63(3):20.

Blessin, C. W., Dimlen, R. J., and Webster, O. J. 1962. Carotenoids of corn and sorghum. II. Carotenoid loss in yellow endosperm sorghum grain during weathering. Cereal Chem. 39:389.

Bradbury, D., Hubbard, J. E., MacMasters, M. M., and Senti, F. R. 1960. Conditioning wheat for milling. A survey of the literature. Miscellaneous publication No. 824 U.S.D.A.

Briggs, C. H. 1925. The conditioning and milling of grain. Northwest Mill. 144:988.

Butcher, J., and Stenvert, N. L. 1973. Conditioning studies on Australian wheat. III. The role of the rate of water penetration into the wheat grain. J. Sci. Fd. Ag. 24:1077.

Cleve, I. H. 1954. Conditioning of wheat. The outer layer process. Mill. 123:478.

Fan, L. T., Chu Pu-Shan, and Shellenberger, J. A. 1963. Diffusion of water in kernels of corn and sorghum. Cereal Chem. 40:303.

Fraser, C. W., and Haley, W. L. 1932. Factors that influence the rate of absorption of water by wheat. Cereal Chem. 9:45.

Gillespie, A. 1948. The importance of time tempering. Mill. Prod. 13(3):22.

Jackson, G. M., and Varriano-Marston, E. 1980. A simple autoradiographic technique for studying diffusion of water into seeds. Plant Physiol. 65:1229.

Jones, C. R. 1949. Observations on the rate of penetration of water into the wheat grain. Mill. 113:80.

Kuprits, R. N. 1965. Technology of grain processing and provender milling. Translated from Russian. U.S.D.A. and National Science Foundation, Washington, D.C., 1967.

Martin, J. H. 1970. History and Classification of *Sorghum bicolor* (Linn.) Moench. In: "Sorghum Production and Utilization," p. 1, Wall, J. S., and Ross, W. M. (eds.), Avi Publishing Co.: Westport, Conn.

Mustafa, A. I. 1969. Evaluation of new varieties of sorghum grain for wet milling. Master's Thesis, Kansas State University.

Sorenson, J. W., Jr., and Person, N. K., Jr. 1970. Drying, storing, and handling sorghum grain. In: "Sorghum Production and Utilization, "p. 469, Wall, J. S., and Ross, W. M. (eds.), Avi Publishing Co.: Westport, Conn.

Weinecke, L. A., and Montgomery, R. R. 1965. Experimental unit now suitable for scale-up to mill production size. Am. Mill. Proc. 93(4):8.

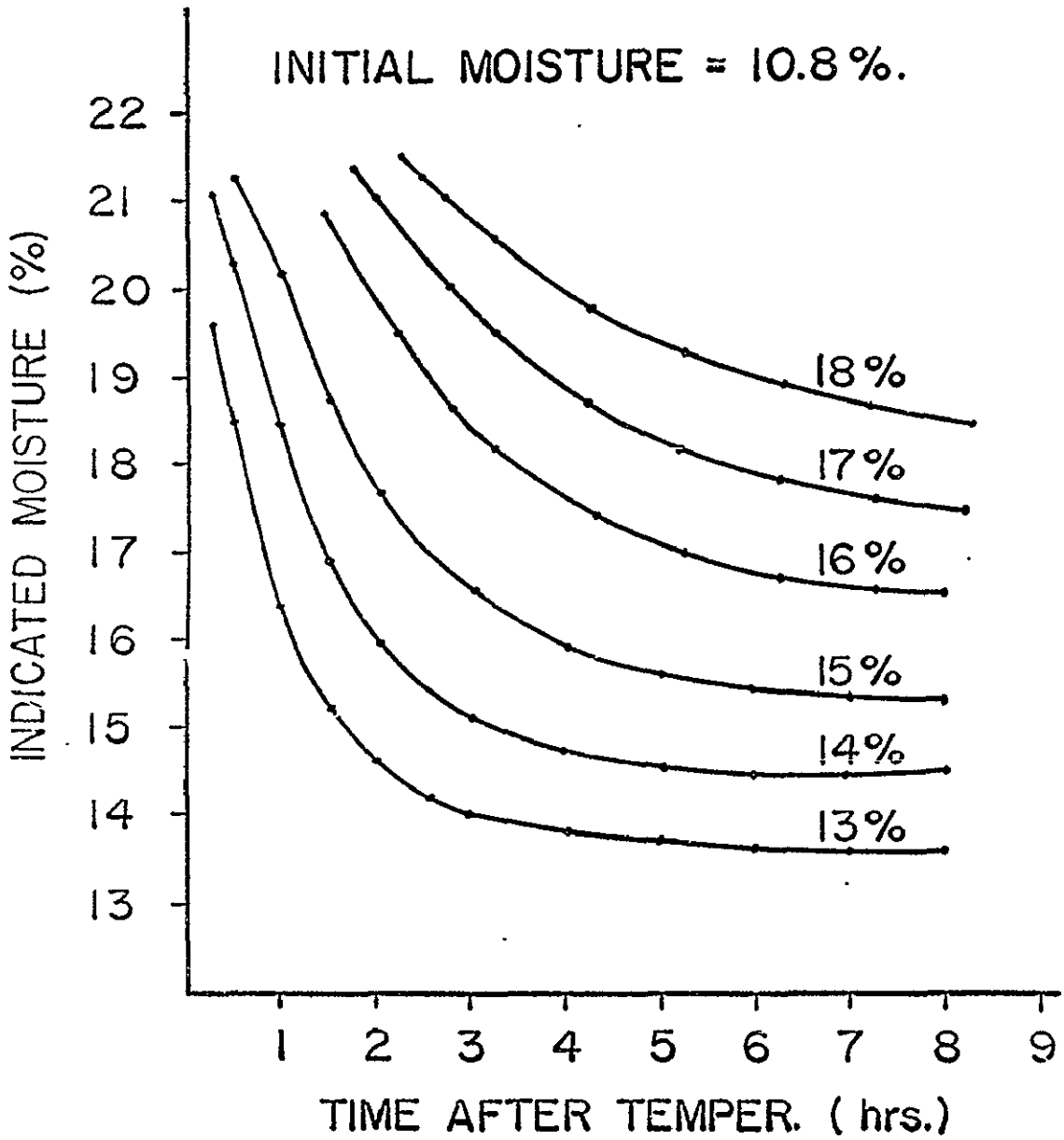


Figure 1. Effect of tempering moisture level and time on the absorption of water by grain sorghum with an initial moisture content of 10.8%.

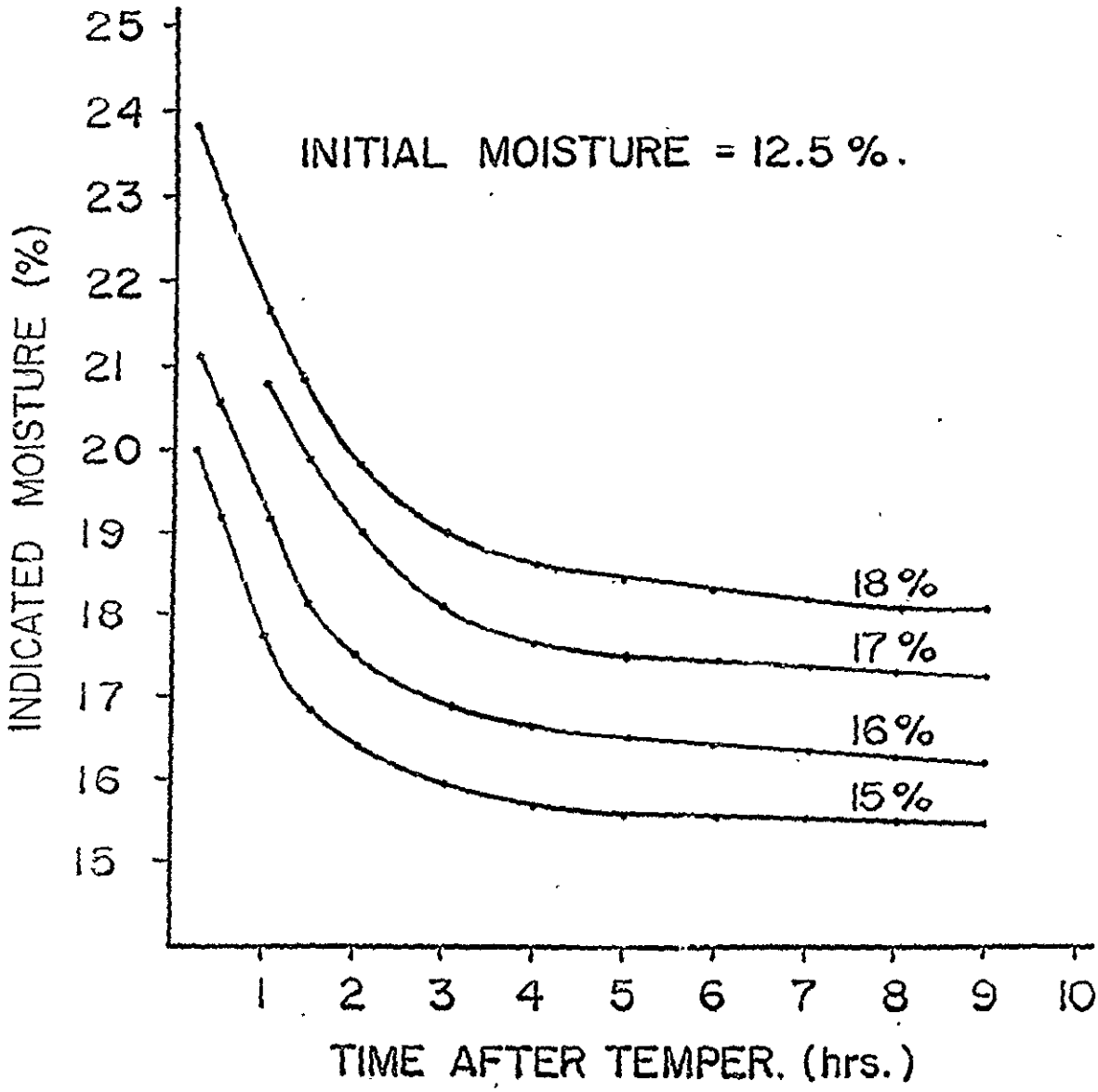


Figure 2. Effect of tempering moisture level and time on the absorption of water by grain sorghum having an initial moisture content of 12.5%.

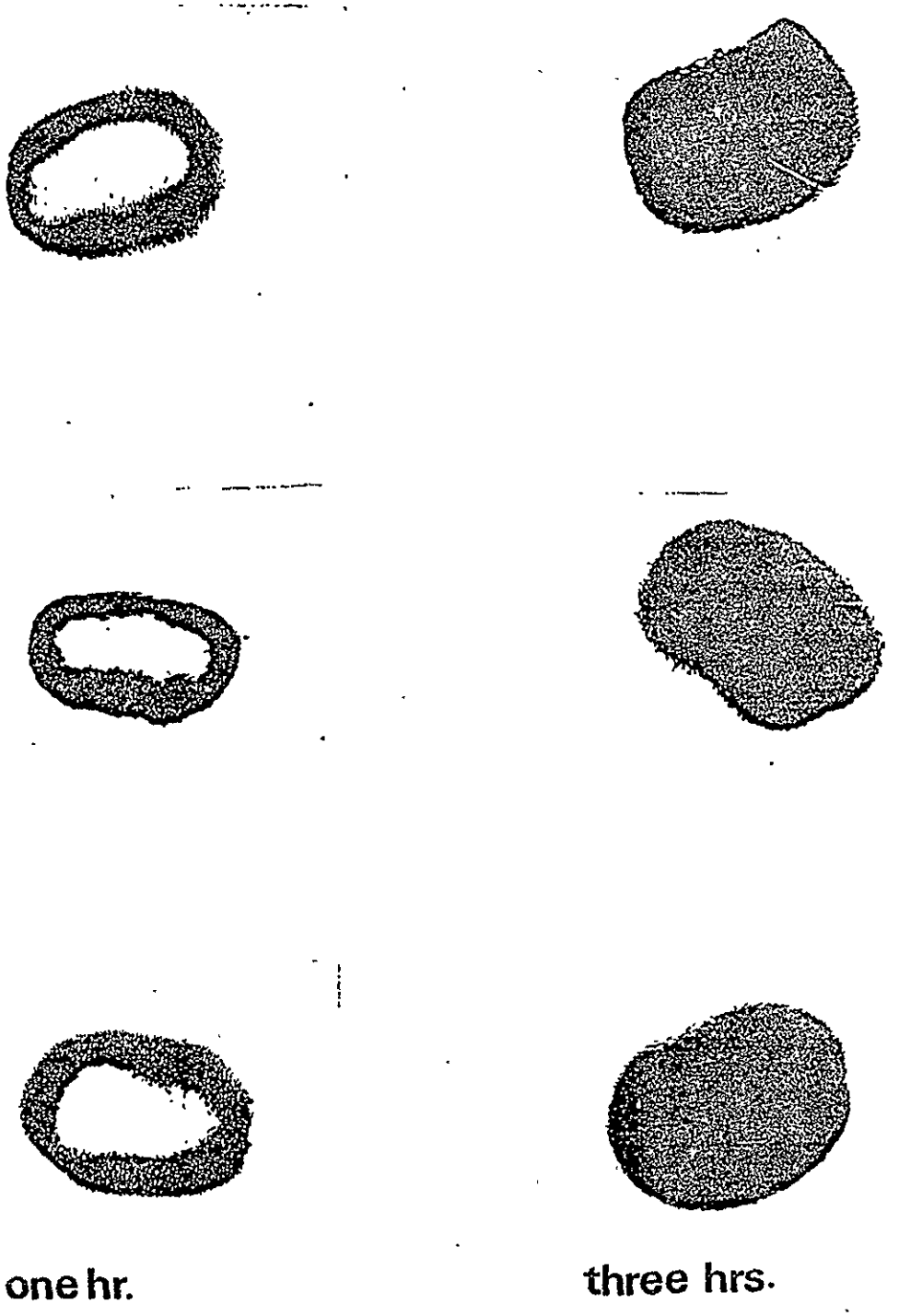


Figure 3. Autoradiograms showing the penetration of tritiated water into sorghum kernels after 1 and 3 hr. of tempering.

Grits from Grain Sorghum Dry Milled on Roller Mills

A. A. Abdelrahman and E. Farrell

ABSTRACT

Dry milling sorghum with a prebreak system produced grits with lower fat and ash contents than grits produced without a prebreak. Yields of bran and fines (-30LW) increased and the quantity of grits decreased as temper moisture increased. The optimum tempering treatment for the production of grits with maximum yield and low fat content was 17% moisture and 8 hr tempering.

Although sorghum is widely used for human food, and potential for other uses is great, sorghum milling technology is far from adequate. In developing countries, most grain is milled by grinding on stone mills or in a wooden mortar and pestle (Vogel and Graham, 1979).

Modern dry milling processes for sorghum use roller mills and pearlers. Hahn (1969) and Hoseney et al. (1980) have thoroughly reviewed those methods. A major problem in sorghum dry milling is separating germ from endosperm; tempering the grain appears to facilitate the separation (Hahn, 1969).

Our objective was to determine the suitability of a simple system consisting of roller mill, sifters, and gravity separators for milling sorghum into refined endosperm fractions with low fat and ash. We wanted to develop a commercial dry milling process to produce grits from sorghum.

MATERIALS AND METHODS

Materials

The commercial low tannin sorghum, grown in Kansas in 1978, we used was cleaned on a Carter Dockage Tester, scoured with an experimental scourer, and the light debris removed with a Kice Aspirator. Test weight of the cleaned grain was 59.8 lbs/bushel; its 1000-kernel weight was 24.9 g. The grain contained 9.1% protein (N x 6.25), 3.3% fat, 1.5% ash, and 12.4% moisture.

Milling Equipment

A pair of corrugated rolls (6" x 6") with adjustable belt drive were used to break the kernels into small particles that then were separated on a Gyro Laboratory Sifter having a 2.1 in. throw run at 225 rpm. After sifting, a gravity separator was used to separate particles based on density.

Milling Procedure

Initially the milling system consisted of three breaks and three sifters followed by three gravity tables (Fig. 1). A sample of 300 g, tempered to 17% moisture for 4 hr., was run through the system.

In wheat milling processing, a prebreak (no differential) is used to crack the kernels open before the first break. That creates more surface area, which fosters cleaner endosperm removal from the bran (Farrell, 1980). To study the effect of a prebreak instead of a normal break on the end-products of sorghum milling, we tempered a sorghum sample to 17% moisture for 4 hr, then passed it through the system shown in Figure 2. The prebreak rolls had a fine corrugation and a differential of 1:1.3.

To study the effect of different tempering conditions on the behavior of the sorghum during milling, we modified the prebreak milling system by eliminating the first gravity separator and adding two more breaks to grind the grits going to the first gravity separator (Fig. 3). Samples were tempered to four moisture levels (16, 17, 18, & 19%) and held for three time periods (2, 4, & 8 hr) before milling. Twelve combinations of temper moisture levels and holding times were tested. In each case the samples were milled with a constant roll and feed setting. The percentages total products in the fractions from each sample were determined. Each fraction was analyzed for moisture, fat, and ash (AOAC, 1975).

RESULTS AND DISCUSSION

Dry Milling System

The data in Table 1 compare the prebreak system with the sorghum dry-milling system using three breaks. The prebreak system produced grits with lower fat than when it was not used. It tended to open the grain rather than crush it, so it produced less bran powder and it gave more endosperm separation in subsequent breaks than the three-break system.

The prebreak system still yielded refined coarse grits (+10W) with high fat content (Table 1). When the modified system (Fig. 3) was used, a small fraction with high fat content was separated leaving grits with low fat content (Table 2), suggesting that the overs of the 10 wire contained the germ. Apparently, the sorghum germ remained attached to 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 dry and wet milling (Rooney and Clark, 1968; Wall and Ross, 1969).

Effect of Tempering

The effect of different tempering conditions on the behavior of sorghum during milling was studied by comparing the total yield, fat, and ash contents of each fraction. For each sample, four fractions were obtained after grinding and sifting (Fig. 3): bran, germ, fines (-30LW), and grits (-10W + 30LW).

The interaction between moisture and time on total production, fat, and ash was tested by Tukey's test (Ostle and Mening, 1975), and the characteristic root test. Both tests failed to show a significant interaction between moisture and time on total product, fat, or ash. The main effects of moisture and time on each fraction also were studied by analysis of variance (ANOVA). The f-values for each effect are given in Table 3.

Bran separation. The amount of bran produced (T.P.) increased as the moisture content increased (Fig. 4). Fat and ash were affected less by moisture except at 19% where both fat and ash decreased markedly. At the higher moisture level some endosperm apparently remained attached to the bran and lowered its fat and ash contents. As tempering time increased, total production of bran decreased (Fig. 4), but tempering time did not significantly affect either ash or fat content of the bran. As tempering time increases, moisture penetrates deeper into the kernel leaving the bran with less water so it is less tough and breaks up more easily into particles that pass through the 8W sieve.

Our results indicate that the effect of moisture on sorghum bran is the same as that reported by Gillespie (1948). Moderate amounts of moisture make the bran tough and easy to separate while excessive moisture makes it difficult to separate from the endosperm material.

Germ separation. Level of tempering moisture significantly affected total production, fat, and ash content of the germ (Table 3). As the moisture level increased, germ produced increased (Fig. 5). However, at 19% moisture and 2 hr tempering, the quantity of germ produced decreased. Some germ probably remained attached to the bran as the quantity of bran produced was much more than expected.

Fat and ash contents of the germ decreased as tempering moisture increased. Tempering time had no significant effect on the total product or on fat and ash contents of the germ (Table 3).

Fines (-30LW) production. Temper moisture significantly affected the total production of fines (Table 3). As moisture increased, fines produced increased (Fig. 6).

The fines are derived mainly from the floury endosperm, which is easily released upon grinding. As tempering moisture increased, the corneous endosperm became soft and more easily broken into fines. The increase in fines came from the corneous endosperm, not the bran, because fat and ash decreased as the fines increased (Fig. 6).

Less fines were produced after a 4 hr temper than after 2 or 8 hr temper (Fig. 6). The decrease in fat and ash with increasing tempering time indicates that the increased fines at 2 hr comes from reduction of the outer layers while the increase in fines at 8 hr comes from the reduction of corneous endosperm. At high tempering moisture (19%), total production of fines increased with time and fat and ash contents decreased.

Grits (-10W + 30LW) production. Both tempering moisture and holding time significantly affected total production, fat, and ash of the grits (Table 3). Increasing moisture decreased total production (Fig. 7), probably by increasing the friability of the grits (corneous endosperm) so they more easily reduced to fines. On the other hand, high moisture may have caused some outer layers of the endosperm to remain attached to the bran.

As tempering time increased, grits yield increased probably from the reduction of kernel outer layers. Some bran may have been included with the grits because fat and ash contents of the grits increased.

Refinement of Grits on the Gravity Separator

The coarse and medium grits obtained from different tempering conditions were refined with a gravity separator (Fig. 3). Total product, ash, and fat content of refined coarse grits after tempering for various lines at 16% moisture are given in Table 4. Data from other tempering conditions (17, 18 & 19%) were similar to those in Table 4.

The separator operated at high efficiency to separate refined grits from bran. An average of 81% of the material from the separator was refined grits with low fat and ash (Table 4). The remaining 19% was bran characterized by the high fat and ash of that product. Our data on sorghum refining grits on the gravity separator agree with findings of Anderson et al. (1969) who reported that a gravity separator for grit-germ separation gave results comparable to flotation in sodium nitrate solution.

SUMMARY AND CONCULSIONS

Dry milling of sorghum with a prebreak system produced grits with lower fat and ash contents than grits produced without a prebreak. During dry milling with roller mills the oil-rich germ stays with the material remaining over the 10-wire sieve.

Tempering conditions affected the behavior of sorghum during milling. An increase in temper moisture increased yields of bran and fines (-30LW). and reduced the quantity of grits produced, so tempering water affects the dry milling performance of grain sorghum as it does wheat; it toughens the bran while working the endosperm soft and friable. The optimum tempering treatment for the production of grits with maximum yield and low fat content was 17% moisture and 8 hr tempering.

The gravity separator was effective in separating grits from bran. The suction of the gravity separator helped remove bran particles during the refining of grits. Yield of refined grits separated by the gravity separator varied with the amount of bran in the throughput.

Table 1: Effect of Prebreak Milling System on Distribution of Grain Sorghum Products

	3 Breaks			Prebreak + Two Breaks		
	T.P.[1] (%)	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

[1]Total product

Table 2. The Effect of a Milling System with Prebreak Plus 4 Breaks on Distribution of Grain Sorghum Products

	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

Table 3. F-Values for the Main Effects of Moisture and Time on Total Product, Ash, and Fat of Bran, Germ, Fines, and Grits

		Moisture	Time
Bran	T.P.	34.38*	9.12*
	Ash	2.52	2.41
	Fat	8.15*	1.99
Germ	T.P.	4.55*	0.39
	Ash	19.22*	1.89
	Fat	11.12*	2.69
Fines (-30LW)	T.P.	12.99*	2.81
	Ash	51.62*	10.50*
	Fat	56.06*	28.29*
Grits (-10W + 30LW)	T.P.	248.42*	14.97*
	Ash	55.27*	13.36*
	Fat	61.48*	14.55*

*Significant at $P < 0.05$

Table 4. Performance of Gravity Separator in Separating Coarse Grits (-10W, +16W) from Sorghum Tempered to 16% Moisture

Temper time hrs	High side (%)				Low side (%)			
	System yield[1] (%)	T.P.[2] (%)	Ash (%)	Fat (%)	System yield (%)	T.P. (%)	Ash (%)	Fat (%)
2	82	42.6	0.70	1.77	18	9.5	2.32	5.31
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

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

[2]Percentage of product of the overall system.

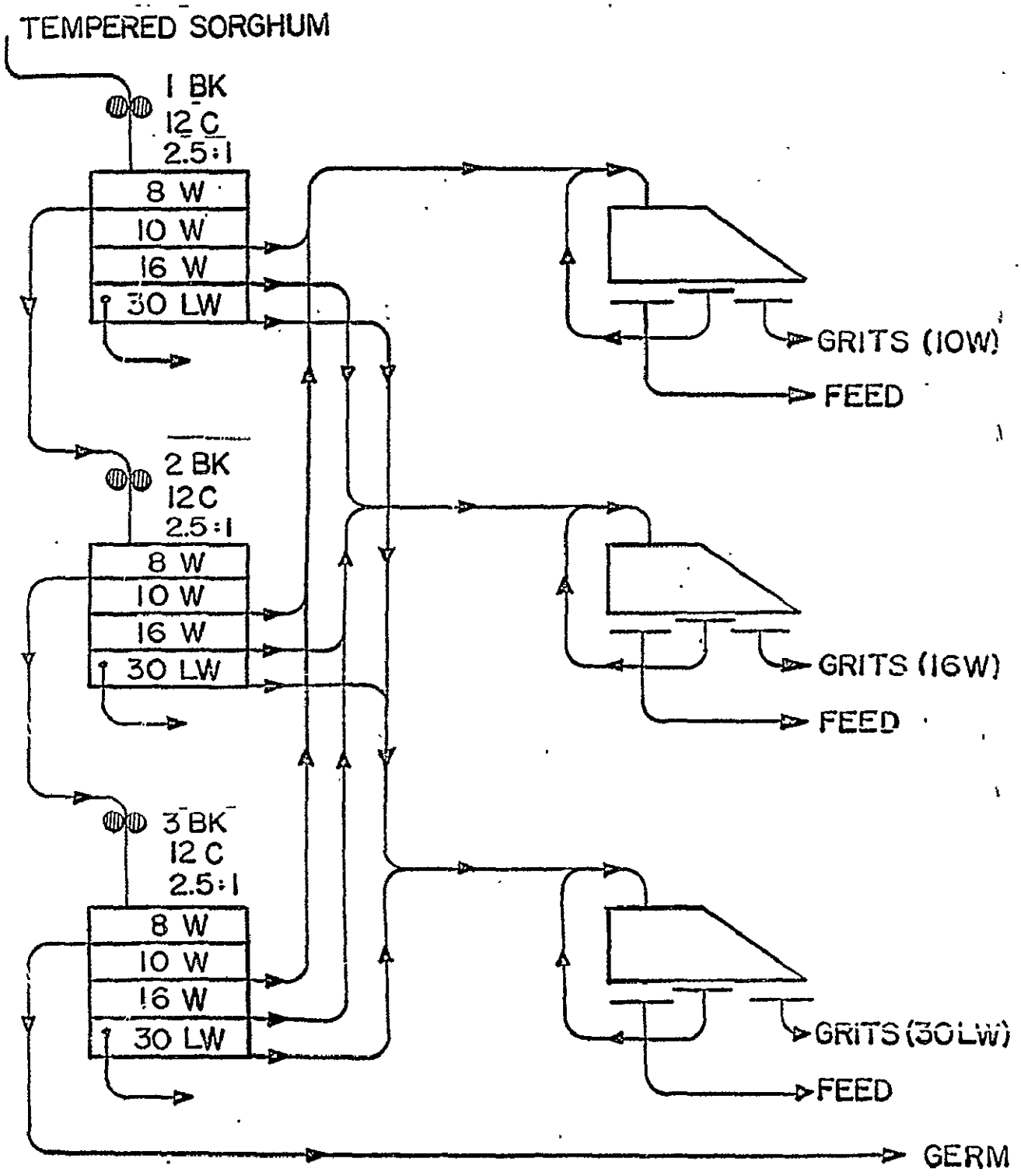


Figure 1. Flow sheet of sorghum milling system using 3 breaks.

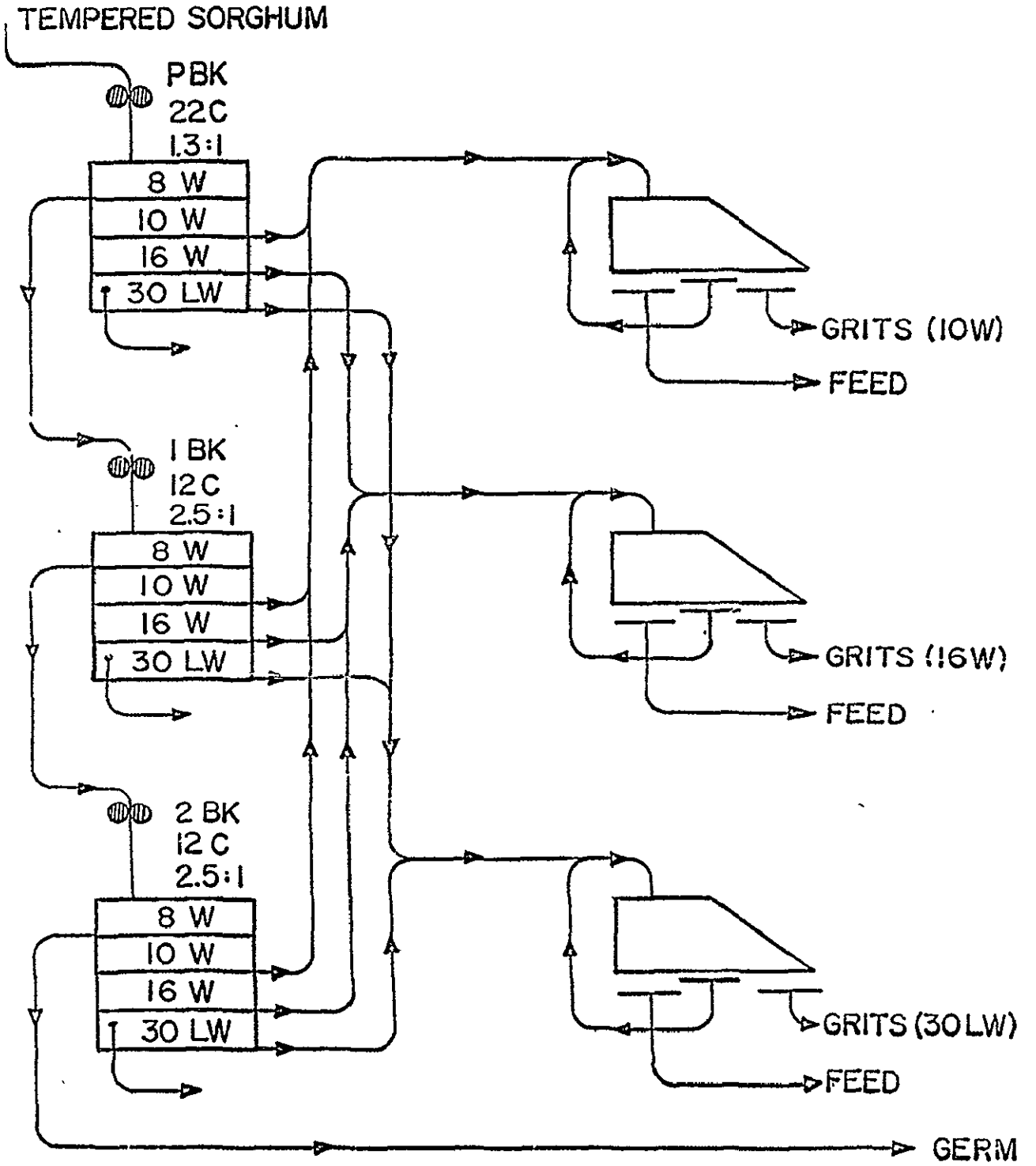


Figure 2. Flow sheet of sorghum milling system using a prebreak and 2 breaks.

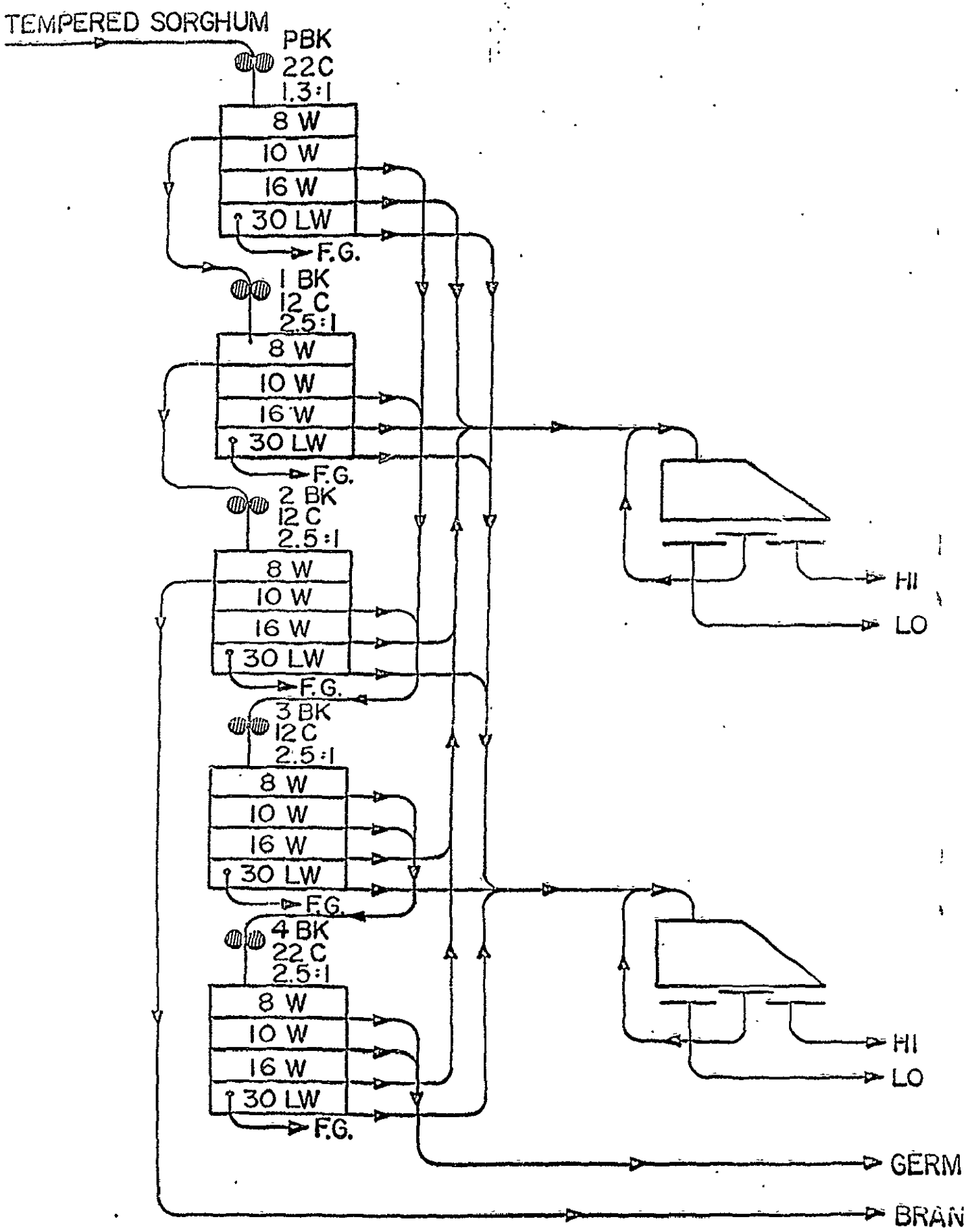


Figure 3. Modified prebreak system used to study the effect of tempering on sorghum.

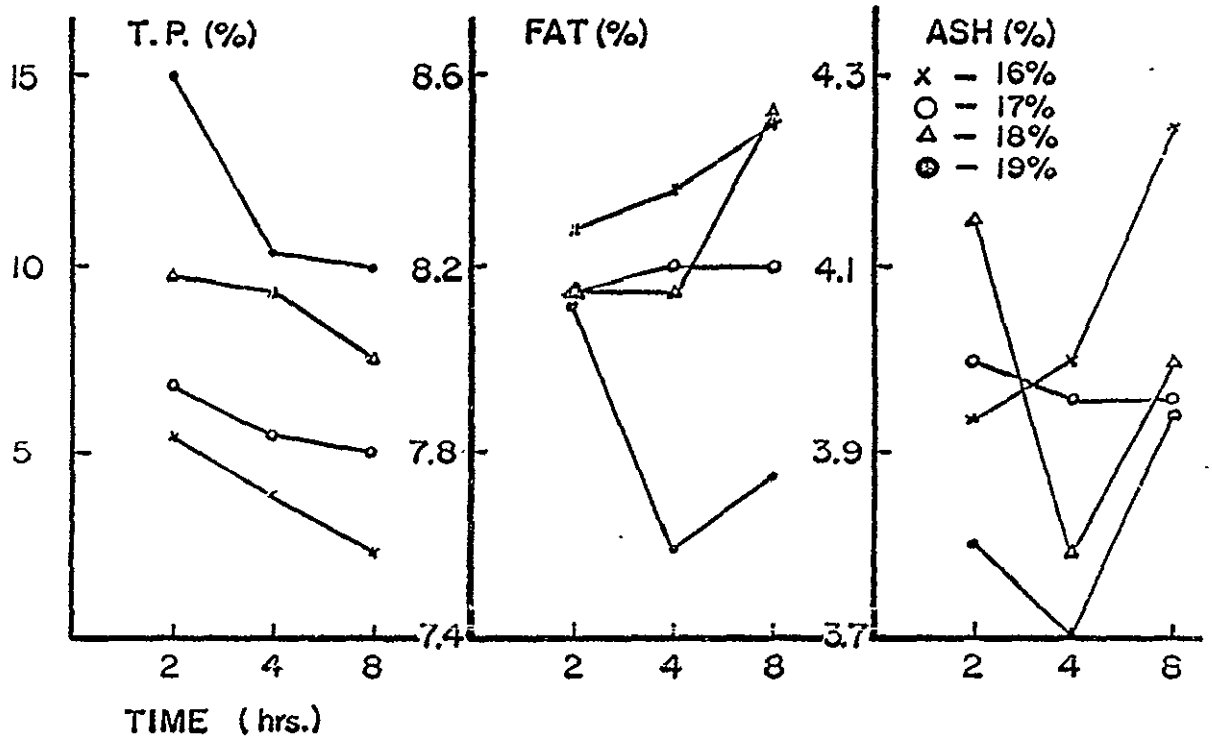


Figure 4. Effect of tempering conditions on bran separation.

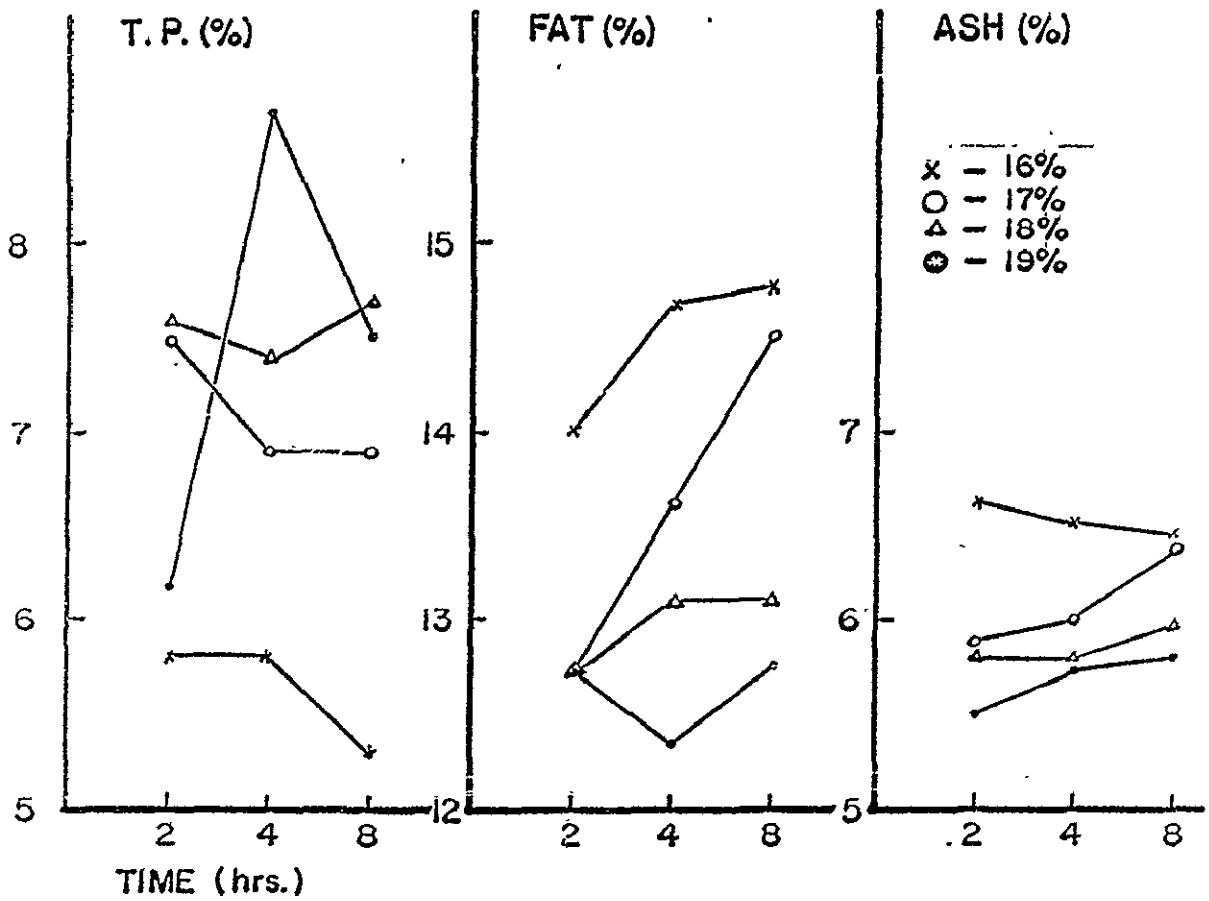


Figure 5. Effect of tempering on sorghum germ separation.

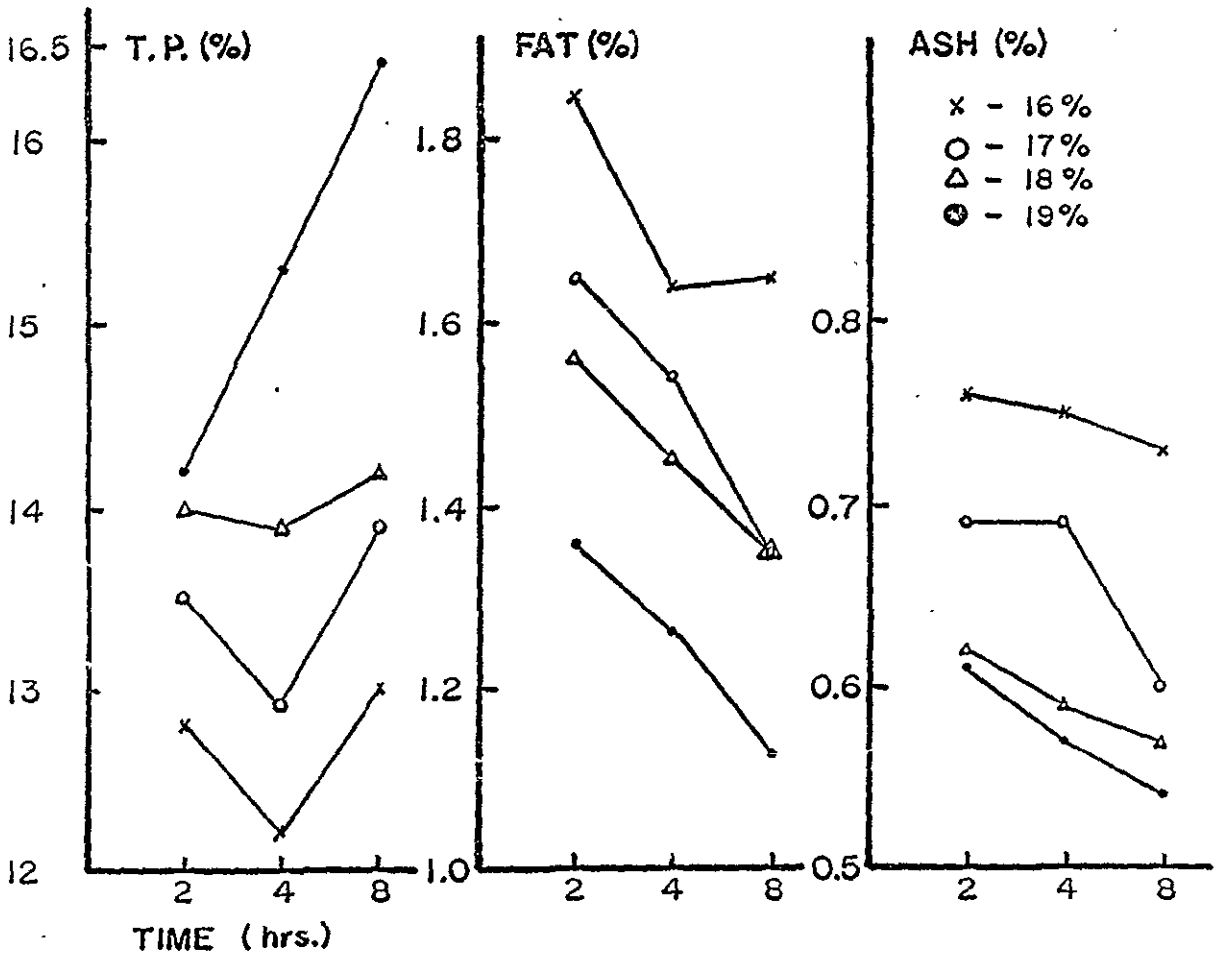


Figure 6. Effect of tempering on sorghum fines (-30LW) production.

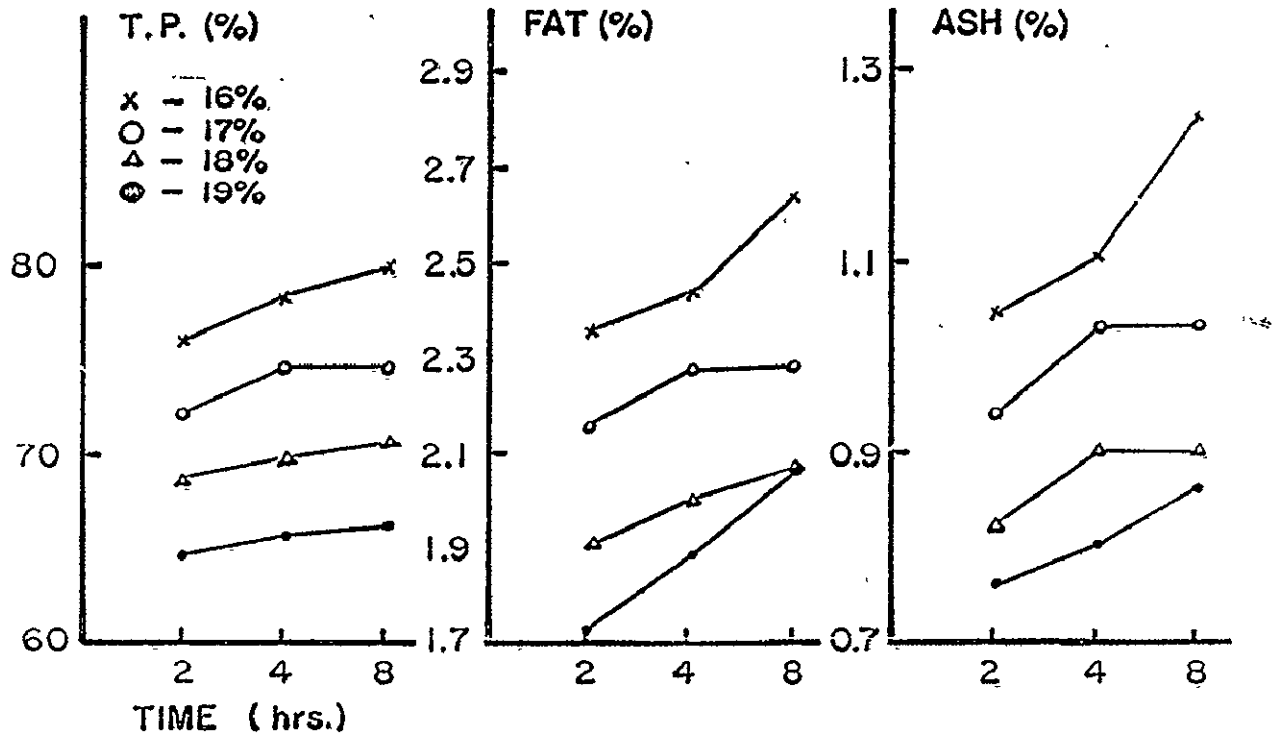


Figure 7. Effect of tempering on sorghum grits (-10W + 30LW) production.

LITERATURE CITED

Anderson, R. A., Montgomery, R. R., and Burbridge, L. H, 1969. Low-fat endosperm fractions from grain sorghum. Cereal Sci. Today. 14:366.

Association of Official Analytical Chemists. 1975. Official Methods of Analysis (12th ed.). The association. Washington, D. C.

Farrell, E. P. 1980. Unpublished data.

Gillespie, A. 1948. The importance of time tempering. Milling Prod. 13(3):22.

Hahn, R. R. 1969. Dry milling of grain sorghum. Cereal Sci. Today. 14:234.

Hoseney, R. C., Varriano-Marston, E., and Dendy, D. A. V. 1981. "Sorghum and Millets." Adv. Cereal Sci, & Technol., Vol. 4. Pomeranz, Y. (ed.). In press.

Ostle, B., and Mensing, R. W. 1975. Statistics in Research. Basic Concepts and Techniques for Research Workers. pp. 382, 3rd edition. Iowa State University Press: Ames.

Rooney, L. W., and Clark, L. W. 1968. The chemistry and processing of sorghum grain. Cereal Sci. Today. 13:257.

Vogel, S., and Graham, M. 1979. Sorghum and Millet: Food Production and Use. IDRC, Ottawa, Ont.

Wall, J. S., and Ross, W. M. 1969. Composition and structure of sorghum grains. Cereal Sci. Today. 14:264.

"Sorghum and Millets"

Chapter for

Advances in Cereal Science and Technology

Vol. IV

Y. Pomeranz, Editor

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I. INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Moench] and the various millets are major food crops in Asia and Africa. They are grown in semi-arid areas and usually as dry-land crops. Most of the grain produced in those areas is consumed directly as food for humans. Sorghum, millet, and corn (maize) are coarse grains that tend to produce gritty tasting products unless they are cooked properly. Traditionally sorghum and millet have been considered poor man's food and the crops of last resort, with crop failure often meaning starvation.

Relatively little millet is grown in the Western Hemisphere. In contrast, the United States produces over 1/3 of the total sorghum in the world. Other than small amounts in Argentina and other South American countries the rest of the sorghum is grown in the Eastern hemisphere. In India sorghum and millets compose about 14% of the total grain production (Subramanian and Jambunathan, 1980). The U.S. crops are grown under quite different conditions than those in India and Africa. In general, U.S. sorghum is produced under higher fertility, and relatively high rainfall conditions and gives much higher yields (Rachie, 1969). For all practical purposes all the sorghum grown in the U.S. is used for animal feed, with only minor amounts finding their way into food products.

The literature covering sorghum and millets is difficult to locate and often contradictory. Much of it is in meeting reports that have limited distribution. The U.S. literature is relatively small and scattered over several disciplines. The non-U.S. literature is large but also scattered in many journals. Both sorghum and millets are referred to by a number of common and scientific names, resulting in much confusion in the literature. Our objective is to compile most of the literature in this chapter and, we hope, to reduce some of the confusion. Areas not covered in this review are (1) uses of sorghum, both grain and fodder, as animal feed, (2) sweet sorghum as food, and (3) the agronomic production of the crop.

II. SORGHUM

A. Structural Characteristics of Sorghum

Sorghum kernels are generally spherical (Fig. 1) and have a thousand kernel weight ranging from 20 to 30 g. Kernel colors may be white, red, yellow, or brown.

The schematic diagram in Figure 2 shows the relative proportions of the various parts of a sorghum kernel. Hubbard et al. (1950) hand-dissected kernels and found that the pericarp, germ, and endosperm composed 7.9%, 9.8%, and 82.3% of the grain, respectively. They also reported the composition of the fractions (Table I). The pericarp, aleurone layer and endosperm portions are clearly observed in Figure 3. Numerous authors have described the structural features of sorghum as viewed with the optical microscope (Swanson, 1928; Sanders, 1955; Watson et al., 1955; Rooney, 1973; Sullins and Rooney, 1974, 1977; Blakely et al., 1979).

Scanning electron micrograph (SEM) of the outer layers of a sorghum kernel reveal a complex pericarp consisting of three layers: the epicarp, the mesocarp, and the endocarp (Fig. 4). Unlike other cereal grains, sorghum mesocarp can contain starch granules ranging in size from 1 to 4 μm; however, in certain genotypes a thin pericarp with only remnants of mesocarp cells are found. The presence of a thick or thin mesocarp is controlled by a single, dominant gene. Cross and tube cells constitute the endocarp layer.

The mature sorghum caryopsis may (Fig. 4) or may not (Fig. 5) have a pigmented inner integument. The inner integument is often erroneously called a testa layer. The testa is the seed coat that is joined to the outer edge of the inner integument. Some cultivars have been reported to lack a testa (Rooney and Sullins, 1977; Hoseney et al., 1974). Obviously all mature seeds have a testa (seed coat), but certain grain sorghums lack an inner integument.

The aleurone cells are the first layer of endosperm cells (Fig. 6). Ultrastructural observations on sorghum aleurone cells indicate that they contain protein bodies surrounded by numerous lipid bodies (Fig. 6). Some protein bodies contain crystalloid inclusions.

Cells containing high concentrations of protein and few starch granules are found just beneath the aleurone layer (Fig. 7). Most of the protein is in the form of protein bodies, 2 to 3 μm in diameter, which appear to have a lamellar structure (Adams and Novellie, 1975a). Acid protease, acid phosphatase, glycosidase, and nuclease activities have been detected in the protein bodies (Adams and Novellie, 1975a; Adams et al., 1976). Prolamines are the major components of the protein bodies (Seckinger and Wolf, 1973; Hoseney et al., 1974). Matrix protein, consisting mostly of glutelin (Seckinger and Wolf, 1973), surrounds protein bodies (Fig. 8). Adams and Liebenberg (1975) have suggested that, unlike in wheat, rye, and triticale where protein bodies coalesce to form matrix protein as the seed matures, protein bodies of sorghum and corn persist into maturity and become a major source of storage protein.

The cells below the peripheral endosperm layer are part of the hard endosperm and contain polygonal starch granules packed tightly together and surrounded by protein bodies (Fig. 8). The size and number of protein bodies in the hard endosperm have been related to lysine content (Seckinger and Wolf, 1973; Hoseney et al., 1974); cultivars with high lysine contents generally have smaller or fewer protein bodies.

The floury endosperm, with its large intergranular air spaces (Fig. 9), is structurally different from the compact hard endosperm. The spherical starch granules have small particles of protein adhering to their surfaces or are loosely associated with papery sheets of protein. Vitreous and opaque areas of sorghum endosperm contain identical quantities of nitrogen (Palmer, 1972). The opaque appearance of the floury endosperm is related to the diffraction of light by the air spaces.

The terms "hard" and "soft" have been used to designate vitreous and opaque areas of sorghum endosperm as well as the general appearance of individual kernels. Simmonds (1974) has suggested that, for wheat, the causal factors determining vitreosity and physical hardness are different. Therefore, some kernels may appear vitreous but be classified as soft by objective measurements. Like wheat, visual determination of sorghum kernel hardness may be arbitrary so satisfactory physical methods are needed that provide quick and accurate analyses of grain hardness.

B. Sorghum Proteins

The proteins in sorghum were covered in a review by Wall and Paulis (1978) in volume 2 of this series. Thus, we shall concentrate on the substantial literature appearing in the last few years and refer to older literature only as necessary.

The protein content of sorghum, as with all cereals, varies widely (Johnson et al., 1968; Sisodia et al., 1979; Haikerwal and Mathieson, 1971; Worker and Ruckman, 1968; Miller et al., 1964; Deyoe and Shellenberger, 1965). Protein values, usually reported as N x 6.25, vary from about 6% to 25%. Most of the variability is caused by those factors that affect grain yield. Worker and Ruckman (1968) reported a correlation coefficient of $r = -0.85$ for grain yield and protein content. Important factors affecting protein content were reported to be planting date, cultivar, seed size, and air temperature; of course, the level of nitrogen fertilization exerts a major influence on grain protein content (Burleson et al., 1956; Waggle et al., 1967).

The amino acid composition of sorghum, as reported by a number of workers, is given in Table II. In general, sorghum is high in glutamic acid, leucine, alanine, proline, and aspartic acid. The amino acid composition is similar to that of corn (Wall and Paulis, 1978). Briley et al. (1979) have recently reported methods of computing amino acid content of sorghum samples that eliminate systematic errors in certain amino acids.

As with most cereals, lysine appears to be the first limiting amino acid (Adrian and Sayerse, 1957). The level of lysine and certain other

amino acids in the grain varies with the protein content of the grain (Waggle and Deyoe, 1966). Table III, reproduced from Waggle and Deyoe (1966), shows that the level of all amino acids is positively and rather highly (r = 0.71 to 0.98) correlated with protein content. The slope of the correlation line, however, varies widely. When the amino acid distribution (grams of amino acid per 100 g protein) is correlated with protein content, a different picture is presented. Glutamic acid, alanine, and leucine are highly positively correlated with protein content and lysine and glycine are highly negatively correlated with protein content. Waggle and Deyoe (1966) also presented a confidence interval for lysine as a function of protein content (Fig. 10). Similar results for lysine and leucine have been reported by Deosthale et al. (1970a), Chevassus and Agnes (1979), and Sikka and Johari (1979).

The protein and amino acid composition varies with the anatomical part of the sorghum kernel. Haikerwal and Mathieson (1971) hand-dissected grains and reported that the protein content was high in the germ and low in the pericarp with the endosperm protein content being close to that of the total kernel. Both germ and pericarp were high in lysine and relatively low in leucine. Shoup et al. (1969) and Jones and Beckwith (1970) had reported similar results working with milling fractions.

The existence of a dense, high protein layer of endosperm cells just below the aleurone cells is well documented in sorghum (Normand et al., 1965; Hubbard et al., 1950; Rooney et al., 1972). This layer has been implicated in processing problems for the wet-milling of grain sorghum (Watson et al., 1955).

The amino acid composition of immature grain sorghum (late dough stage, 40% moisture) was found to be markedly different from mature sorghum (Deyoe et al., 1970). The immature sorghum was much higher in lysine, aspartic acid, and glycine and much lower in glutamic acid, proline and leucine. Protein content of the immature and mature samples was similar. Therefore, from an amino acid standpoint the immature grain was more balanced.

Improved amino acid balance was also obtained by the discovery of a high lysine mutant gene (hl) in sorghum (Singh and Axtell, 1973). Analysis of sixty-two floury endosperm lines selected from over 9000 lines in the world sorghum collection gave two lines of Ethiopian origin, IS 11167 and IS 11758, that were exceptionally high in lysine (3.34 and 3.13, g/100 g protein, at 15.7 and 17.2% protein). Inheritance studies suggested that the increased lysine concentration was controlled by a single recessive gene. The gene's effect was to increase lysine, arginine, aspartic acid, glycine, and tryptophan and to decrease glutamic acid, proline, alanine, and leucine.

Another high-lysine sorghum, P-721 opaque, was produced by chemical mutagen treatment of normal grain (Mohan and Axtell, 1975). The P-721 has an opaque endosperm, is photoperiod insensitive, dwarf, and has plump white seeds. The two high lysine Ethiopian lines, on the other hand, are photoperiod sensitive, tall, late, and have shriveled or dented seeds. This is not to reduce the significance of their discovery but does indicate that substantial breeding will be required before those sorghums make an impact

on nutrition. Part of that work has been started at CIMMYT (Singh, 1976). Modified recombinants with varying degrees of kernel vitreosity were obtained in crosses between normal and high lysine Ethiopian lines.

Another approach to improving nutritive value of sorghum was used by Wang and Fields (1978). They reported that germination increased the levels of lysine, methionine, and tryptophan. Their results were confirmed and extended by Wu and Wall (1980), who reported that the lysine content of germinated (10 days) normal sorghum increased from 2.2 to 3.2 g/16 g of nitrogen. The lysine content of high-lysine sorghum germinated 7 days ranged from 3.0 to 7.8 g/16 g nitrogen in lysine. The absolute amount of protein per kernel did not change but there was a loss of about 10% dry matter.

The classical Osborne-Mendal extraction of protein fractions from grain sorghum has not been particularly successful. Virupaksha and Sastry (1968) modified the procedure by extracting kafirin with 60% ethyl alcohol at 60°C and the glutelins with 0.4% NaOH. Their total yield of extracted protein ranged from 80.7 to 103.4%. However, it appears that they did not extract in sequence and thus their results may be high. Skoch et al. (1970), using a sequential scheme and the Osborne-Mendal solvents, reported extracting only 26 to 40% of the nitrogen from sorghum meals.

The advantage of using hot aqueous ethanol rather than room temperature ethanol for extraction of kafirin was confirmed by Kaikerwal and Mathieson (1971). Jones and Beckwith (1970) reported that aqueous 60% tertiary butyl alcohol at room temperature was as effective as 70% ethyl alcohol at 60°C in extracting kafirin.

Jambunathan and Mertz (1973) reported that the solvent system of Landry and Moureaux (1970) was quite effective in extracting grain sorghum proteins. They found 83 to 96% of the protein extractable. Using this procedure they reported that the distribution of proteins among the five fractions was distinctly different for high tannin and low tannin sorghums. The high tannin samples gave lower values in the saline fraction (fraction 1) and higher values in the borate buffer + 2-mercapto-ethanol + sodium dodecyl sulfate fraction (fraction 5). Neucere and Sumrell (1979) and Chavan et al. (1979a) have found similar effects of tannin on the fractionation of proteins using the more classical Osborne procedure.

The solvents used by Wu and Wall (1980) were water, 1% NaCl, 60% t-butyl alcohol, 60% t-butyl alcohol + 0.05% dithiothreitol, and borate (0.0125 M borax + 0.043 N sodium hydroxide + 0.425 M sodium chloride) + sodium dodecyl sulfate + 0.05% dithiothreitol buffer at pH 10. The solvent series extracts albumin plus globulin (water + 1% NaCl, 16%), kafirin (17%), cross-linked kafirin (31%), and glutelin (25%), respectively. The percentage of each fraction is that reported by Wu and Wall (1980) for normal sorghum. The fraction solubilized in 60% t-butyl alcohol + dithiothreitol has been called both cross-linked kafirin and alcohol soluble reduced glutelin. Polyacrylamide gel electrophoresis (Paulis and Wall, 1979) and amino acid composition indicate that the fraction is similar to kafirin and not to glutelin. Thus, the term cross-linked kafirin appears preferable.

Protein fractions isolated from grain sorghum have not been studied extensively. Sastry and Virupaksha (1969) studied the alcohol soluble or kafirin proteins by polyacrylamide electrophoresis and found them to be a complex mixture of several proteins. The electrophoretic pattern of reduced and alkylated kafirin was similar to that of unmodified kafirin, so they concluded that the disulfide bonds of kafirin occur predominantly in the intrachain form.

The other major group of proteins, the glutelins, were studied by Beckwith (1972). Glutelin was isolated by first extracting the albumins, globulins, and prolamines and treating the residue with α-amylase (Paulis et al., 1969). Beckwith (1972) reported that the glutelins contain more basic amino acid than do the prolamines. Many of his protein fractions were colored, indicating that protein-pigment complexes were present. Reduction of disulfide bonds in the sorghum glutelin increased nitrogen solubility in 6 M guanidine hydrochloride to 85-90%. The proteins were also soluble in 8 M urea but the system gelled on standing. Disruption of the disulfide bonds also produces proteins (peptides) that can migrate under electrophoresis so it is quite likely that glutelin protein fractions of grain sorghum consist of small protein chains joined together through disulfide linkages.

The amino acid composition of isolated protein fractions has been reported by several workers (Virupaksha and Sastry, 1968; Neucere and Sumrell, 1979; Wu and Wall, 1980; Guiragossian et al., 1978). In general, albumins and globulins are relatively rich in basic amino acids. The kafirin and cross-linked kafirin fractions are very low in basic amino acids and relatively high in glutamic acid and leucine. The glutelins are relatively high in basic amino acids and glutamic acid and contain moderate levels of leucine.

Work with high-lysine sorghum (Jambunathan et al., 1975; Paulis and Wall, 1979; Wall and Bietz, 1980) has shown that the alcohol soluble fractions, kafirin and cross-linked kafirin, are lower as a percent of total protein and the water- and salt-soluble protein and the glutelin are higher as a percent of total protein than normal cultivars. Those changes in the distribution of protein fractions are responsible for the increase in lysine and decrease in leucine found with the high-lysine sorghums.

The production and composition of a protein concentrate from normal and high-lysine sorghum were described by Wu (1978). The major solubility of proteins occurs at pH 8 and above.

C. Carbohydrates

Sugars

Total sugar content in sorghum varies with stage of grain development. In normal sorghum, maximum levels of 9% to 13% occur within 12 days after pollination, followed by a rapid reduction to 1% to 2% after 20 days (Kersting et al., 1961). Total sugar content in normal, mature sorghum cultivars ranges from 0.9% to 6.0% (Watson and Hirata, 1960; El Tinay et al.,

1979; Barham et al., 1946; Bhatia et al., 1972; Edwards and Curtis, 1943; Subramanian et al., 1980; Neucere and Sumrell, 1980). White sugary cultivars can contain twice the quantity of sugars as normal sorghums (Karper and Quinby, 1963).

Free reducing sugars constitute 0.2% to 0.9% of sorghum, with glucose and fructose as the principal components (Watson and Hirata, 1960; Nordin, 1959; Barham et al., 1946; Bhatia et al., 1972; Subramanian et al., 1980). Maltose is not found in germinated grains (Newton et al., 1980).

Nonreducing sugar content ranges from 0.3% to 2.1% (Bhatia et al., 1972; El Tinay et al., 1979; Neucere and Sumrell, 1980), with sucrose being the major constituent (Nordin, 1959; Watson and Hirata, 1960; Newton et al., 1980). The trisaccharide, raffinose, and the tetrasaccharide, stachyose, also were found in small amounts in mature grains (Nordin, 1959; Watson and Hirata, 1960; Neucere and Sumrell, 1980; Subramanian et al., 1980).

Bhatis et al. (1972) reported that 0.67% to 1.23% of the glucose and 0.13% to 0.60% of the fructose in two sorghum cultivars were bound in oligosaccharides. Sharam and Bhatia (1979) isolated three oligosaccharides from ripening sorghum kernels. Those oligosaccharides consisted of fructose and glucose units in ratios of 2:1, 4:1, and 9:1 and may be intermediates in the formation of starch during grain development. Other studies in Bhatia's laboratories (Bhatia et al., 1980; Bhatia and Uppal, 1979; Sharma and Bhatia, 1980) indicate that sucrose can be a direct precursor of starch in sorghum; its glucose moiety is transferred to starch via a sucrose transglucosylase system.

Starch

Starch contents of 32% to 79% have been reported for sorghum cultivars (Kersting et al., 1961; MacMasters and Hilbert, 1944; Horan and Heider, 1946; Roofayel, 1967; El Tinay et al., 1979; Watson and Hirata, 1960; Sisodia et al., 1979). The lowest values in that range (32-57%) are generally for sugary sorghums. Waxy sorghums also tend to have lower starch contents than do the nonwaxy cultivars.

Sorghum starch granules (Fig. 11) are polygonal or spherical in shape and range in size from 4 μm (Wall and Blessin, 1970; Miller and Burns, 1970). The physicochemical properties of sorghum starch granules are affected by amylose content, which ranges from 0.8% to 1.0% for waxy starches and from 21% to 34% for normal starches (Deatherage et al., 1955; Horan and Heider, 1946; Miller and Burns, 1970). Amylose contents of 33% to 62% also have been reported for some sorghum hybrids (Lin and Pi, 1964). All of the reported values were based on data obtained by iodine titration methods. The results, therefore, represent only an estimate of amylose content and not the actual content because iodine binding by starch is dependent on chain length and degree of branching as well as amylose content (Bates et al., 1943).

Gelatinization temperature ranges are affected by amylose:amylopectin ratios. In a study of 125 sorghum lines, Heusdens and King (1962) found that waxy starches had slightly higher initial and endpoint gelatinization

temperatures than the nonwaxy starches. Initial and endpoint temperature ranges for waxy starches were 63.0 to 65.2°C and 72.1 to 73.4°C, respectively, compared to initial and endpoint temperatures of 63.0 to 63.8°C and 70.8 to 71.9°C, respectively, for nonwaxy starches. Those birefringent endpoint temperatures agree with values reported by Freeman et al. (1968) for 85 sorghum cultivars. MacMasters and Hilbert (1944), however, reported slightly lower initial temperatures (49-58°C) and slightly higher endpoint temperatures (75-78°C) for 11 waxy sorghum starches. Variability in values reported by different authors may be due to differences in genotype and environment under which the sorghum was grown (Freeman et al., 1968).

Because waxy milo starch has greater swelling power and solubility than nonwaxy starch (Leach et al., 1959), it is not surprising that these starches show distinct amylograph pasting curves (Fig. 12). Pasting temperatures between 69 to 73°C have been reported for waxy milo compared to 80 to 86°C for nonwaxy types (Lindemann, 1951; Horan and Heider, 1946; Otterbacker and Kite, 1958). At the same starch concentration, waxy starches produce higher peak viscosities, greater thinning on cooking, and little setback on cooling compared to the nonwaxy counterparts.

Studies on the susceptibility of raw sorghum starch to α-amylolytic enzymes indicate that attack is confined to the surfaces with a few granules showing concentric shells (Nordin and Kim, 1960; Harbers and Davis, 1974; Tovar et al., 1977; Rooney and Sullins, 1977). Waxy starch appears to be more susceptible to α-amylolysis than nonwaxy starch (Tovar et al., 1977; Rooney and Sullins, 1977). Susceptibility of sorghum starch to α-amylases also is affected by heat processing of sorghum grains (Harbers, 1975; McNeill et al., 1975; Holmes et al., 1966; Osman et al., 1970; Hinman and Johnson, 1974a & b; Riggs et al., 1965).

Nonstarchy polysaccharides

Cellulose. Kamath and Belavady (1980) reported cellulose levels ranging from 1.19% to 5.23% for three sorghum cultivars. No information has been published on the physicochemical properties of sorghum cellulose.

Pentose-containing polysaccharides. Pentose-containing polysaccharides have been termed pentosans, a description which disregards chemical structure, particularly since those polymers usually contain some other nonpentose sugars. Differences in solubilities have led researchers to further subdivide pentosans into water-soluble and water-insoluble components. The water-insoluble pentosans have sometimes been referred to as hemicelluloses.

The pentosan content of whole sorghum grain ranges from 2.51% to 5.57% depending on variety and location of growth (Karim and Rooney, 1972a). The major portion of the pentosans is found in the pericarp, with a gradual decrease in pentosan content from the periphery to the center of the endosperm.

Pentosans purified from grain sorghum pericarp have been classified as water-soluble, cold-water soluble, hot-water soluble, and alkali soluble depending on the isolation procedure employed (Karim and Rooney, 1972b;

Woolard et al., 1976a). The alkali-soluble pentosans have been further characterized into hemicelluloses A and B (Woolard et al., 1976a). Glucose was the predominant sugar in the cold- and hot-water soluble pentosans (Table IV) isolated from the pericarp by Woolard et al. (1976a). This is in contrast to the relatively low levels of glucose found in the water soluble fraction of Karim and Rooney (1972b).

Hemicelluloses A and B, which were extracted from the pericarp with aqueous NaOH, contain arabinose and xylose as the predominant sugars (Woolard et al., 1976a). Karim and Rooney's (1972a) alkali soluble fraction resembles hemicellulose A in that it also contains glucose as a major component sugar (Table IV).

Woolard et al. (1976a) further fractionated hemicellulose B on DEAE cellulose into 13 polysaccharide components (Table V), many of which were highly branched and had primary chains containing β(1→4) linked xylopyranose residues. Differences in uronic acid contents among the various hemicellulose B components accounted for their separation by DEAE cellulose. The B(A) groups had a higher uronic acid content than the B(B) groups (Woolard et al., 1976b; 1977a, 1977b).

Hemicelluloses A and B and water-soluble pentosans were also isolated from the endosperm of sorghum (Woolard et al., 1976c; 1977c). The major component of hemicellulose A was a β-D-glucan, a linear polymer containing β-(1→3)- and β-(1→4)- glucosidic linkages (Woolard et al., 1976c). Hemicellulose B fractions had biochemical characteristics similar to those of the comparable fractions of the pericarp (Woolard et al., 1977c).

Cold- and hot-water-soluble pentosans from the endosperm are D-glucans containing a large proportion of α-linked D-glucosyl residues (Woolard et al., 1977c). The cold-water solubles contained glucan A (d.p. 23), a polysaccharide with (1→4)- and (1→6)-linked D-glucopyranose residues in the ratio of 2:1 with a ratio of 4:1 of α- and β-linkages. Branching points occurred every three D-glucose residues per molecule of glucan A. Glucan B (d.p. 20), purified from the hot-water solubles, was structurally similar to glucan A but differed in the ratio of (1→4)- to (1→6)-linkages, being 6:1 for glucan B (Woolard et al., 1977d).

D. Sorghum Lipids

The lipid content and fatty acid composition of grain sorghums have been extensively studied (Wall and Blessin, 1970; Paul et al., 1972; Rooney, 1978; Badi et al., 1976a; Neucere and Sumrell, 1980; Price, 1975). Sorghums, in general, contain 2.0 to 4.1% "free" lipids (petroleum ether extractable) and 0.1 to 0.56% "bound" lipids (extractable with water-saturated butanol). The major portion of the lipid is located in the germ (Hubbard et al., 1950).

Sorghum lipids are highly unsaturated, with oleic and linoleic acid accounting for at least 76% of the total fatty acids (Table VI). The fatty acid composition of grain fractions obtained by wet milling indicates that the germ lipids contain the highest proportion of unsaturated

fatty acids (84%). The protein fraction contains about 75% unsaturates and the starch contains 52% unsaturated acids and about 32% palmitic acid (Baldwin and Von Sniegowski, 1951; Von Sniegowski and Baldwin, 1950).

Thin-layer chromatography has been used to tentatively identify lipid components in grain sorghums (Paul et al., 1972; Badi et al., 1976a; Price, 1975). Nonpolar lipids comprise 86% of the total lipid (Price, 1975), and the major components of that fraction are triglycerides (Table VII). Minor components of the nonpolar lipids include diglycerides, sterols, pigments, nonesterified fatty acids, sterol esters, and hydrocarbons. Bound lipids contain a higher percentage of nonesterified fatty acid than the free lipids.

Nonesterified, esterified, and glycosylated sterols and triterpene esters have been identified in sorghum (Palmer and Bowden, 1975a). More than twenty, 4-demethylsterols, 4-monomethylsterols, and triterpenes have been isolated from mature sorghum (Palmer and Bowden, 1975b). Some of the sterols identified were cholesterol, campesterol, stigmasterol, sitosterol, 28-isofucosterol, and 24-ethylidene-cholest-7-3β-ol. β-Sitosterol composed from 43 to 46% of the 4-demethylsterols (Bowden and Williams, 1971; Palmer and Bowden, 1977). The components of the triterpene fraction include lupanol, α-amyrin, and isoarborinol (Palmer and Bowden, 1977).

Sorghum waxes, also classified as nonpolar lipids, have been isolated and the major classes of components have been identified (Cannon and Kummerow, 1957; Dalton and Mitchell, 1959; Hubbard et al., 1950; Seitz, 1977; Bianchi et al., 1979). Surface wax from sorghum (0.22% to 0.5% of the grain) contains n-alkanes, esters, aldehydes, alcohols, and nonesterified fatty acids. Dalton and Mitchell (1959) and Seitz (1977) found that the major wax constituents are alcohols (40-46%) and esters (46-50%). Conversely, Bianchi et al. (1979) reports that aldehydes (32%), alcohols (34%), and acids (24%) are the major components of sorghum wax.

Extensive structural studies of the major wax compounds, using gas chromatography, mass and infrared spectrometry, have been completed (Bianchi et al., 1979). The n-alkanes consisted of straight chains, mainly heptacosane and nonacosane. Chain length ranges for aldehydes and free alcohols were similar to each other and had high levels of C28 and C30 compounds. Nonesterfied fatty acids were 25% oleic acid and 20% linoleic acid as well as acids with 28 and 30 carbons. Major concentrations of C40 to C46 chain acids were also reported.

The polar lipids of sorghum, mainly glycolipids and phospholipids, constitute 3% and 11%, respectively, of the total lipids (Price, 1975). Mono- and digalactosyl diglycerides, phosphatidyl choline, phosphatidyl ethanolamine, and phosphatidyl serine are among those components which have been tentatively identified in the polar lipids (Paul et al., 1972; Price, 1975).

E. Enzymes

Amylases

About 90% of the total sorghum consumed in South Africa is as beer,

most of which is home-brewed (Aucamp et al., 1976). Because sorghum amylases play an important part in that brewing process, extensive studies have been conducted on those enzymes.

Determination of amylase activity in sorghum malts has proven to be difficult due to their relative insolubility (Novellie, 1959). In a series of experiments Novellie (1960a) showed that, depending on the cultivar malted, sorghum malt amylases can be either water soluble or insoluble. Amylases in birdproof and sweet sorghum grains were partly or entirely insoluble while those in normal grains were completely soluble. Novellie suggests that the amylases themselves are not water insoluble but are, in fact, tenaciously bound to an insoluble material. Partial solubilization of bound sorghum amylases was obtained by using salts, surface active agents, or basic substances. Maximum solubilization was obtained using histidine, proteins, peptone, ethylenediamine, and compounds having an -N·C(X)·N- group, where X is not oxygen.

Early studies by Kneen (1945) had suggested that sorghum malts contained only trace amounts of β-amylase. Work by Novellie (1960b), however, indicates that β-amylase contributes from 18 to 39% of the saccharifying activity in South African malts. Further studies on purified sorghum β-amylase (Novellie, 1960b; Botes et al., 1967a) indicated that sorghum malts contained low levels of β-amylase. However, the activity of the purified enzyme was comparable to other cereal β-amylases.

Unlike in barley, wheat, and rye, β-amylase is not found in ungerminated sorghum grains (Novellie, 1959, 1960a, 1960b), but upon germination both α- and β-amylase are synthesized at the same rate, i.e., the ratio of β- to α-amylase remains constant. The actual ratio of the two enzymes varies with malting temperature and sorghum variety (Dyer and Novellie, 1966). Dyer and Novellie (1966) showed that under their malting conditions more β-amylase was synthesized at 30°C than at 20°C. Moisture content had no effect on the enzyme ratio.

Other studies on the effects of malting conditions on amylase development in germinated sorghum indicated that high germination temperatures and moistures produced optimum development of diastatic power (Novellie, 1962a). Optimum temperatures for the formation of amylases were 20 to 30°C; germinating at 35°C lowered diastatic activity. Moisture levels of at least 58 to 60% during the early stages of germination resulted in higher diastatic activities than when water was limiting. Unfortunately, high moisture conditions during malting greatly elevate malting losses (Novellie, 1962b). Jayatissa et al. (1980) found that, in general, sorghum malting losses were higher than those encountered in malting barley.

Since sorghum α-amylases contribute significantly to the total diastatic activity of malts, their properties have been extensively studied. Four α-amylase isozymes, with molecular weights ranging from 48,200 to 51,000, have been identified in malted sorghum (Botes et al., 1967b). The activity of purified α-amylase is similar to values reported for crystalline barley α-amylases. Optimum pH for activity is 4.6 to 4.7 (Dube and Nordin, 1961; Botes et al., 1967b). Oligosaccharides having 6, 7, and 8 glucose

residues are produced when sorghum α-amylase acts on soluble starch (Dube and Nordin, 1962).

Proteases

Ungerminated sorghum has low proteolytic activity, but on germination the activity increases three fold (Garg and Virupaksha, 1970a). Most of that activity is located in the endosperm.

The preparation and enzymatic properties of acid proteases from germinated grain sorghum have been elucidated (Garg and Virupaksha, 1970a). The purified, crystalline protease has a molecular weight of 80,000, as determined by gel filtration, and has no metal ion requirements. Intact disulfide groups in the enzyme protein are necessary for activity, but free SH groups do not participate in the enzymatic reaction. The pH for optimum activity of the acid protease is 3.6 (Garg and Virupaksha, 1970a). At pH 5, only 20% of maximal activity is exhibited; minimal activity occurs at pH values greater than 5. Optimum temperature for activity is 50°C.

The substrate specificity of sorghum acid protease is narrow, cleaving only peptide linkages involving the α-carboxyl group of either aspartic acid or glutamic acid (Garg and Virupaksha, 1970b). That enzyme does not have serine at the active site so the protease is not inactivated by presently identified sorghum proteinase inhibitors (Kumar et al., 1978; Kumar et al., 1979).

Other enzymes

Insoluble glucosidases have been detected in protein bodies and spherosomes of grain sorghum (Adams and Novellie, 1975b), and, like the water-insoluble amylases, they are solubilized by peptone solutions (Watson and Novellie, 1974; Watson et al., 1974). Glucosidase activity in aleurone lytic bodies was found to be much higher than that of embryo lytic bodies (Adams et al., 1975).

Numerous other enzymes have been detected in the protein bodies and spherosomes of mature sorghum seeds (Adams and Novellie, 1975b). Those include acid protease, β-galactosidase, phytase, p-nitrophenyl phosphatase, and RNase.

F. Vitamins and Minerals

A knowledge of vitamin and mineral contents of grain sorghum is essential in evaluating its nutritional quality, because many diseases can result from deficiencies in one or more of those nutrients. The vitamin and mineral contents, averaged from a number of sources, of sorghum are presented in Table VIII.

Sorghum contains more thiamine than pearl millet but approximately the same amount of riboflavin (Carr, 1961; Hoseney and Varriano-Marston, 1980). Compared with corn, sorghum contains equivalent levels of riboflavin and pyridoxine, lower levels of carotene, and higher levels of pantothenic

acid, niacin, choline, folic acid, and biotin (Tanner et al., 1947; Miller, 1958). The greatest total quantity of B-vitamins is located in the germ portion of the grain (Hubbard et al., 1950). Long term storage of sorghum can result in significant losses in thiamine and niacin (Pushpamma and Reddy, 1979).

Data are scarce on the fate of vitamins during the processing of sorghum for foods and beverages. Changes in the B-vitamin content of sorghum during brewing processes were studied by Aucamp et al. (1961). Malting increased the riboflavin content 40 to 70% but had little effect on niacin and thiamine. No significant synthesis of niacin occurred during alcoholic fermentation, but there was a 16 to 32% increase in thiamine and a 70 to 80% increase in riboflavin. Consumption of 1/2 gal of Bantu beer supplies an average of 2.1 mg thiamine, 1.3 mg riboflavin, and 7.2 mg niacin. The quantity of beer meets the minimum daily requirements for thiamine and riboflavin, but only 40% of daily niacin requirement.

Equally important as the vitamin content is the bioavailability of sorghum vitamins. Vitamins, determined by chemical or microbiological assays, may be only partially available when consumed by test animals or humans. For example, using a chick growth assay, Frigg (1976) found that biotin in sorghum was only 20 to 30% bioavailable; biotin in wheat was essentially unavailable. Bioassay studies by Anderson et al. (1978), using chicks, later showed that the available biotin in sorghum was 0.092 mg/kg compared to 0.108 mg/kg in corn and 0.043 mg/kg in wheat.

The relationship between the content of other vitamins in sorghum and bioavailability has also been studied. Niacin content of sorghum exceeds the RDA's for swine but most of that niacin is unavailable (Luce et al., 1967). Using bioassays for B-vitamins, Reder (1934) found that sorghum riboflavin was essentially unavailable to albino rats. Smith (1930) found that when yellow sorghum was fed to rats as the only source of vitamin A, it was not as effective as yellow corn in promoting normal growth. Deosthale et al. (1969) have, however, demonstrated that β-carotene content in sorghum is genetically determined so it may be possible to develop cultivars that have high levels of β-carotene.

Information on the bioavailability to humans of vitamins in sorghum is limited to studies by Obizoba (1979) and Srikantia (1978). In the former study it was noted that humans fed dietary mixtures consisting of 70% wheat flour (WF) and 30% sorghum (S) showed higher niacin balance (+105) than those fed WF:S mixtures of 50:50 or 25:75 (+60 and +40, respectively). This may have been due to higher levels of niacin in the 70% WF diet. Diets containing blends of WF (25%) and high lysine (25%) and normal (50%) sorghums induced negative riboflavin balance in the subjects. Conversely, that same diet, which had the highest folic acid content of all diets tested, also produced the highest balances of that nutrient. Srikantia (1978) noted endemic pellagra among jowar (sorghum) eaters in India and suggested either (a) breeding sorghum cultivars with enhanced leucine: isoleucine balance or (b) increasing the niacin content of the diet.

The role of minerals in human health and disease is well recognized. In recent years the importance of micronutrients in the diet has been emphasized because trace elements such as Zn and Cr affect dietary protein and carbohydrate utilization (Schwarz and Mertz, 1957; Oberleas and Prasad, 1970).

The total mineral (ash) content of sorghum ranges from 1.2% to 2.2% (Hubbard et al., 1950; Aucamp et al., 1961; Deosthale and Belavady, 1978; Neucere and Sumrell, 1980). Sixty-nine percent of those minerals are located in the germ, 21% in the endosperm, and 11% in the bran (Hubbard et al., 1950).

The mineral elements in sorghum are shown in Table VIII. As in most cereal grains, P and K are the major minerals in grain sorghum. A large portion of the total P (48-70%) is in the form of phytate P (Kurien et al., 1960), which may affect the absorption of Ca and other minerals by the human digestive tract.

More than 20 micronutrients, elements present at concentrations less than 100 mg/g, have been identified in sorghum. Fe contents in sorghum are, in general, higher than Handbook 8 (Watt and Merrill, 1963) values for corn or wheat. In addition to those trace minerals listed in Table VII, Sn, Ag, Be, Bi, Ga, and Fe have been determined for sorghum at levels between 0.05 and 0.5 mg/g (Pinta and Busson, 1963). Environmental factors, such as location, appear to have a greater effect on mineral and trace element composition than does genotype (Deosthale and Belavady, 1978).

The bioavailability of sorghum minerals by humans has not been extensively studied. Kurien et al. (1960) reported that boys fed diets containing 25%, 50%, or 100% sorghum (in combination with rice), and having mean dietary P contents of 0.74 to 1.09 g, retained 0.17 to 0.31 g P. The higher P contents in sorghum compared to rice promoted higher P retention. Conversely, the amount of Ca retained decreased as the proportion of sorghum in the diet increased. This may or may not be related to the higher phytate content of diets containing sorghum. McCance and Widdowson (1942) suggest that absorption of Ca, P, and Fe by humans is decreased by phytate in cereal grains.

Obizoba (1979) fed five college women isonitrogenous mixed cereal grain diets containing wheat flour, three varieties of sorghum, and navy bean flour. Calcium balances of subjects fed sorghum (S) and wheat wheat flour (WF) blends in WF:S ratios of 50:50, 25:75, and 70:30 ranged from +147 to +167, with diets containing 70% WF and 30% S showing the highest Ca balance. Adding 20% navy beans to a diet containing 50% WF and 30% S further increased Ca balance to +188. Diets containing 50% WF and 50% S produced the lowest P and Fe balances while combinations of 70% WF and 30% S induced the most positive Mg balance.

Bioavailability studies on South African sorghum beer indicated that iron absorption by humans was more than 12 times greater from the beer than from a gruel made from the materials used to prepare the beer (Derman et al., 1980). Iron absorption was inhibited by high solid content (100 g/l) in

the beer. Improved iron absorption was attributed to reduction of solids during fermentation and accumulation of ethanol and lactic acid, which increased iron solubility.

G. Polyphenolics

Sorghum, as do other cereal grains, contains polyphenolics in both the outer layers and the endosperm. Many polyphenolics are colored and responsible for bran pigmentation. Some polyphenolics are colorless while others act as a reversible indicator, producing a color as the pH is changed. Other polyphenolics are irreversibly changed to colored pigments at extremes of pH. In general, polyphenolics are responsible for the colors found in food products and the starch isolated from sorghum.

In addition to the pigments discussed above, certain cultivars of sorghum and barley contain a special class of polyphenolics, the tannins. There has been, and continues to be, confusion in the scientific literature on tannins. Tannins are polyphenols which interact with and precipitate protein. Their name is derived from their ability to precipitate the protein in hides and thus tan the raw hide to leather. There are two types of tannins widely distributed in plants, the hydrolyzable and condensed tannins. The hydrolysable tannins are composed of a sugar and a phenolcarboxylic acid. They are readily hydrolyzed by enzymes or acid. In contrast, the condensed tannins are not affected by enzymes but decompose upon treatment with acid, forming small amounts of anthocyanidins (hence their classification as proanthocyanidins) with the remainder being polymerized to amorphous phlobaphens (Haslam, 1966; Ribereau-Gayon, 1972). Chemically the condensed tannins are oligomers of polyhydroxyflavan-3,4-diols, or hydroxyflavan-3-ol, or oligomers of combinations of those two classes of compounds. An excellent discussion of the proanthocyanidin polymers is given by Foo and Porter (1980).

There is no evidence to suggest that sorghum contains significant quantities of hydrolyzable tannins. On the other hand, considerable data indicate that certain sorghum cultivars, the bird-resistant types, contain condensed tannins.

In many areas where sorghum is grown, depredation by birds is a serious problem with losses of up to 100% reported (McMillian et al., 1972; Tipton et al., 1970). Sorghum that is high in tannins and has an open panicle structure deters attacks by birds (Burns, 1971; McMillian et al., 1972; Neihaus and Schmidt, 1970; Tipton et al., 1970). The high tannin content also has been related to reduced germination in the head (Harris and Burns, 1970) and reduced seed molding (Harris and Burns, 1973).

Bird-resistant sorghums are not birdproof. There is no question that birds will eat bird-resistant grain if no other is available. Bird resistance is related to the presence of condensed tannins in the grain. It has been speculated that the tannins precipitate the mucoprotein in the bird's mouth, producing an astringency that birds do not like.

Bullard et al. (1980) evaluated 15 varieties of bird-resistant sorghums for preference by birds. The varieties were divided into 3 groups (7 least, 7 intermediate, and 1 most preferred). The 7 least preferred were essentially uniform in polyphenolic properties whereas substantial variation occurred among the remaining 8 varieties.

Bird resistance and the presence of condensed tannin in grain sorghum appear to be related to the presence of a pigmented inner integument in the grain. No reports of bird resistance or condensed tannins have been found for grain not containing a pigmented inner integument. The inner integu- occurs just outside the aleurone cells. A large pigmented inner integument is present in certain cultivars (bird resistant) and absent in others (Figs. 4 and 5). The thickness of the inner integument varies with different varieties of bird-resistant sorghum. Most bird-resistant sorghums grown in the U.S. have a dark brown pericarp. This has led to assumptions that the brown pericarp and the presence of a pigmented inner integument are related. That assumption is not true because many cultivars, particularly the feteritas from Africa, have a white pericarp and a pigmented inner integument. A convenient bleach test to determine the presence of the pigmented inner integument was described by Weak et al. (1972).

Effect of tannins on animal performance

High tannin content causes several problems in the utilization of bird-resistant sorghums. Those problems include lowered digestibility indices (Armstrong, et al., 1974a, 1975; Chang and Fuller, 1964; Connor et al., 1969; Cummins, 1971; Maxon et al., 1973; McGinty, 1968; Saba et al., 1972; Schaffert et al., 1975; Jambunathan and Mertz, 1973), possible carcinogenic effects (Morton, 1970; Singleton and Kratzer, 1973), lower palatability due to astringency (Bate-Smith and Rasper, 1969), and off colors in milled products and foods (Bate-Smith and Rasper, 1969; and Blessin et al., 1963; Rooney et al., 1980).

Many studies have detailed the detrimental effects of tannins on animal and bird growth (Armanious et al., 1973; Armstrong et al., 1974a; Cummins, 1971; Damron et al., 1968; Davis, 1973; Davis and Harbers, 1974; Maxon et al., 1973; McCollough, 1970, 1973; Nelson and Cummins, 1975; Potter and Fuller, 1968; Rahman, 1972; Rostagno et al., 1973a; Schaffert et al., 1975; Vohra et al., 1966; Elkin et al., 1978a, Armstrong et al., 1974b, Nelson et al., 1975; Rostagno et al., 1973b). In addition to effects on growth, leg abnormalities in chicks consuming high tannin sorghum grain have been reported (Elkin et al., 1978b). The effect of high tannin on iron availability has been reported as minor (Radhakrishnan and Sivaprasad, 1980).

The effect of tannins on animal and bird performance is presumably because of their ability to bind proteins making them insoluble and indigestible. The tannins also bind with enzymes such as α-amylase (Miller and Kneen, 1947; Strumeyer and Malin, 1969; Davis and Harbers, 1974; Maxon et al., 1973) and proteolytic enzymes (Chibber et al., 1980). Sorghum condensed tannins bind to starch and reduce its digestibility (Davis and Hoseney, 1979a).

Isolation and characterization of condensed tannins

The condensed tannins are polymers of either flavan-3-ols (catechins) or flavan-3,4-diols (leucoanthocyanidins) or polymers of combinations of the two flavonoids. A condensed tannin (precipitate protein) usually has molecular weights between 500 and 3000. Monomers do not precipitate protein and as the polymer becomes large they presumably lose their water solubility and become inert.

Condensed tannins bind not only with protein but also with most separation media used in chromatography. Thus, it is relatively easy to remove nontannin polyphenolics from condensed tannins. Polyphenols can be eluted from thin-layer plates, paper chromatograms, and columns but condensed tannins are bound at the point of application with no elution techniques available. Strumeyer and Malin (1975) have reported that condensed tannins can be removed from Sephadex LH-20 with 50% acetone. Thus, the polyphenolics from sorghum can be extracted and separated into condensed tannins and nontannins by the scheme in Figure 13.

Strumeyer and Malin (1975) found a single red pigment (cyanidin) generated by alcoholic HCl treatment of condensed tannins from Leoti and Georgian 615 varieties. Bates-Smith and Rasper (1969) had reported luteolinidin as the principal product of heating Kafir sorghum tannin with acid.

Nontannin pigments

The seed coat of many sorghums has a reddish or brownish color while others have little or no apparent pigmentation. Some of the pigments migrate during steeping or tempering prior to milling and thus give dry or wet-mill fractions containing objectionable pigments.

Blessin et al. (1963) reported that some types of grain sorghum contained water-soluble leucoanthocyanins (anthocyanogens) while other types did not. Treatment of the isolated leucoanthocyanin with 12 N HCl at room temperature gave a product tentatively identified as fisetinidin. Yasumatsu et al. (1965) identified three anthocyanogen-type flavonoids from sorghum. The pigments were extracted with methanol and separated by paper chromatography. Hydrolysis of the three pigments with boiling acid gave the same two compounds from each of the pigments. One was tentatively identified as eriodictyol and the other was pelargonidin. Recently, Kaluza et al. (1980) reported that Sepharose CL-6B and Sephacryl S-200, that are useful in isolating polyphenolics by column chromatography.

In the most comprehensive studies of the pigments to date, Nip and Burns (1969, 1971) reported that in red varieties of sorghum, pigments were found mainly in the stylar area, the epidermis, and cross and tube cells. In general, the mesocarp was not colored.

Chromatographic separation of the pigments extracted with acidified methanol gave three major pigments, two yellow and one orange. Nip and Burns (1969) reported that the two yellow pigments were similar to apigeninidin-5-glucoside and kaempferol-3-rutinoside-7-glucuronide. The

unidentified orange pigment had anthocyanin properties. Pigments from white seeded sorghum varieties were identified as two forms of apigeninidin and two forms of luteolinidin (Nip and Burns, 1971). Bate-Smith (1969) reported that the red color of the seed coat of sorghum was due to complex "phobophenes" made up of apigeninidin and luteolinidin. Gupta and Haslam (1978) isolated a polymeric procyanidin from the seed coat of sorghum. They showed it has a molecular weight of between 1700 and 2000. Fletcher et al. (1977) have proposed a biosynthetic pathway. Much more work is required to understand the pigments of sorghum.

Estimation of tannin content

The determination of tannins in cereals presents several major problems. Tannins, polyphenolics that precipitate proteins, are contaminated with polyphenolics that do not precipitate proteins. Thus, procedures that measure total polyphenolics are clearly unsatisfactory. The second major problem is that we have no isolated tannins of known structures to use as standards. Third, both hydrolyzable and condensed tannins precipitate protein but they are quite different chemically.

Because of the above problems, many workers have used the protein precipitation property as the basis for their estimation. The molecular weight of the tannins along with possible differences in molecular shape can influence their interaction with protein and thus cause divergent results from chemical determination. That is a major argument for use of precipitation methods.

Bate-Smith (1973) developed an assay based on precipitation of hemoglobin. The procedure has the disadvantages of requiring fresh blood and of saponins interfering with the assay (Bate-Smith, 1977). Goldstein and Swain (1965) used inhibition of β-glucosidase as their assay but as with the inhibition of other enzymes (i.e., Davis and Hoseney, 1979a; Maxson et al., 1973; Strumeyer and Malin, 1975; Daiber, 1975) the results are somewhat difficult to interpret. Hagerman and Butler (1978) precipitated tannin with bovine serum albumin, isolated the insoluble tannin-protein complex, dissolved the complex in alkaline solution, added ferric chloride, and measured the absorbance at 510 nm. Their results showed linear results with both hydrolyzable and condensed tannins.

Maxson and Rooney (1972) examined a number of procedures for the chemical determination of tannins in sorghum. Although no method was judged adequate, three methods were identified as having potential: (1) the procedure of Bate-Smith and Rasper (1969) where tannin is determined by treating the grain with concentrated mineral acid in the cold and measuring the color produced at 550 nm; (2) the ferric ammonium sulfate method based on the work of Mejbaum-Kalzenellenbogen and Kudrewicz-Hubica (1966); and (3) the Maxson and Rooney (1972) modification of the vanillin-hydrochloric procedure of Burns (1971).

As pointed out by Strumeyer and Malin (1975) the ferric ammonium sulfate method measures hydrolyzable tannins and low molecular weight polyphenols but not condensed tannins. Thus, the relatively low values

and small changes in value from low to high tannin cultivars obtained with that method are explainable.

Maxson and Rooney (1972) reported that the Bate-Smith and Rasper (1969) procedure was rapid and reproducible. They also noted that different cultivars gave different absorption maxima, which suggests that different sorghums contain different tannins.

The vanillin assay appears to be the best procedure to determine sorghum tannins. The chief advantage of the method is its specificity for flavanols or compounds which have a single bond at the 2,3 position on the B ring (Sarkar and Howarth, 1976). The flavanol monomers and dihydrochalcones give a positive test and are not tannin. However, the specificity is much better than for the Prussian blue procedure (Price and Butler, 1977), which detects all phenols but with different sensitivity (Fig. 14). The same general criticism applies to UV methods (Sharp et al., 1978).

Price et al. (1978), in a critical evaluation of the vanillin procedure, found that using catechin as a standard overestimates the tannin content. They also found the use of a blank to correct for background color was essential. El Tuhami et al. (1980) reached a similar conclusion. Price et al. (1978) also reported that the reaction was extremely temperature sensitive. Dalby and Shuman (1978) noted a reversible temperature dependence on the absorption for the vanillin reaction. With adequate temperature control, the assay gave excellent reproducibility. Earp et al. (1981) has recently evaluated several methods to determine tannins and applied the methods to sorghums with widely varying kernel characteristics.

Interaction of proteins with tannins

Chibber et al. (1978) reported that protein distribution, as determined by the Landry-Moureaux (1970) procedure, shifted as a high tannin sorghum was progressively dehulled. Their finding was interpreted as consistent with strong interactions between tannins and the kafirin (prolamine) fraction in sorghum. Fishman and Neucere (1980) gave gel filtration evidence of glutelin-tannin interaction.

The nature of the bond between tannins and protein is not clear. If we ignore the covalent bonding brought about by atmospheric or enzymatic oxidation -- hydrogen bonding, ionic bonding, and hydrophobic bonding all appear likely. Such complexes result in the precipitation of proteins under neutral or acidic conditions (Hoff and Singleton, 1977; Oh and Hoff, 1979). Ionic bonding is excluded by the absence of charged groups in condensed tannins at low pH (Oh et al., 1980). Those workers also present evidence that hydrophobic bonding may be the major mode of interaction. Nontannin polyphenolics also react with protein, probably by the same mechanism. The major difference is that protein-polyphenolics may retain their solubility. For a discussion of protein-phenolic interactions see Van Sumere et al. (1975).

Changes in tannins during maturation

Upon ripening of many fruits there is a "disappearance" of tannin (Goldstein and Swain, 1963). A similar trend was reported for sorghum condensed tannins (Davis and Hoseney, 1979b). Using an α-amylase inhibition test procedure and expressing the results as % inhibition per kernel the tannin content increased to a peak, 4 to 6 weeks preharvest, and then either remained constant or declined depending on the variety. Gel filtration on Sephadex LH-20 indicated that the molecular weight of the tannins declined as the inhibitory activity was lost.

Price et al. (1979) found similar results in a study of 12 sorghum varieties using the vanillin test. Tannin contents of mature seeds, varied from 3 to 93% of the maximum found in the immature seeds suggesting that varieties of sorghum can be found with high level of tannin during the immature stage, when birds are a problem, but with low tannin levels at harvest. Some workers have reported tannins to increase (Johari et al., 1977) or remain constant during maturation (Tipton et al., 1970).

Detoxification of high tannin sorghum

Price and Butler (1978) reported that moistening high tannin sorghum with ammonium hydroxide markedly reduced the tannin content as measured by the vanillin assay. The same treatment strikingly improved the nutritional quality of the high tannin sorghum when fed to rats and chicks. Chavan et al. (1979) reported similar results when grain was soaked in sodium or potassium hydroxide; soaking the seed in water alone was effective but at a much slower rate.

Reichert et al. (1980) have reported that soaking high tannin seeds in water, HCl, or NaOH and storing the seeds anaerobically was effective in reducing the tanning content as measured with the vanillin assay. Tannin content was also markedly reduced by germination. Rat feeding studies showed that the soaking treatments produced weight gains equivalent to a diet containing low tannin sorghum.

Price et al. (1980) found that the level of tannins was reduced when high-tannin sorghum was boiled in water on dilute sodium bicarbonate. The protein binding capacity of tannin in the ground grain is similarly diminished by preparation of a batter and is further decreased by cooking. However, normal cooking procedures do not overcome the harmful nutritional effects of tannin in sorghum.

H. Nutritional Quality of Sorghum

Amino acid bioassays

Most information on the biological value of sorghum protein has been obtained from animal rather than human subjects. Bioassays using a variety of animal subjects indicate that lysine is the first limiting amino acid in sorghum (Pond et al., 1958; Bressani and Rios, 1962; Chang and Chao, 1969; Harden et al., 1976). Other limiting amino acids are threonine (Pond et al.,

1958; Harden et al., 1976) and methionine (Bornstein and Lipstein, 1971; Wessels, 1970; Jensen et al., 1965; Ilori and Conrad, 1976; Waggle et al., 1966). Conversely, high leucine contents are common to grain sorghum (Axtell et al., 1972). Amino acid levels, and therefore protein quality, are affected by genetic and environmental factors (Deosthale and Mohan, 1970; Deosthale et al., 1970a; Nawar and Clark, 1970; Ilori and Conrad, 1976).

Amino acid imbalances

To be nutritionally sound, sorghum must provide not only adequate levels of the essential amino acids but also the correct balance of amino acids. Amino acid imbalances in sorghum appear to be an important factor determining the quality of its protein. It has been suggested that high leucine contents in sorghum may be related to the increased incidence of pellagra among people who subsist mainly on that grain (Gopalan, 1968; Srikantia, 1978). Deosthale et al. (1972) suggest that sorghum leucine to lysine ratios lower than 4.6 are "unsafe" with regard to the prevention of pellagra. In a study of three sorghum cultivars, Belavady and Rao (1979) found that levels of leucine below 11 g/100 g protein did not induce black tongue in dogs.

Evidence of disturbance in niacin metabolism caused by a high level of leucine in the diet has been provided by several authors. Gopalan and Srikantia (1960) and Belavady et al. (1963) found that feeding leucine to normal or pellagrin human subjects resulted in increased excretion of quinolinic acid (an intermediate in the biosynthesis of NAD and NADP from tryptophan) and decreased excretion of the 6-pyridone ring of N'-methylnicotinamide. Raghuramulu et al. (1965) later showed that adult rats fed a sorghum diet adequate in tryptophan but high in leucine excreted more N'-methylnicotinamide and niacin than when fed a wheat diet. In addition, dogs fed sorghum diets or nonpellagragenic diets supplemented with leucine showed the same pathological changes observed in canine black tongue (Belavady, 1975). Administration of niacin alleviated the pathological symptoms. Gopalan (1968) and Belavady (1975) have thoroughly reviewed the literature converning the possible role of leucine in the development of pellagra.

Antinutritional factors

Antinutritional factors can decrease the protein value of sorghum. Filho (1974) reported trypsin inhibitor activity in sorghum, but he later concluded that the effect was probably due to nonspecific binding of tannins to protein. The effects of tannins on nutritional quality have been reviewed in another section of this chapter. The deleterious effects of cannins on animal growth can be decreased by treating with polyethylene glycol or NH_3 (Ford and Hewitt, 1979) or by soaking the grain in water, NH_4OH, NaOH, or KOH (Price and Butler, 1978; Chavan et al., 1979; Reichert et al., 1980).

Improvement in the protein value of sorghum diets

Whole sorghum, when fed as the only source of protein in the diets of 8 to 30 months old Peruvian children, was found to be a poor source of dietary energy and resulted in poor nitrogen absorption and retention (MacLean and Graham, 1980). Extended cooking times or pressure cooking did not appear to improve its nutritional quality. From their limited data, MacLean and Graham (1980) concluded that wheat, rice, potato, and maize were superior to sorghum as sources of protein and energy. On the other hand, they reported that children eating Thriposha, a blended food containing pearled, extruded sorghum, showed excellent nitrogen absorption and retention. MacLean and Graham (1980) recommend that whole sorghum should not be used in AID sponsored feeding programs if any other major staple foods are available. This appears to be contrary to reports that certain healthy population groups in Sudan exist on diets consisting solely of Marisa, a fermented drink made from sorghum (Badi, 1980).

MacLean and Graham (1980) rejected the use of diet blends containing whole sorghum based on a study by Kurien et al. (1960). Kurien et al. (1960) found that when children (ages 10 & 11) were fed diets in which part of the rice was replaced by sorghum, substantial reductions in nitrogen absorption and retention occurred when sorghum replaced 50% and 100% of the rice in the diet. However, replacing 25% of the rice with sorghum results in only slightly lower nitrogen absorption and retention. Kurien et al. (1960) showed that subjects on all diets maintained positive nitrogen balance.

The protein value of sorghum for animals and humans can be improved by supplementing diets with limiting amino acids (Narayanaswamy et al., 1970; Harden et al., 1976; Fernandez et al., 1974; Nawar and Clark, 1970; Bornstein and Lipstein, 1971; Daniel, et al., 1966; Adrian et al., 1979). Daniel et al. (1966) found a significant improvement in nitrogen retention of growing girls when sorghum diets were supplemented with lysine and threonine.

Rather than adding synthetic amino acids to the diet, legumes are often combined with sorghum to increase the total lysine content of the diet (Desai et al., 1970; Pushpamma and Devi, 1979; Pushpamma et al., 1979). Some legumes performed better in growth trials than did others. Pushpamma and Devi (1979) found that PER's for rats were higher when sorghum was combined with redgram, greengram, or horsegram. In addition, nitrogen balance studies on preschool children showed that a sorghum-blackgram combination performed as well as combinations of rice and redgram but that sorghum-redgram combinations did not (Pushpamma et al., 1979). Children fed sorghum-legume combinations daily for over a year grew well and did not show signs of niacin deficiency even though the levels of niacin in the diets were lower than recommended allowances. Those data suggest that sorghum-legume diets are nutritious and can be safely consumed by infants (Pushpamma et al., 1979).

Supplementation of sorghum with leafy vegetables (Talwalkar and Patel, 1970) or other cereal grains (Obizoba et al., 1979) can also improve the biological value of sorghum protein. Obizoba et al. (1979) found that mean

nitrogen balances were higher when college women were fed a 25:25:50 combination of wheat flour (WF), high lysine sorghum (HLY), and normal sorghum (PN), respectively, compared to 50:50 (WF:HLY) or 70:15:15 (WF:Nigerian Normal:HLY) combinations. Nitrogen balance and digestibility increased as the sorghum content of the diet increased, suggesting that sorghum was better utilized by human females as a nitrogen source than wheat flour. Furthermore, high lysine sorghum was found to be a better protein supplement than WF or PN when it provided 2% of the total dietary nitrogen. Axtell (1976) had earlier reported that high lysine sorghum mutants improved protein biological value in rats.

The nutritional value of sorghum can be improved through germination (Wang and Fields, 1978; Wu and Wall, 1980). Increases in lysine, methionine and tryptophan levels were observed when sorghum grains were germinated (Wang and Fields, 1978). In addition, the relative nutritional value (RNV), determined by the phagotropic protozoan *Tetrahymena pyriformis* W, increased from 56% for the ungerminated sorghum to 63% for the germinated grains. Wu and Wall (1980) noted increases in lysine-rich albumins and globulins as well as a diminution of leucine levels as a result of sorghum germination.

Natural fermentation of sorghum also improves its nutritional value. Au (1979) found that lysine and methionine levels increased and RNV was significantly improved when sorghum was fermented at 25°C or 35°C for 4 days.

Protein and calorie digestibility of sorghum

Digestibility of sorghum by animals varies among cultivars and has been related to factors such as seed coat and endosperm color and starch type. Calorie and protein digestibility in swine indicate that sorghum varieties having yellow seed coats are superior to brown-seeded types (Noland et al., 1977). Furthermore, yellow floury endosperms showed greater calorie and protein digestibility than varieties having white floury, white corneous, or yellow corneous endosperms (Noland et al., (1977).

The effect of starch type, i.e., waxy versus normal, on sorghum digestibility has not been clearly determined. Cohen and Tanksley (1973) found that digestible and metabolizable energy values for the growing pig were the same for normal and waxy starch varieties. Lichtenwalner et al. (1978) showed that ruminal digestibility was increased by incremental doses of the waxy gene. That increase may have been due to the increased solubility of proteins in the waxy grains compared to nonwaxy varieties.

Sorghum protein and calorie digestibility in animals can be improved by including a methionine hydroxy analog to the diet rations (Brommelsiek et al., 1979) or by processing the grain using combinations of heat, pressure, and moisture (Liang, 1969; Hinman and Johnson, 1974a, 1974b; Holmes et al., 1970).

Studies on protein digestibility of sorghum in humans are limited, and values for sorghum calorie digestibility in humans have not been reported. Kurien et al. (1960) reported apparent protein digestibility

coefficients ranging from 64% to 69% in 10 and 11 year old boys consuming diets consisting of combinations of rice and sorghum. Daniel et al., (1966) found that the true digestibility of sorghum diets in 11 to 12 year old girls increased from 74% to 77% by supplementing the diets with lysine and threonine. In a study of college women, Obizoba et al. (1979) reported that increasing the sorghum content in a diet blend of wheat and sorghum increased protein digestibility.

III. PEARL MILLET

Pearl millet (*Pennisetum americanum* (L.) Leeke), often identified even in recent literature as *Pennisetum typhoides*, and in older literature as *P. glaucum* is also known as bulrish millet in Africa and bajra in India. Pearl millet is the largest seeded and most widely grown of the millets. It is one of the most drought tolerant of man's food crops and is grown primarily in the dry Sahel zone across Africa and in the semi-arid areas of India. As water is more available, sorghum usually replaces pearl millet.

Recent annual cultivation of pearl millet has averaged 31 million hectares with production of about 18 million metric tons. This accounts for about 1.8% of total cereal production (Pomeranz, 1975). In the area where it is grown, grain yield is often low. However, with pearl millet, a low yield is not necessarily bad. It is grown as a crop of last resort and a low yield is infinitely better than no yield, because no yield often means starvation. Thus, a consistently low-yielding cultivar is preferred to a potentially high-yielding cultivar that may fail completely in a poor year.

Serious attempts to develop improved cultivars of pearl millet have been made only in the last 20 years (Brunken et al., 1977). Both head type and plant height vary quite widely. An attempt to expand and maintain a world collection of pearl millet is under way at the International Crop Research Institute for the Semi-arid Tropics (ICRISAT) in Hyderabad, India. The highly cross-pollinated nature of pearl millet is a great problem with regard to maintenance of identity (van der Maesen, 1978).

I. Structure of Pearl Millet

Pearl millet kernels (Fig. 1) are generally tear shaped and weigh about 8.9 g/1000 kernels. This is about one-third the weight of sorghum. Seed sizes vary widely among different cultivars of millet and within different locations within a single head.

A SEM picture of a fractured kernel (Fig. 15) shows that the germ is large in proportion to the rest of the kernel. The kernel contains both translucent and opaque endosperm portions. The ratio of translucent to opaque endosperm varies considerably among cultivars. The pericarp has three layers: the epicarp, the mesocarp and the endocarp. Unlike some sorghums, pearl millet does not have starch in the mesocarp (Badi et al., 1976a; Sullins and Rooney, 1977). Sullins and Rooney (1977) also reported that the five pearl millet samples they examined did not contain a pigmented inner integument.

The aleurone cells are a single layer thick and appear to be firmly attached to the pericarp. Most of the lipid in the grain is found in the aleurone, germ, and pericarp (Lai and Varriano-Marston, 1980a). The translucent endosperm (Fig. 16) is devoid of air spaces and contains polygonal starch granules embedded in a protein matrix. The protein matrix also contains protein bodies ranging in size from 0.3 to 4 μm (Badi et al., 1976a; Sullins and Rooney, 1977; Adams et al., 1976). Those protein bodies have a well defined internal structure as shown by the pattern of electron scattering in the transmission electron micrographs (Fig. 17).

The floury or opaque endosperm contains many voids or air spaces. Starch granules in that area are spherical (Fig. 18). There appear to be no protein bodies in the opaque endosperm.

J. Chemical Composition

Protein

Although it is precarious to compare the protein content of different grains, it is generally true that pearl millet has a higher protein content than other cereals grown under similar conditions. The reason for the higher protein content is not clear. The protein content of pearl millet was increased when it was treated with nitrogen at the rate of 88 kg/ha (Sawhney and Naik, 1969). Deosthale et al. (1971) reported similar results for protein content and also reported that yield increased with nitrogen application up to 120 kg N/ha. Higher levels of nitrogen decreased yield. Recently data on inbred hybrids and F_1 hybrids gave similar results (Bailey et al., 1980).

In a study of selfed, sibbed, open-pollinated, and intermated plots, Burton et al. (1980) found that self-pollinated seed of pearl millet should be used for the most accurate estimation of grain characteristics. A minimum seed population and a standard pollen source could serve as an alternate but less desirable substitute for selfed seed for crops, such as pearl millet, with a high degree of self-incompatibility. High and low values for amino acids found in pearl millet meal are given in Table IX. The data show wide variability for most amino acids, often varying by a factor of at least 2. In general, pearl millet is low in lysine, tryptophan, threonine, and the sulfur containing amino acids as are other cereals. Certain lines, however, show values for lysine and tryptophan equal to those found in opaque-2 corn. It is also noteworthy that the leucine to isoleucine ratio for pearl millet is about 2:1, which is much lower than that found for sorghum or the other millets.

As would be expected, the amino acid composition varies with different anatomical parts of the grain. Pearl millet flour is lower in lysine, arginine, and glycine and higher in methionine than is the whole meal (Badi et al., 1976a). Pearl millet bran is high in lysine, arginine, glycine, and aspartic acid and low in glutamic acid and the sulfur containing amino acids.

The cereal proteins are generally high in the alcohol soluble prolamines. The prolamines are low in lysine and other nutritionally critical amino acids (Pomeranz, 1975). High-lysine maize, barley, and sorghum have all been shown to be the result of depressed synthesis of prolamines (Mertz, 1975). It is not known if the high-lysine pearl millets also have low levels of prolamines.

The distribution of protein classes in pearl millet and the amino acid composition of the different protein classes have not been studied in detail. Early attempts to fractionate the proteins by successive extraction with water, cold 70% ethanol, hot 70% ethanol, and dilute base gave low protein recoveries in the extracts (Narayamurti and Aiyar, 1930; Abhyander et al., 1939).

Sawhney and Naik (1969) fractionated several pearl millet varieties with a modified Mendel-Osborne procedure. They reported that the storage proteins, prolamines plus glutelins, accounted for about 60% of the total protein. The distribution of the various fractions varied across cultivars. Nitrogen recoveries varied from 72 to 92%.

Nwasike et al. (1979) used the Landry-Moureaux procedure to fractionate pearl millet proteins. They reported that their extraction of protein was 100%. In general, their results showed millet protein to be more similar to that of corn than to that of grain sorghum in distribution and lysine content of the protein fractions. Narayamurti and Aiyar (1930) reported that a prolamine fraction from pearl millet had a surprisingly high level of tryptophan (2.8 g/16 g N). Sawhney and Naik (1969) reported a similar value for tryptophan in their prolamine fraction. Contrary to this, Nwasike et al. (1979) reported very low levels of tryptophan in their prolamine and prolamine-like fractions obtained by the Landry-Moureaux procedure. The reason for those contrary results is not clear.

The water-soluble proteins from pearl millet genotypes containing high, medium, and low total protein were compared by using gel chromatography, gel electrophoresis, and selected enzyme activity (Galyean et al., 1980). High protein genotypes were rich in low molecular weight proteins. Lipoxidase and proteolytic activities were greatest in the high protein samples. Several attempts have been made to improve the protein content of pearl millet. Rabson et al. (1979) determined dye-binding capacity and Kjeldahl nitrogen as an index of total basic amino acid sin mutants. Lines were selected for high dye-binding capacity relative to protein content.

Changes in protein and enzyme activity during grain development was studied by Gupta et al. (1980). The combining ability for a number of traits in pearl millet was detailed by Khangura et al. (1980). In general, hybrids having higher grain yield had bold, hard grains but low protein contents. A few hybrids combined high yield with an average protein content.

The preparation of protein concentrate from pearl millet has been described (Bailey and Sumrell, 1980). The millet protein gave minimum solubility at pH 4.0. About 80% of the protein was extracted as a concentrate.

Carbohydrate

The starch content of pearl millet ranges from 56 to 65% of the grain (Freeman and Bocan, 1973; Sheorain and Wagle, 1973; Bailey et al., 1980). The starch granules are both spherical and polygonal in shape and range in size from 4 to 12 μm (Fig. 19). A rather large hilum is clearly visible (Fig. 20) in fractured polygonal granules (Badi et al., 1976b).

Iodine affinities of pearl millet starch ranged from 4.43 to 5.05%, suggesting that pearl millet starch has an amylose content equal to that of most other cereals (Table IX). Beleia et al. (1980) reported amylose contents of 20 to 22% for 5 cultivars. Badi et al. (1976b) had reported 17% amylose in one sample of pearl millet starch.

The gelatinization temperature of pearl millet starch falls within the ranges reported for sorghum and corn starches (Table X). Starch swelling at 85°C ranged from 10.5 to 12.5; solubility varied from 3.2 to 9.3% (Freeman and Bocan, 1973; Beleia et al., 1980). A plot of starch solubility at equal swelling power (Fig. 21) indicates considerable variability among cultivars.

Pearl millet starch gives an amylogram peak viscosity similar to that of sorghum and corn starches. However, pearl millet flour has been reported to give low amylograph peak viscosities (Badi et al., 1976b) and low falling numbers (Beleia, 1980). Those results imply that pearl millet flour from sound grains has a high α-amylase activity.

Sullins and Rooney (1977) have reported that pearl millet starch is more resistant than sorghum starch to attack by pancreatic α-amylase or amyloglucosidase. A study of the action pattern of millet α-amylase on starch indicates that it shows higher amylolytic action on wheat starch than on millet starch (Beleia, 1980). The enzymes preferentially attack the spherical granules and appear to attack more vigorously at the center of the granule than at the periphery. Sullins and Rooney (1977) have also suggested that degradation of the starch by amylases is more complete in the granule center than in the outer portions. The increase in β-amylase activity in germinated pearl millet has been studied by Sheorain and Wagle (1973).

Bailey et al. (1979) reported that pentosans soluble in 80% ethanol had relatively high glucose and galactose contents (28.4 and 18.5%, respectively). The pentosans extracted with water at 50°C had galactose as the principal sugar. Arabinose and xylose were the predominant sugars in pentosans extracted at room temperature or 0.5 N alkali. On the basis of sedimentation coefficients, Bailey et al. (1979) suggested that the pentosans extracted in water at room temperature or in alkali had branched structures while those solubilized in water at 50°C had a linear configuration. Hank and Rasper (1974) have reported on the effects of millet nonstarchy polysaccharides on the rheological behavior of wheat doughs.

Crude fiber has been reported to range from 1.96% to 3.88% of whole pearl millet (Carr, 1961; Reichert and Youngs, 1977; Desikachar, 1977).

Crude fiber values of 0.58, 0.72, 0.96, and 1.12% were reported for pearl millet dehulled with a barley pearler, an abrasive mill, an attrition mill, or a wooden pestle, respectively (Reichert and Youngs, 1976). There is little or no information available on the chemical structure or characteristics of fiber in pearl millet.

Relatively few data are available on the type or amount of free sugars in pearl millet. Lineback and Pompipom (1978) reported 10 mg glucose/g of flour in one sample. Bhatia et al. (1972) reported water soluble sugars of 4.6 and 5.4% in two samples. Subramanian et al. (1980) reported values ranging from 2.16% to 2.78% for nine cultivars. Five sugars -- stachyose, raffinose, sucrose, glucose, and fructose -- were separated by gel filtration. Sucrose was the predominant sugar, accounting for about 2/3 of the total sugars.

Lipids

The level of "free" lipids (petroleum ether extractable) extracted from pearl millet cultivars has been reported to vary from 3.03% to 7.40% (Sharma and Goswami, 1969; Goswami et al., 1969a & b, 1970a & b; Rooney, 1978; Lai and Varriano-Marston, 1980; Ahuja et al., 1979). The free lipids from pearl millet had acidity values which ranged from 2.02 to 11.95 mg/100 g and saponification values from 190 to 333 mg/g (Sharma and Goswami, 1969; Agarwal and Sinha, 1964). The fatty acids in the free lipids were reported by Agarwal and Sinha (1964) as oleic (53.8%), linoleic (34.9%), palmitic (10.8%), stearic (0.28%), and myristic (0.20%).

In a study of 65 lines of pearl millet Jellum and Powell (1971) found the following levels of fatty acid: linoleic (40.3 to 51.7%), oleic (20.2 to 30.6%), and palmitic (17.7 to 25.0%). They also reported average values of 3.69% for linoleic acid, 3.9% for stearic acid, 0.64% for arachidic acid, and 0.55% for palmitoleic acid.

The "bound" lipids (extractable with water-saturated butanol) of pearl millet have not been studied in detail. Two Indian varieties were found to contain 0.5% bound lipids. Bound lipid contents ranging from 0.58 to 0.90% were reported for 18 samples of pearl millet grown in Kansas (Lai and Varriano-Marston, 1980a). The major components of the polar bound lipids were phosphatidyl choline, sterol glycosides, and di- and monogalactosyl diglycerides. Acylglycerols were the major nonpolar bound lipids (Pruthi and Bhatia, 1970; Badi et al., 1976a; Lai and Varriano-Marston, 1980a).

The quality of pearl millet quickly deteriorates once it has been ground into a meal (Reddy, 1978). It is generally assumed that lipid components are responsible for that quality deterioration. Storage of millet flour at 30°C, 95% R.H. for 3 months gave a 3% decrease in the amount of ether extractable lipids (Carnovale and Quaglia, 1973). No explanation was given for the decrease. Nechaev et al. (1973) showed essentially no change in total ether extractable lipids in millet during storage.

Carnovale and Quaglia (1973), using infrared to study extracted lipids, showed increases in absorption due to the -COOH group indicating an increase in fat acidity. In general, their data suggest that hydrolytic as well as oxidative changes in lipids occur during storage. Lower grade flours gave more rapid and pronounced changes than refined flours.

Thiam et al. (1976) suggest that the major cause of quality deterioration in millet flour during storage is microbial growth. However, they found that millet flour (85% extraction) stored at 30°C, 50% RH, for four months did not show odor or taste deterioration. Conversely, millet meal stored at 19°C, 58% RH, showed detectable changes in odor after only 4.5 days (Lai and Varriano-Marston, 1980b). The time at which odor changes were detectable corresponded to 30 mg KOH required to titrate free fatty acids in 100 g meal.

Minerals and Vitamins

Pearl millet has been reported to vary in ash from 1.46 to 3.88% (Goswami et al., 1969a & b, 1970a & b; Deosthale et al., 1971; Burton et al., Varriano-Marston and Hoseney, 1980). In general, these values are high compared to those reported for other cereals (Casey and Lorenz, 1977).

The range of values for certain of the mineral constituents of pearl millet are presented in Table XI. The Na, Mg, and Cu contents are within the ranges reported for wheat. Levels of Ca vary over a wide range, with some of the values extremely low. The levels of Mn and Mo in pearl millet are considerably lower than those found in wheat while the levels of P, K, and Fe are higher than those reported for wheat.

Varriano-Marston and Hoseney (1980) reported high levels of Si and K in the covering layers (includes aleurone) of pearl millet. A major portion of the phosphorus was found in the germ; high levels of Fe were found in both germ and covering layers. In general, the endosperm was low in minerals; the predominant elements detected were S, K, and Fe.

Relatively little work has been reported on the vitamins in pearl millet. Thiamine and riboflavin contents of 0.22 mg/100 g and 0.26 mg/100 g, respectively, were reported for one sample of millet (Carr, 1961). Dassenko (1980) reported a niacin content of 36.9 mg/g for one millet random mating population. No published data were found for vitamin E in pearl millet. Aykroyd et al. (1963) reported a vitamin A level of 220 I.U./100 g, a thiamine value of 0.33 mg/100 g, a riboflavin value of 0.16 mg/100, and nicotinic acid level of 3.2 mg/100 g of pearl millet. Hariharan et al. (1965) reported a vitamin A content of 153 I.U./100 g for the "poor pearl millet diet."

Pigments

The most common and generally preferred color of pearl millet is slate grey. However, the grain can vary from an off-white to a dark brown and in West Africa yellow seeded varieties are preferred.

In parts of Africa millet is often soaked overnight in water containing tamarind pods or sour milk (Vogel and Graham, 1979). The soaking not only alters the flavor but also bleaches the grain. Reichert and Youngs (1979) showed the bleaching to be pH dependent. Citric acid or 0.2 N HCl was as effective as sour milk or tamarind pods. Reichert (1979) showed that C-glycosylflavonoids (glucosylvitexin, glucosylorientin, and vitexin) were responsible for the natural grey color of pearl millet. Butler (1980) has shown that pearl millet does not contain tannins.

K. Nutritional Quality

Kurien et al. (1961) studied the metabolism of nitrogen, calcium, and phosphorus in undernourished children. Diets were varied from 100% rice to 100% pearl millet. All children maintained a positive nitrogen balance during the study. The apparent digestibility of protein decreased as pearl millet increased in the diet. Higher levels of pearl millet in the diets gave higher levels of both calcium and phosphorus in the diets. The retained phosphorus increased and calcium decreased as the percentage of pearl millet in the diet increased.

Much of the information on the nutritional quality of pearl millet for human food has been extrapolated from studies conducted with weanling rats. As noted by Vaghefi et al. (1974), rats have many shortcomings as test animals for human nutrition. Examples are the rat's much higher protein requirement, as a result of its much faster growth rate and the rat's relative inactivity in test cages.

The most widely used guides to nutritional quality are weight gains and protein efficiency ratio (PER). In evaluating the PER several factors must be kept in mind. The PER is only a measure of the quality (amino acid balance) of the protein and does not measure the usefulness of a sample or type of grain as a food. To accurately measure PER, other factors such as vitamins or minerals must not be limiting and the protein content of the diet must be 10% or less.

Table XII gives PER's for pearl millet alone or supplemented with amino acids or other plant proteins. In general, the PER for pearl millet is higher than that reported for wheat or sorghum (Pushpamma et al., 1972; Rao et al., 1964; Oke, 1977). Lysine appears to be the first limiting amino acid in pearl millet as shown by the large increase in PER as when pearl millet is supplemented with lysine. The data of Daniel et al. (1965) and Hariharan et al. (1965) both show the effect of vitamins and minerals on the growth rate of rats fed pearl millet.

As with other grains, milling processes influence pearl millet PER and digestibility (Goussault and Adrian, 1977). The traditional pounding of pearl millet did not alter the PER from that of the original grain. However, additional milling progressively lowered PER. On the other hand, Dassenko (1980) showed that the PER significantly increased when pearl millet was milled to a 67% extraction.

Most studies of nutritional quality of pearl millet have been on the raw grain. In a study including milling, fermentation, and cooking, Dassenko (1980) showed that cooking millet into chapaties lowered the PER while cooking as a gruel did not alter PER. Fermentation before cooking significantly lowered the PER. Milling to a flour improved PER, suggesting that some component(s) in the outer layer of the grain is decreasing PER. Dassenko (1980) also showed that milling or cooking or fermentation and cooking did not increase protein digestibility. Milling and fermentation had no effect on carbohydrate digestibility. Cooking improved carbohydrate digestibility of flour but not millet meal.

Millet porridge, a traditional Nigerian weanling food, was found to have a PER of 1.22 (Ifon, 1980). Substituting 22.5% soy flour increased the PER to 2.18; adding lysine or methionine did not raise the PER further. Similar results were reported by Thiam (1980) in Senegal for weaning foods based on millet. Supplementation with soy and ground nut protein was beneficial but additional supplementation with amino acids or skim milk gave no further benefit.

Energy is the first need of man, or indeed of any animal, thus, one can measure the nutrient requirements based on calories (Hansen, 1973). When this technique is applied to pearl millet (Oke, 1977) one finds that millet satisfies the requirements for protein, iron, and vitamins B_1 and B_2. Thus, as has been shown by millions of people in India and Africa who consume millet each day, pearl millet is an excellent food.

IV. OTHER MILLETS

In addition to the more widely grown and larger seeded pearl millet, there are three other millets of sufficient importance to warrant discussion (Fig. 1). Proso millet (*Panicum miliaceum*) is used in birdseed mixtures in the United States, and it is grown primarily in eastern Colorado and western Nebraska. Some is also grown in South America and Australia for birdseed trade. However, it is grown mainly as a human food in the Soviet Union and Eastern Asia (Rachie, 1975).

Finger millet (*Eleusine coracana*), also known as ragi, is an important food crop in parts of India and Africa. It is a small round seed, generally red. The last of the other millets to be discussed is foxtail millet (*Setaria italica*). It is grown in many parts of the world either as a food grain or as forage, but most extensively in China and India. Rachie (1975) gives the production of various millets on a worldwide and regional basis.

The work on the other millets has lagged behind that on sorghum and pearl millet. Recently, increasing numbers of reports have been appearing in the literature. Although not discussed in detail in this review, varagu millet (*Paspalum scorbiculatum*) has recently been characterized as to carbohydrate and lipid composition (Paramahans and Tharanathan, 1980).

Proso Millet

Proso millet is, in general, very low in basic amino acids, particularly lysine (Lorenz et al., 1980; Jones et al., 1970). It is high in alanine and leucine and appears to have a high leucine to isoleucine ratio (3.5:1). Ambegaokar et al. (1965) reported proso millet to be primarily limiting in threonine.

Lorenz and Dilsaver (1980) studied the solubility of proso millet protein at various pH values. They reported the isoelectric point of the protein to be 5.0 and noted that the millet proteins are much less soluble than wheat proteins. Jones et al. (1970) fractionated proso millet proteins into four fractions: water soluble (5%), 1% sodium chloride (4%), 60°C, 60% t-butyl alcohol solubilized only 3% of the total nitrogen. Amino acid analysis of the protein fraction showed the t-butyl alcohol soluble fraction to be very low in lysine (0.1%) and high in leucine. Alcohol-soluble proteins from millet were found to be oligomers of a 20,000 molecular weight polypeptide (Maki and Tashiro, 1979).

Starch isolated from proso millet was characterized and compared with wheat and rye starches by Lorenz and Hinze (1976). The millet starch had higher water binding capacity and gelatinization temperatures than did wheat starch. In general, solubilities of millet starch were lower than those of wheat starch; millet starch also gave higher amylograph viscosities.

The amylose/amylopectin ratio of millet starch was reported by Rakhimbaev (1968a). The type of millet was not identified but was probably proso. The amylose content for seven varieties over two crop years varied from 12.0 to 19.5%. Most of the variation was due to the genotype and not a result of the crop year. The values are lower than the 22 to 25% amylose found for most cereal starches.

Enzymatic hydrolysis of proso millet starch has been reported (Kapustina and Dudkin, 1972). The amylase complex of millet (presumably proso) malt was studied by Zherebtsov and Kosmacheva (1980). The α-amylase was unstable to acid but relatively heat stable, while β-amylase was acid-stable but thermolible. A stable dextranase was also reported that cleaved both α-1,4 and α-1,6 - glucosidic bonds. Other enzyme activities of proso millet were reported by Skovron and Lorenz (1979).

Rakhimbaev (1968b) studied the sugars of millet (presumably proso). Sucrose, raffinose, glucose and fructose were the major sugars. Becker and Lorenz (1978) found sucrose and raffinose to be the major sugars in proso millet with galactose, glucose, and fructose present only in trace amounts.

The tocopherol content of millet (presumably proso) was compared with that of wheat, and changes in tocopherol content during 12 months storage were followed (Seit-Ablaeva et al., 1973). Millet lipids had a lower tocopherol content than did lipids from other cereals. In addition, the tocopherol content of grain products decreased rather rapidly during storage.

The lipid content of millet (presumably proso) varies from 3.55 to 3.95% (Olifson et al., 1979). Nechaev et al. (1973) reported the change in fatty acid composition of free lipids, glyceride fractions, and free fatty acids of millet (proso) during storage. Changes in the overall fatty acid composition were slight. However, nonesterified linoleic acid increased and esterified linoleic acid decreased. They attributed the changes to hydrolytic decomposition of triglycerides. Lipase activity in 50 varieties of proso millet was studied (Pavolva and Olifson, 1979). Optimum conditions were 37°C at pH 4 and the lipase was most active on millet or sunflower oils. The activity varied from 2 to 46 mg KOH/10 g grain.

Lorenz et al. (1980) reported that proso millet could be dehulled with a barley pearler by using a 0.5 mm screen. After pearling, a hammermill was used to produce flour. The same authors also reported that the millet could be milled on a Quadrumat Jr. Mill without prior dehulling and that it was feasible to comill with wheat if the grains were tempered separately. Crabtree and Dendy (1979) reported similar results using a Buhler laboratory mill.

Unfortunately, Lorenz et al (1980) did not report the proximate analyses for the millet they worked with; however, they did report analyses of flour and bran. From those data, it is clear that the grain was high in protein, ash, and lipid compared to with other cereals. The hull was very high in ash (bran 15%) and was reported to contain a high level of silica. The lipid material was mainly in the germ because the lipid content of the flour and bran fraction varied widely depending on the milling conditions. Jones et al. (1970) reported that dehulled proso millet contained 4.9% lipid. Vitamin and mineral contents of proso millet have been reported by Aykroyd et al. (1963).

Lorenz and Dilsaver (1980) studied the use of proso millet flour in a number of traditional wheat flour products. Loaf volume and mixing time decreased as level of millet flour was increased. Bread was considered acceptable when up to 15% of wheat flour was replaced with millet flour. Amylograms indicated a very low α-amylase activity in the proso millet flours. Cookie spread increased and cookie top grain improved with increasing amounts of millet flour added to wheat flour. The millet flour imparted a slight but objectionable grittiness to the cookies. Noodles of acceptable quality were made with 20% proso millet flour in the blend; higher levels of millet flour caused the noodles to be gritty.

Awadalla (1974) also studied the supplementation of wheat flour with proso millet in Egyptian bread. He reported that replacing part of the wheat flour with millet decreased the baking quality.

The effect of germinating millet on its cooking properties was studied (Alekseeva et al., 1978). The fat, starch, and protein did not change, however, the hydrolytic enzymes increased greatly. It was impossible to obtain normal cooking properties from sprouted millet.

The use of proso millet in human diets has been studied (Kies et al., 1975). Millet alone gave a negative nitrogen balance, presumably due to lower digestibility. Supplementation of the millet with triticale or soy greatly improved nitrogen balance.

A. Finger Millet

Rachie and Peters (1977) and Hulse et al. (1980) have recently reviewed the composition and botanical characteristics of finger millets. The proximate analysis of a commercial sample of finger millet (ragi) as reported by Kurien and Desikachar (1966) was protein (N x 6.25) 8.8%, lipid 1.8%, ash 3.2% and crude fiber 3.6%. The lipid content is much lower than that reported for other millets and is lower than the range (3.4-4.0%) reported by Wankhede et al. (1979a) for three cultivars. Kurien and Desikachar (1966) also reported high levels of calcium (0.47%) and phosphorus (0.27%). Milling on a Buhler mill gave up to 72% yield of flour and materially reduced the protein, ash, and fiber contents of the flour. The protein, thiamine, and calcium contents of the flour was about one half of the whole meal while the phosphorus was much less. Pore and Magar (1979) reported that 75% of the P was in the form of phytic acid. Deosthale et al. (1970) reported the following values for the B-vitamins in finger millet: thiamine, 110 to 610 μg/100 g, and niacin 270 to 870 μg/100 g. The sterol lipids in finger millet have been reported by Mahadevappa and Raina (1978).

The protein content and amino acid composition of finger millet were studied by Virupaksha et al. (1975). Twelve varieties of finger millet ranged in protein content from 6.77 to 11.03% (N x 6.25). A similar protein range was reported by Deosthale et al. (1970) for twenty varieties. Using the Landry-Moureaux (1970) procedure, protein extraction ranged from 60 to 84% (Virupaksha et al., 1975). More protein was solubilized from the whole meal than from the endosperm flour. In general, the lysine content of the finger millet was quite high, ranging from 2.89 to 5.52 g/100 g protein. Deosthale et al. (1970) reported lysine values ranging from 2.1 to 3.8% protein. Also of interest was the leucine to isoleucine ratio of about 3 (Virupaksha et al, 1975); Indira and Naik (1971) had reported a ratio of 2. Amino acid analysis of the protein in the various solubility classes showed that the prolamine was low in lysine (0.4%) but the water- and salt-soluble protein and the glutelin fraction were both high in lysine (about 7.0%).

It is generally believed that the occurrence of tannins in cereals is limited to grain sorghum and barley. However, Ramachandra et al. (1977) analyzed 19 Indian and 10 African varieties of finger millet for tannins using the vanillin-HCl procedure. Two Indian cultivars gave values over 1% (catechin equivalents); two African cultivars had even higher values (3.47 and 3.42%). They also showed that the high tannin lines alter the distribution of protein solubility fractions by the Landry-Moureaux procedure. The glutelin fraction had the highest tannin content. The high tannin lines had lower *in vitro* protein digestibility. Dehulling the finger millet greatly lowered the tannin level and increased *in vitro* protein digestibility.

The starch from finger millet was studied by Wankhede et al. (1979b) and Tharanathan et al. (1980). Starch from finger millet gave single stage swelling and low solubility. Gelatinization temperature range was reported as 62° and 70°C. Amylose contents ranged from 15.8 to 17.5%, similar to values reported for proso millet (Rakhambaev, 1968a) but lower than that found for most cereal starches.

The carbohydrate composition of finger millet was studied by Wankhede et al. (1979a). Xylose, fructose, sucrose, maltose, maltotriose, raffinose, and higher oligosaccharides were found as free sugars, with sucrose being the principal sugar. Cold-water-soluble gums constituted about 0.5% of the grain and contained xylose, arabinose, and glucose as the major sugar constituents. Hot-water-soluble gums contained mostly glucose, with xylose, arabinose, mannose, and galactose found in minor quantities. Wankhede et al. (1979a) also characterized hemicelluloses and cellulose from finger millet.

Malleshi and Desikachar (1979) studied the malting quality of new high yielding cultivars of finger millet. Of the six cultivars studied, 4 were reported as relatively good malting and two were poor. The poor cultivars had low amylase activity.

The nutritive value of finger millet has been studied in rats (Kurien, 1967; Hemanalini et al., 1980) and children (Joseph et al., 1959; Kurien and Doraiswamy, 1967). In a study with 9- and 10-year old girls, Joseph et al. (1959) replaced rice in a vegetarian diet with 25% and 50% finger millet. Although the intake of protein was only about 28 g, all the subjects were in positive nitrogen balance. They also found that more calcium was retained from diets containing finger millet and concluded that replacing part of the rice in the diet with finger millet would help overcome calcium deficiency of rice diets. The availability of calcium from flour was significantly more than that from whole meal (Kurien, 1967); however, 49% of the calcium was in the husk (Kurien et al., 1959).

With 36 boys between the ages of 7 and 12, Kurien and Doraiswamy (1967) replaced about 50% of the cereal in the diet with whole or refined finger millet flour. They found no significant differences in the height, weight, nutritional status, or blood chemistry of the children fed the two diets over a 5 1/2 month period. No significant differences were found in the retention of nitrogen, calcium, and phosphorus between the two diets. There was a significant increase in apparent digestibility of the protein of refined flour versus whole meal.

N. Foxtail Millet

Relatively little work has been reported on foxtail millet. Taira (1968) studied the amino acid composition of ten varieties that varied in protein content from 10.6 to 15.2% (dry basis, N X 6.25). In general foxtail millet appeared to be low in lysine (1.5 to 2.4%) and high in proline and leucine. The leucine to isoleucine ratio was about 3. However, Baptist and Perera (1956) and Mangay et al. (1957) report a much lower ratio. When compared with the FAO amino acid pattern, foxtail millet was low in lysine but not tryptophan.

Foxtail millet prolamines were separated into four fractions by gel filtration (Maki and Tashiro, 1978, 1979). SDS electrophoresis patterns showed two bands of 21,000 and 12,000 molecular weight, respectively. Danno and Natake (1980) sequentially solubilized 97% of foxtail millet protein into five solvents: water, salt, ethanol, sodium dodecyl sulfate (SDS), and 2-mercaptoethanol. More than 15 different molecular weight classes of proteins ranging from 11,000 to 150,000 were found.

The starch of foxtail millet starch gelatinizes over the range 55° to 62°C (Wankhede et al., 1979b). The starch granules had both small (5 to 8μm), oval and large (8 to 25μm), polygonal shapes. The strach gave a single stage swelling and low solubility. However, foxtail millet starch had significantly higher water binding capacity than proso millet starch (Lorenz and Hinze, 1976). Iodine affinity for foxtail millet starch was 3.1%, indicating a low amylose content (Wankhede et al., 1979b). The saccharides in foxtail millet were studied by Becker and Lorenz (1978). Mature kernels contained sucrose, raffinose, and myo-inositol and trace amounts of glucose, fructose, and galactose.

Nonstarchy carbohydrates of foxtail millet were also studied by Wankhede et al. (1979a). In general, the free sugars and gum were very similar to those in finger millet. The gums from both species contain the same sugars but in different proportions.

The lipids of foxtail millet apparently have not been studied. However, Wankhede et al. (1979a) have found foxtail millet to be quite high in total lipid (15%).

Weanling rats had poor weight gains on a 86% foxtail millet diet (Tashiro and Maki, 1979). Supplementation with 0.4% lysine and 0.1% threonine gave better growth than casein. Foxtail millet was effective (mainly by virtue of its tryptophan content) in correcting an induced niacin deficiency in rats (Mangay et al., 1957). Takahashi et al. (1978) reported that an isolated foxtail millet protein fraction was equal to wheat gluten when fed to rats. Ganapathy and Chitre (1976), in studying the poor ability of foxtail millet to promote growth of rats, concluded that a high ratio of arginine to lysine was responsible.

VI. MILLING OF SORGHUM AND MILLET

The traditional milling of sorghum and millet is by pounding. Pounding involves the use of a mortar and pestle to remove the outer bran (Fig. 22). Both dry and slightly wet (tempered) grain is used. After pounding, the outer bran can be removed by winnowing. This process is still widely used in both Africa and India, although mechanical burr mills are being found in smaller villages (Vogel and Graham, 1979).

Another traditional milling technique is by the use of hand-operated stone mills (Fig. 23) and saddlestones. With sufficient skill, the operator can produce meal of controlled particle size. The bran is removed by winnowing and the products varying in density can be separated by tapping a hand-held gravity table (Fig. 24). In traditional milling, the

separation generally involves removing only the outer portion of the bran. With grain sorghum, the pericarp tends to separate in the mesocarp layer. Thus, a considerable part of the bran remains with the endosperm and germ. As shown by Shepherd (1979), with at least some grain sorghums, the outer bran comes off easily in rather large flakes. Those types of sorghum would thus mill easily and be much preferred if one was pounding the grain.

O. Dry Milling

The object of dry milling operations is primarily to separate the grain into its anatomical parts. The bran would include the pericarp, testa, and aleurone. The germ should be obtained as a separate and intact entity. The endosperm would then be free of contamination and could be reduced to the particle size desired. Of course, in practice such clean-cut separations are never obtained.

Hubbard et al. (1950) hand dissected sorghum and reported the yield and composition of the various components. Those results are invaluable in judging how good a separation one is making in dry milling. They reported that the endosperm ranged from 80 to 85% of the kernel. This, of course, gives the upper limit of high purity flour.

There are two major approaches to the dry milling of sorghum. In the U.S. much of the sorghum dry milling is accomplished on roller mills (Hahn, 1969; Shoup et al., 1970; Anderson, 1969; Anderson and Burbridge, 1971; Stickley, 1973; Miche, 1980). Although processes vary widely, in general, the grain is tempered to make the bran tough and rubbery so that it will not grind easily. Tempering is also useful as it makes the endosperm soft and friable. In general, sorghum is harder than wheat and thus more difficult to grind. Sorghum flour produced from most milling operations is more coarse than wheat flour. Most dry milled sorghum is reduced to grits rather than to flour.

The other major approach to dry milling is peraling or decortication. Sorghum kernels are a slightly flattened sphere so they work well with pearling or decortication equipment. There are several types of decorticating mills; all are designed to remove the outer part of the kernel by abrasion with a minimum breakage of the kernel. Studies of various types of mills used for sorghum and/or millet have been reported (Normand et al., 1965; Hahn, 1969; Rooney et al., 1972; Stringfellow and Peplinski, 1966; Anderson et al., 1969; Raghavendra Rao and Desikachar, 1964; Viraktamath et al., 1971; Rooney and Sullins, 1969; de Man et al., 1973; Kapasi-Kakama, 1977; Desikachar, 1977; Perten, 1977; Rasper, 1977; Wyss, 1977; Miche, 1980; Oomah et al., 1980).

Reichert and Youngs (1976) compared three types of mills, an attrition, an abrasive, and a barley pearler, for dehulling sorghum and millet. They concluded that the abrasive mill was most suitable. Reichert and Youngs (1977) also showed that all mechanical mills tested were much more effective in removing the grain's outer layers and thus various nutrients than was the traditional mortar and pestle. Similar results were reported by Adrian et al. (1975).

At a meeting held at the Food Research Center, Khartoum, Sudan, in April 1979, (sponsored by the Food and Agriculture organization of the United Nations) a new sorghum pearling process developed there was put on public view. Precleaned sorghum is passed through a vertical Schule milling machine and after separation the unbroken pearled sorghum is either packaged for use in soups and as a rice substitute or mixed with brokens and milled to flour in an ASIMA progress mill for use in composite flour bread. The Khartoum plant is specific for sorghum and appears to be more economical than similar large scale processes (Runte, 1979). A new pearling machine from Tropical Products Institute, England, using a novel wire-brush abrasive technique, was also reported at that meeting (Dendy and Pinson, 1979).

At the 1980 Vienna symposium sponsored by the International Association of Cereal Chemists (ICC) (Dendy, ed., in press) the International Development Research Center (IDRC) introduced a film, "An End to Pounding," which shows a new mechanical sorghum milling system developed for Botswana (Eastman, 1980).

Normand et al. (1965) have reported that high protein sorghum flours can be obtained from the outer layers of the starchy endosperm by tangential abrasion. Rooney et al. (1972) reported similar findings. They obtained a fraction contining 25% protein which represented 27% of the original grain. The original grain contained 15% protein.

Degermination is an important factor in sorghum dry milling. The germ is high in oil and must be removed if the flour or grits are to be stored. Hahn (1969) recommends tempering and impact milling. The germ can be separated from the grits if conditions are such that the kernel is not broken into small pieces. Typical sorghum dry milling results are given in Table Xiii. Gravity tables have also been successfully used to separate germ from grits.

Grinding to fine particle size has been accomplished by using impact grinders (Stringfellow and Peplinski, 1966). They reported that sorghum air-classified better than did corn or rice. Wall and Bietz (1980) have shown that the high-lysine sorghum lends itself to fine-grinding and air-classification. Reductions in particle size without a large increase in starch damage were reported by Badi and Hoseney (1976). The technique involved wetting the sample followed by air drying. The dried flour was then passed through smooth rolls.

Little work has been reported on the dry milling of different types of sorghum. Maxson et al. (1971) milled lines with different proportions of corneous and floury endosperm. Grit yields were highly related to endosperm texture, hardness, and density. Anderson et al. (1977) reported that the all floury endosperm, high lysine mutant, P-721, gave a very poor yield of grits upon dry milling.

The comilling of four species of millet with wheat to produce composite flours was reported by Crabtree and Dendy (1979). Combinations of proso and finger millets gave the best extraction rates. The optimum level of proso, for breadmaking, was 10%; the optimum level for finger, pearl, and foxtail

millets was 5%. They concluded that comilling to produce a composite flour was desirable.

P. Wet Milling of Sorghum

In wet milling the object is to separate the grain into starch, protein, and fiber fractions. Sorghum has been commercially wet milled at various times at the CPC plant in Corpus Christi, Texas. The laboratory wet milling of sorghum has been discussed in detail by Watson and coworkers (Watson et al., 1951, 1955; Watson and Hirata, 1954, 1955). In general, wet milling of sorghum is considered more difficult than that of corn. Starch yields are lower and the starch contains more protein. This is thought to result from a higher percentage of peripheral endosperm cells. Those cells contain a relatively high protein content and appear to steep with great difficulty. Sorghum with pigments in the pericarp and/or subcoats is unsuitable for wet milling because those pigments can be leached during the process and thereby discolor the starch (Rooney and Clark, 1968).

Watson et al. (1955) have reported large differences in the starch yields from different varieties. Norris and Rooney (1970) found similar results and reported that peripheral endosperm content was significantly related to protein content of the starch and negatively correlated with starch yield. The composition of the feed products from wet milling of sorghum has been reported by Reiners et al. (1973).

The use of water (Freeman and Watson, 1969) or alkali solution (Blessin et al, 1977) to peel sorghum has been suggested to improve the yield and color of starch produced. Apparently those treatments have not been used commercially.

VI. FOOD USES OF SORGHUM AND MILLETS

The traditional food uses of sorghum and millet have recently been compiled and summarized by Vogel and Graham (1979). The book is a report of a workshop held in Nairobi, Kenya, in 1978, and is an excellent summation of food processing and uses in India, East Africa, and Nigeria. A survey of the many varied uses of sorghum and millet in various parts of India was given by Subramanian and Jambunathan (1980). A general discussion of sorghum and millet foods was presented by Deyoe and Robinson (1979) and Cluskey et al. (1979).

Relatively little has been reported in the scientific literature on the food uses of sorghum and millets. In general, the traditional food uses of sorghum and millet are similar. The products are known under a wide range of names; however, many are the same or minor variations of similar products.

The products can be divided into several types. The flat, unleavened breads of India (chapati or roti; Fig. 25) or South and Central America (tortilla) are examples of one type. Neither sorghum nor millet has the dough forming properties of wheat so it is more difficult to make desirable products from those grains. In some instances hot water

is used to partially gelatinize the starch to aid in forming the product (Desikachar, 1975). Use of micronized (dry heated) sorghum (Rusnak et al., 1980) to make tortillas is also using partially gelatinized starch (Johnson et al., 1980). Tortillas have been traditionally heated with lime (calcium hydroxide) and this is an important flavor component of the product. The use of alkali with sorghum often leads to a number of off-colors (Khan et al., 1980; Rizley and Suter, 1977).

The traditional tortilla is made from maize. Maize does not have dough forming ability so it is similar to sorghum and millet. Thus, other than the color problem caused by the phenolic pigments, sorghum and millet should make good tortillas.

The traditional roti or chapatti, on the other hand, is made from wheat so it is much more difficult to substitute sorghum and millet. The ideal product will puff to give a semi-light product and is light, flexible, uniformly round, and firm but not tough. In general, sorghum and millet do not make ideal rotis.

A scented cultivar of sorghum from India was recently described (Prasada Rao and Murty, 1979). Porridge (sangati) made from the seeds was more scented than were rotis made from the same grain.

Another product is fermented flat bread such as the Sudananase kisra (Fig. 26). A detailed account of kisra preparation is given by El Tinay et al. (1979). Sorghum flour (1 kg) is mixed with water (2:1) in a bowl; a "starter" of previously fermented dough (300 g) is added. At the end of 18 hr fermentation, the pH reaches 3.7, and the dough is spread thin and baked on a hot plate (160°C) for a very short time (~2 to 5 sec). A nonalcoholic drink is made in a similar fashion. The batter is thinner and the product dried to a flake on the iron plate. It is stored, dried, and added to water to make the acidic drink.

Other types of sorghum and millet products include rice substitutes and decorticated whole or cracked grains that are steamed soft (Badi et al., 1980). Sorghum appears to require longer cooking than millet to give a soft product (Viraktamath et al., 1972; Subba Rao et al., 1953). The cous cous of Senegal is a similar product but is agglomerated from a coarse flour instead of being from whole grain.

Much of the sorghum and millet is consumed as a porridge. There are a number of porridges that vary in whether they are fermented and on the ratio of flour to water. The thin porridges, Uji, etc., are made both with and without fermentation. The carboxylic acids produced during fermentation have been identified (Banigo and Muller, 1972). The thicker type porridges, tuwo, etc., are frequently moulded or shaped (Fig. 27). The thick porridge should be stiff enough to mould smooth without cracks and should not stick to fingers or mouth. The thick porridges are the major foods in some countries and may be eaten more than once a day.

A sizable amount of sorghum is consumed in the form of alcoholic beverages (beer). In general, the sorghum beers (Marisa, Fig. 28) are high in soilds content and relatively nutritious (Monawar, 1980). Zammit

(1980) reports vitamin contents of thiamine (0.78 mg/100 g), riboflavin (0.87 mg/100 g), and niacin (7.37 mg/100 g solids) for sorghum beer. Iron absorption from sorghum beer was more than twelve fold greater than from gruel made from the constituents used to prepare beer (Derman et al., 1980).

An area that has received considerable research interest has been the use of composite flours for breadmaking. Generally, addition of more than small amounts of sorghum or millet flour will decrease loaf volume; however, the flavor of bread containing millet is generally reported as excellent (Dendy et al., 1970; Crabtree and Dendy, 1979; Basse, 1978; Badi et al., 1976b; Casier et al., 1977). The use of methyl cellulose gums to produce bread from sorghum flour was reported by Hart et al. (1970). Bijttebier (1980) used gums to make bread from sorghum and millet flours. The use of sorghum and millet in cookies has been reported (Badi and Hoseney, 1976). Work at the Food Research Center in Khartoum, Sudan, has also stressed the production of snacks from sorghum and millet (Badi et al., 1978). Traditional snack foods are limited; however, the use of certain varieties of both sorghum and millet to produce popped grain is certainly an exception.

Table I. Composition of Sorghum Fractions and Whole Grain (Adapted from Hubbard et al. 1950)

Fraction	% of Whole kernel	Ash %	Protein %	Oil %	Starch %
Whole grain	100	1.65	12.3	3.9	73.8
Endosperm	82.3	0.37	12.3	0.6	82.5
Germ	9.8	10.36	18.9	28.1	13.4
Bran	7.9	2.02	6.7	4.9	34.6

Table II. Reported Amino Acid Composition (g/100 g protein) of Sorghum

	Reference			
	Waggle et al. 1967	Jones and Beckwith 1970	Jambunathan and Mertz 1973	Hoseney et al. 1974
Lysine	2.08	1.8	2.14	2.24
Histidine	2.23	2.1	2.01	1.71
Ammonia	--	3.3	--	2.95
Arginine	3.32	3.2	3.59	3.18
Aspartic Acid	6.87	7.0	7.83	6.94
Threonine	3.10	3.5	3.26	3.64
Serine	4.34	4.6	4.52	4.73
Glutamic Acid	22.40	24.9	23.22	22.27
Proline	8.27	9.0	8.16	7.19
Glycine	3.10	3.2	3.07	3.40
Alanine	9.85	9.9	9.89	9.11
Half-cystine	1.56	0.7	0.92	1.73
Valine	5.25	4.9	5.35	4.51
Methionine	1.17	1.3	1.03	1.23
Isoleucine	4.24	3.9	4.08	3.77
Leucine	14.36	14.5	14.27	13.11
Tyrosine	2.14	4.6	4.50	3.41
Phenylalanine	5.30	5.3	5.19	4.89

Table III. Correlation and Regression Coefficients of the Relation Between Protein Level and Amino Acid Composition and Distribution of Sorghum (Source: Waggle and Deyoe, 1966).

	Amino Acid Composition[a] Versus Protein Content		Amino Acid Distribution[b] Versus Protein Level	
	r	Slope	r	Slope
Glutamic acid	0.98	0.277	0.78	0.720
Proline	0.97	0.095	0.57	0.169
Alanine	0.98	0.118	0.74	0.269
Isoleucine	0.97	0.046	0.47	0.065
Leucine	0.97	0.175	0.73	0.460
Phenylalanine	0.97	0.057	0.46	0.072
Lysine	0.66	0.009	-0.84	-0.154
Histidine	0.93	0.020	-0.27	-0.021
Arginine	0.84	0.023	-0.59	-0.106
Threonine	0.94	0.030	-0.26	-0.025
Glycine	0.86	0.020	-0.73	-0.132
Aspartic acid	0.96	0.069	0.03	0.006
Serine	0.96	0.046	0.15	0.019
Valine	0.97	0.052	0.08	0.010
Methionine	0.71	0.011	-0.04	-0.004

[a]Composition, grams amino acid per 100 gram sample.

[b]Distribution, grams amino acid per 16 gram nitrogen.

Table IV. Nonstarchy polysaccharides from sorghum pericarp

Polysaccharide	Ratio ARAB:XYL:GLU	Reference[a]
Water-soluble	2.1:1.0:0.8	1
Cold-water soluble	1.3:1.0:7.2	2
Hot-water soluble	1.3:1.0:20.5	2
Alkali-soluble	1.3:1.0:1.1	1
Hemicellulose A	1.1:1.0:0.7	2
Hemicellulose B	1.2:1.0:0.1	2

[a]1 = Karim and Rooney, 1972b;
2 = Woolard et al., 1976a

Table V. Data on Hemicellulose B Fractions Separated by DEAE Cellulose (Woolard et al., 1976a)

Polysaccharide		Eluting Buffer	Recovery from 80 g Hem. B g	Ratio ARAB:XYL:GLU	{α}D
$B(A)_1$			23.5	1.1:1.0:0.1	-89°
	H-1	Water	4.9	1.0:1.0:0.7	-53°
	H-2	0.0025 M Borate	3.7	1.7:1.0	-86°
	H-3	0.0100 M Borate	10.4	1.0:1.0	-106°
$B(A)_2$			12.7	1.1:1.0:0.1	-86°
	H-4	0.025 M NaCl	7.8	1.7:1.0:0.1	-101°
	H-5	0.050 M NaCl	1.8	1.1:1.0:0.1	-75°
	H-6	0.075 M NaCl	0.9	1.2:1.0:0.1	-61°
	H-7	0.100 M NaCl	0.5	1.4:1.0:0.1	-27°
	H-8	0.300 M NaCl	0.5	1.5:1.0:0.3	$+19^{o}$
B(B)			29.0	1.0:1.0	-92°
	H-9	0.025 M NaCl	16.0	1.0:1.0	-98°
	H-10	0.050 M NaCl	1.9	1.0:1.0	-73°
	H-11	0.075 M NaCl	1.3	1.0:1.0	-70°
	H-12	0.100 M NaCl	2.1	1.0:1.0	-68°
	H-13	0.300 M NaCl	2.6	1.0:1.0	-44°

Table VI. Fatty acid composition of grain sorghum[a]

Fatty Acid	Reference			
	Neucere and Sumrell, 1980[b]	Wall and Blessin, 1970	Freeman and Bocan, 1973[c]	Price 1975
C14:0	< 0.5	0.4	nd	0.2
C16:0	12.9	13.2	12.3	19.5
C16:1	0.9	1.3	nd	0.8
C18:0	3.3	2.0	0.8	1.7
C18:1	37.7	30.5	34.3	28.1
C18:2	38.4	49.7	49.9	44.7
C18:3	2.9	2.0	2.7	5.0
C20:0	0.7	nd	nd	nd
C20:1	1.5	nd	nd	nd
C22:0	1.9	nd	nd	nd
C22:1	0.5	nd	nd	nd
C24:0	1.1	nd	nd	nd

[a]Values reported are means, nd = not determined.

[b]5 samples.

[c]22 samples.

Table VII. Nonpolar Lipids of Sorghum
(Paul et al., 1972)

Lipid	Mean Composition (%) Free	Bound
Partial glycerides	3.4	6.1
Sterols	6.0	5.7
Pigments	5.0	1.5
Free (nonesterified) Fatty Acids	7.9	43.8
Triglycerides	64.5	38.2
Unidentified	5.8	---
Sterol esters + hydrocarbons	7.9	4.8

Table VIII. Vitamin and Mineral Content of Sorghum

Nutrient	μg/g Range	μg/g Mean
Vitamins[a]		
Thiamine	4.6 - 6.8	5.8
Riboflavin	0.8 - 3.1	1.7
Niacin	21 - 84	48
Biotin	0.1 - 0.5	0.3
Folic acid	0.1 - 0.3	0.2
Pyridoxine	2 - 9	6
Pantothenic acid	5 - 16	10
Choline	528 - 954	762
β-Carotene	0.2 - 1.7	0.3
Minerals[b]		
Si	1000 - 3000	2000
Na	100 - 200	---
K	3500 - 5200	4000
Ca	12 - 432	205
Mg	1080 - 2300	1550
P	2500 - 6300	4055
Fe	24 - 200	59
Cu	3 - 10	5
Zn	14 - 75	25
Mo	0.3 - 8	3
Cr	0.2 - 1	0.7[c]
Co	<1	0.5
Mn	7 - 30	15
Ni	<1 - 14	1.7
Se	<1	---
Ti	0.2 - 2	1.0
Sr	0.1 - 3	1.8
V	<1 - 2	---
Al	5 - 69	18
B	1 - 3	1.3
Ba	0.2 - 2	0.8
Li	0.2 - 2	0.7
Pb	0.2 - 2	1.1
Rb	1 - 3	1.2

[a]From Hubbard et al., 1950; Tanner et al., 1947; Knox et al., 1944; Miller, 1958.

[b]From Deosthale et al., 1977; Deosthale and Belavady, 1978; Neucere and Sumrell, 1980; Pinta and Busson, 1963.

[c]Neucere and Sumrell (1980) reported a Cr value of 30 μg/g for one sorghum variety.

Table IX. Range of Amino Acids in Pearl Millet Meals (g AA/16g N).

Amino Acid	Range	
	High	Low
Tryptophan	1.9	0.8
Lysine	3.9	1.9
Histidine	3.1	1.6
Arginine	6.2	3.1
Aspartic acid	11.3	5.0
Threonine	4.3	2.0
Serine	5.9	3.0
Glutamic acid	25.4	11.6
Proline	11.8	3.9
Glycine	6.4	2.2
Alanine	8.8	6.4
Half Cystine	3.3	1.0
Valine	6.2	4.4
Methionine	2.6	1.2
Isoleucine	6.0	3.1
Leucine	12.7	7.6
Tyrosine	5.0	2.4
Phenylalanine	5.9	3.9

Table X. Physicochemical Characteristics of Pearl Millet Starch

Property	Reference[a] 1	2	3
Iodine affinity (% d.b.)	---	4.84,5.05	4.43-4.75
Amylose content (% d.b.)	17	---	20-22
Intrinsic viscosity	---	1.74,1.50	1.47-1.71
Gelatinization temp. °C			
initiation	51	59,67	59-63
end-point	69	70,75	68-70
Amylograph pasting curves			
pasting temp. °C	72	---	76.5
peak viscosity (BU)	560	600,600	400-500
Viscosity 1 hr at 95°C (BU)	640	400,600	340-460
Viscosity after cooled to 50°C (BU)	780	660,760	500-640
Viscosity after 1 hr at 50°C (BU)	755	600-690	460-620
Cold water binding capacity (% d.b.)	---	---	83.6-99.5

[a]1. Badi et al. (1976b) using 50 g starch for the amylogram; 1 sample studied.

2. Freeman and Bocan (1973) using 35 g starch for the amylogram; 2 samples studied.

3. Beleia et al. (1980) using 50 g starch for the amylogram; 5 samples studied.

Table XI. Minerals in Pearl Millet (*P. americanum*)[a]

Element	mg/100g (d.b.)
Na	2.2-4.9
K	366-543
Ca	7-117
Mg	71-156
P	631-1353
Fe	2.1-11.7[b]
Cu	0.42-0.58
Mn	0.66-0.92
Zn	0.10-3.8
Mo	0.014-0.024

[a]Data obtained from: Carr, 1961, Goswami et al., 1969a,b; Shah and Mehta, 1959; Burton et al., 1972; Varriano-Marston and Hoseney, 1980.

[b]Carr (1961) reported an Fe content of 46 mg/100 g of grain for pearl millet ground on stones containing high levels of Fe.

Table XII. Protein Efficiency Ratios of Pearl Millet Alone or Supplemented with Other Nutrients

Diet	Level of protein in the diet (%)	PER	Reference
Pearl millet			
	11	1.67	Hariharan et al., 1965
	5	1.3	Rao et al., 1964
	10	1.4	Rao et al., 1964
	10	1.8	Rao et al., 1964
	11	1.84	Pushpamma et al., 1972
Pearl millet + amino acids			
None	11	1.84	Rao et al., 1964
Lysine	11	2.41	Pushpamma et al., 1972
Tryptophan	11	1.83	Rao et al., 1964
Lys + Trp	11	2.34	Rao et al., 1964
Lysine	10	3.41	Daniel et al., 1965
Lys + threonine	10	3.54	Daniel et al., 1965
Pearl millet + plant protein			
Bengal gram	10	2.16	Rao et al., 1964
Red, black + green gram	10	2.05-2.10	Rao et al., 1964
Coconut cake	10	1.60	Rao et al., 1964
Amaranth leaf	10	1.73	Rao et al., 1964
Grams + amaranth leaf	10	2.04-2.30	Rao et al., 1964

Table XIII. Typical Sorghum Dry Milling Results (Hahn, 1969)

	Yield %	Protein %	Oil %	Fiber %	Ash %
Whole grain	100	9.6	3.4	2.2	1.5
Grit	67	9.6	0.6	0.8	0.5
Bran	12	8.9	5.5	8.6	2.4
Germ	11	15.1	20.0	2.6	8.2
Fines	10	7.1	2.4	1.3	1.0

Legend of Figures

Figure 1. Picture of sorghum (center), pearl millet (upper left), proso millet (upper right), foxtail millet (lower left), and finger millet (lower right).

Figure 2. Diagram showing the component parts of a sorghum kernel: scutellum (S), embryomic axis (EA), stylar area (SA). Source: Rooney, 1973.

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Figure 7. Optical photomicrograph of destarched section of peripheral area of the kernel showing subaleurone (SA) proteinaceous cells, protein granules, and the aleurone layer (AL); 7 μm thick section stained with AO-12 (650X). Source: Seckinger and Wolf, 1973.

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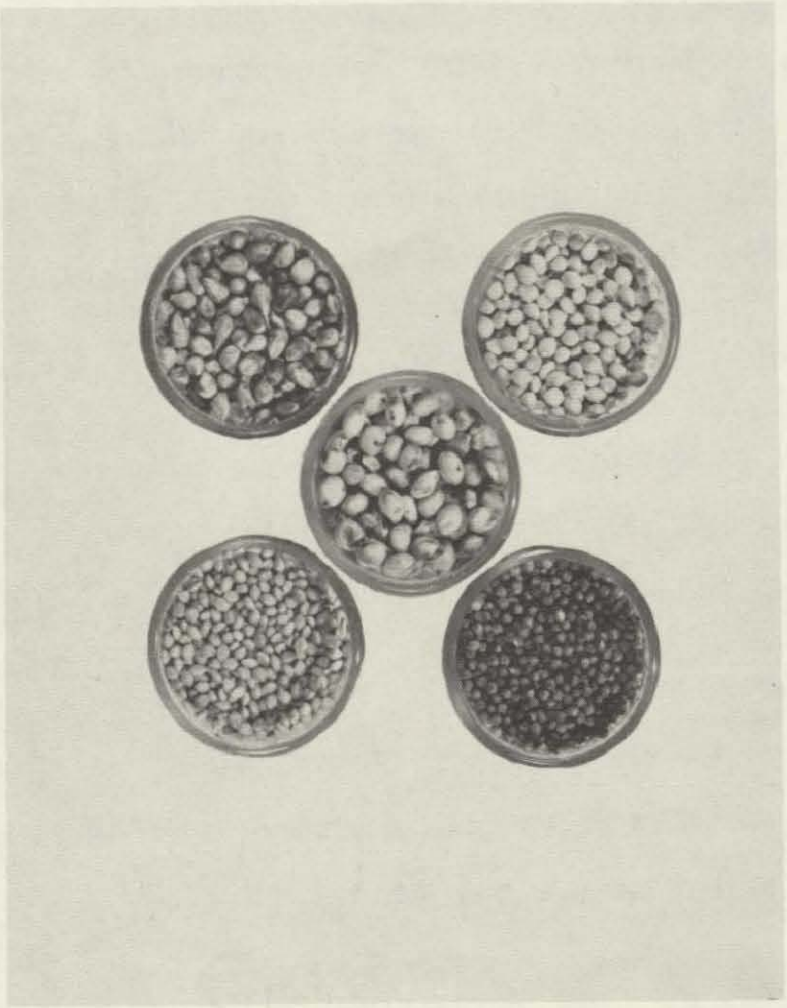

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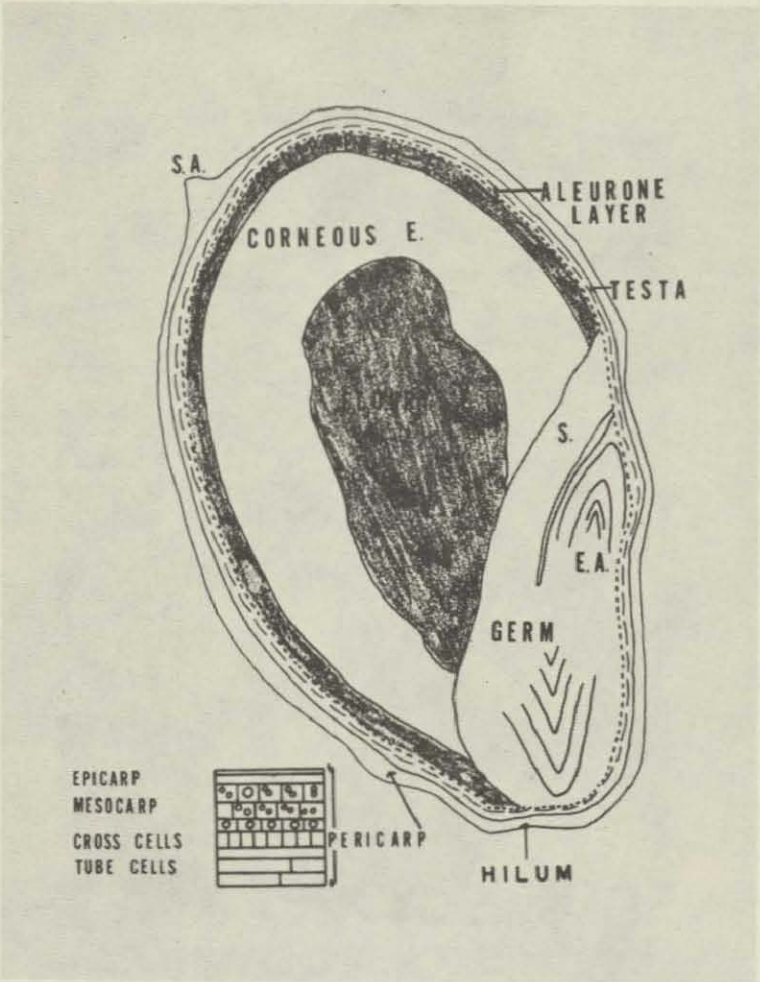

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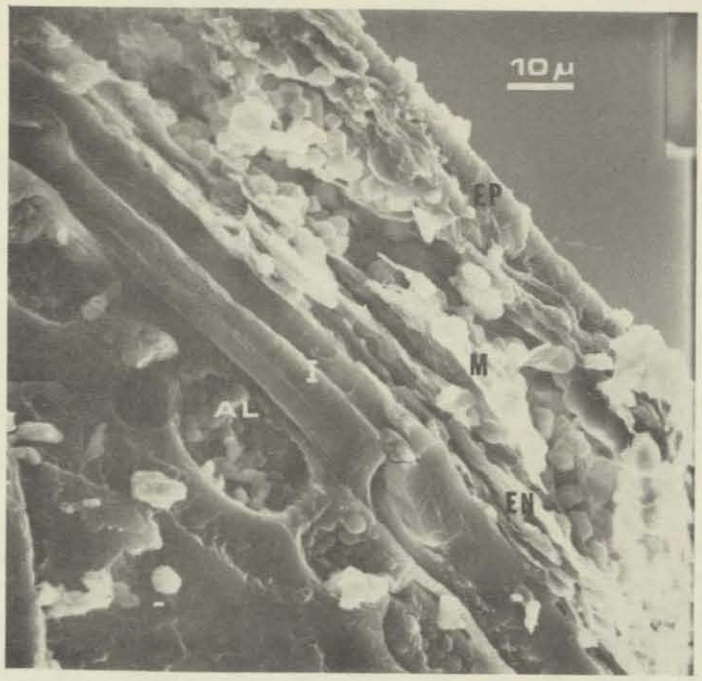

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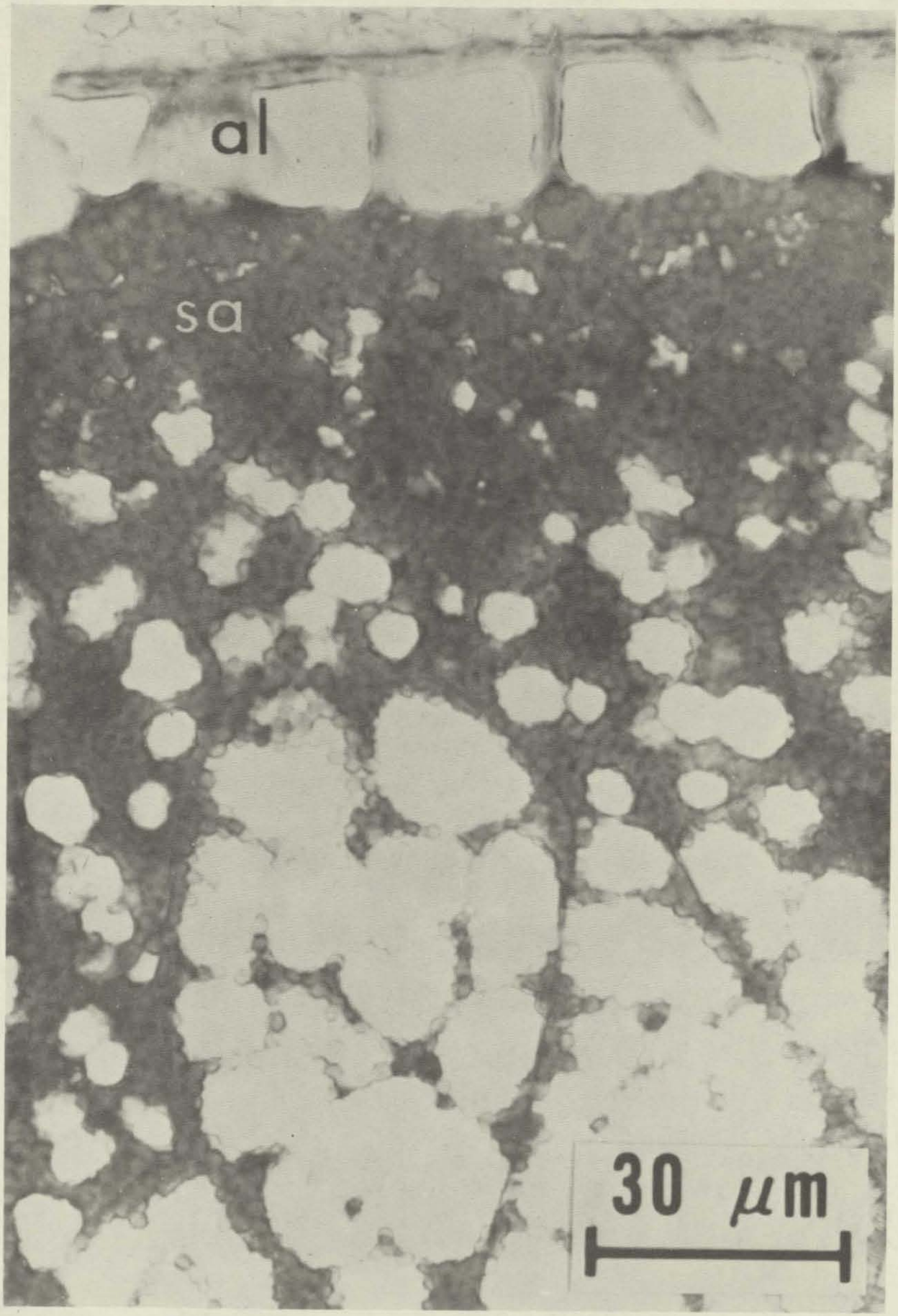

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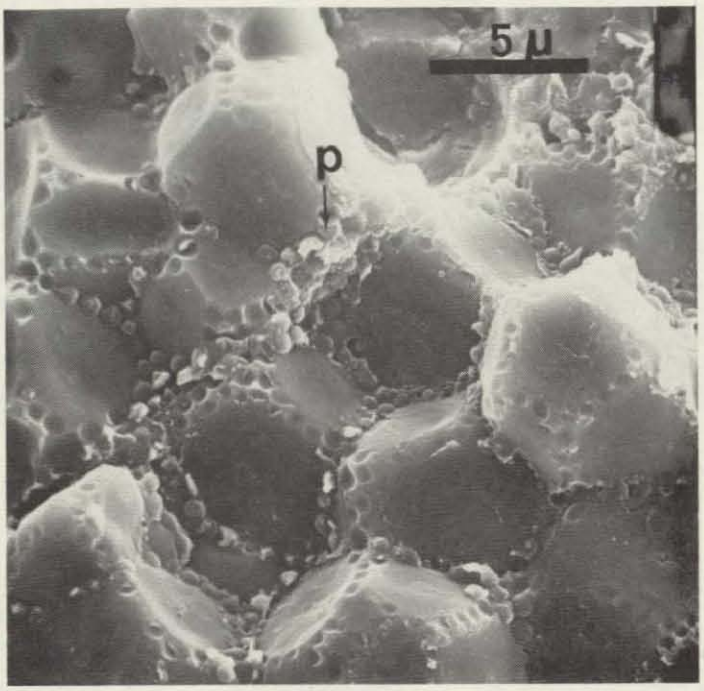

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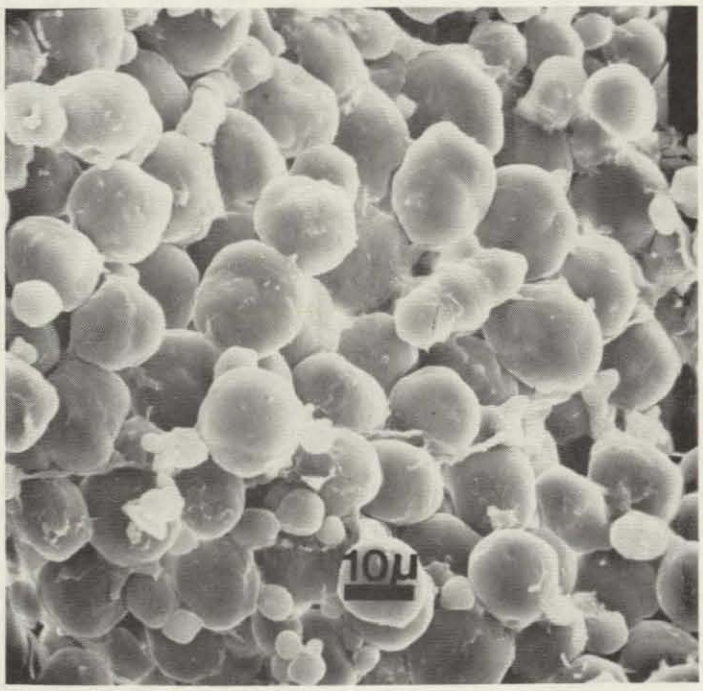

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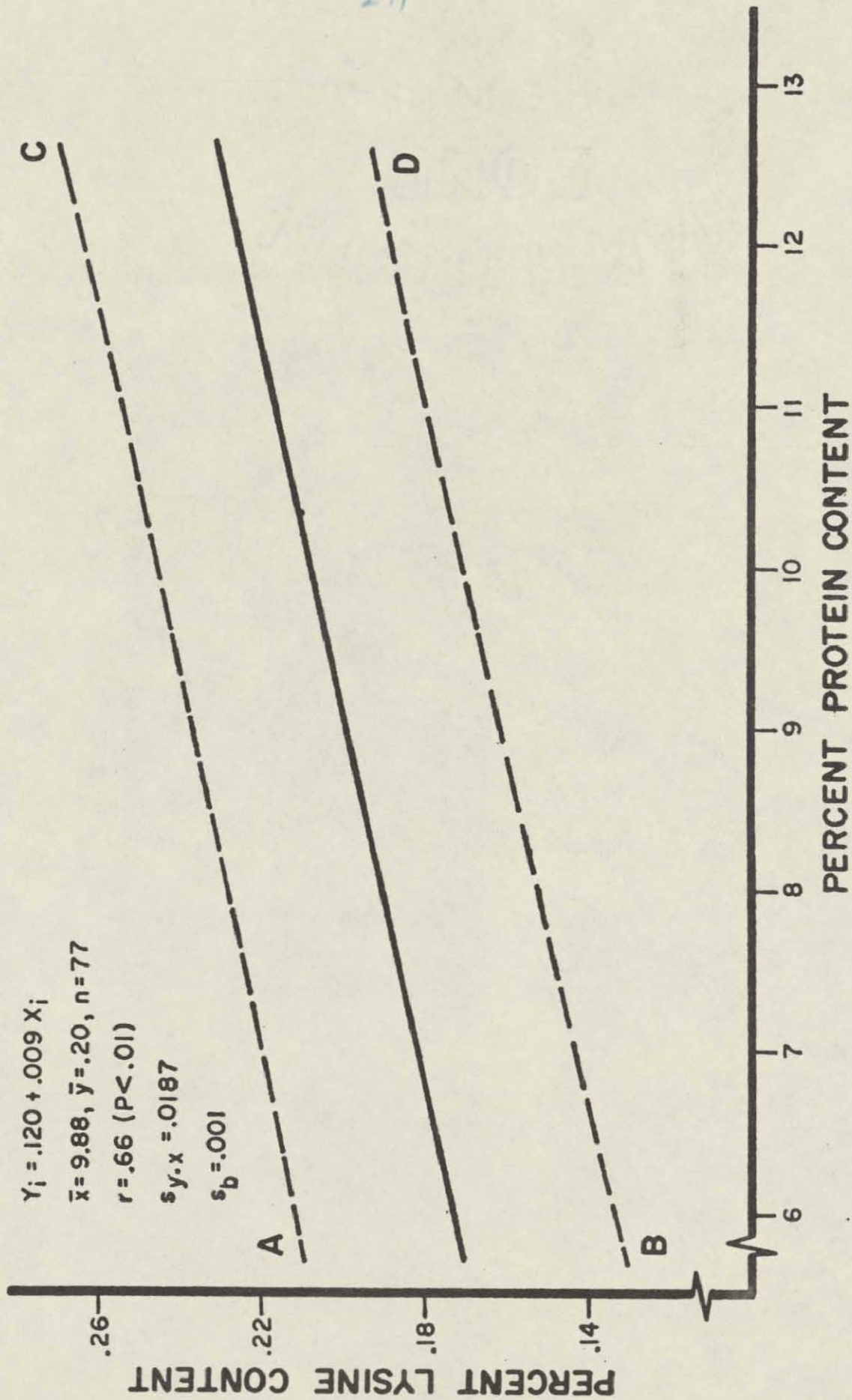

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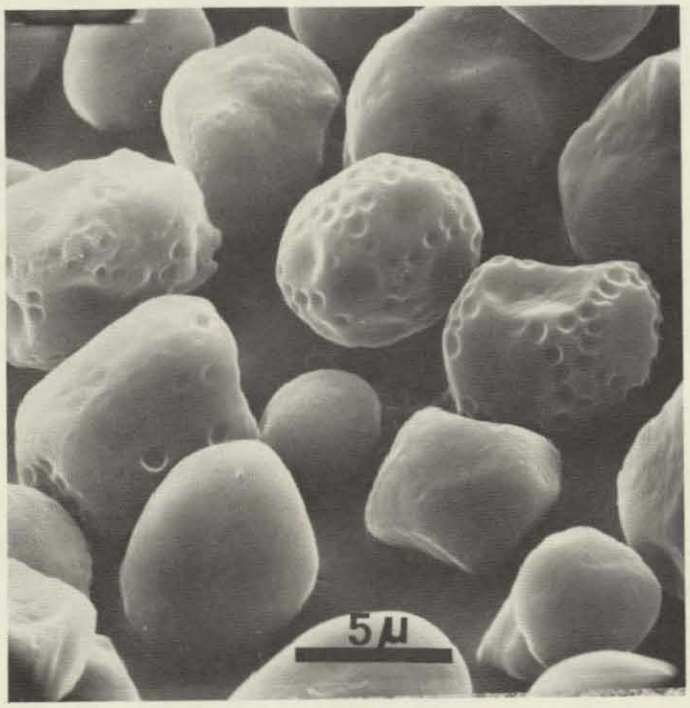

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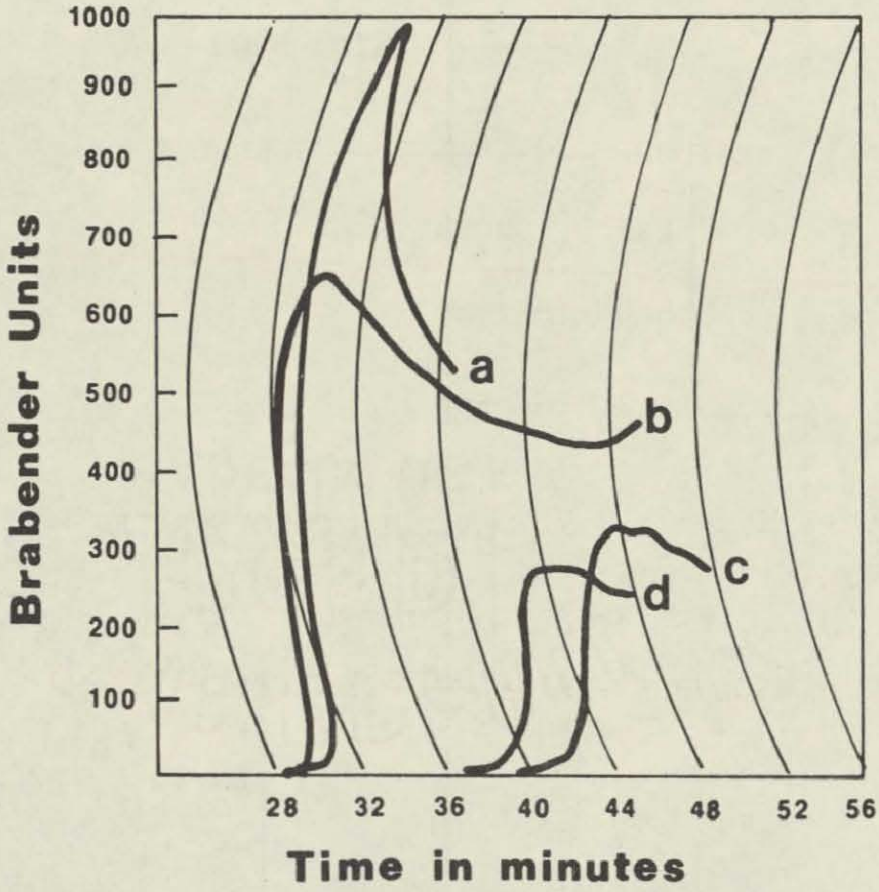

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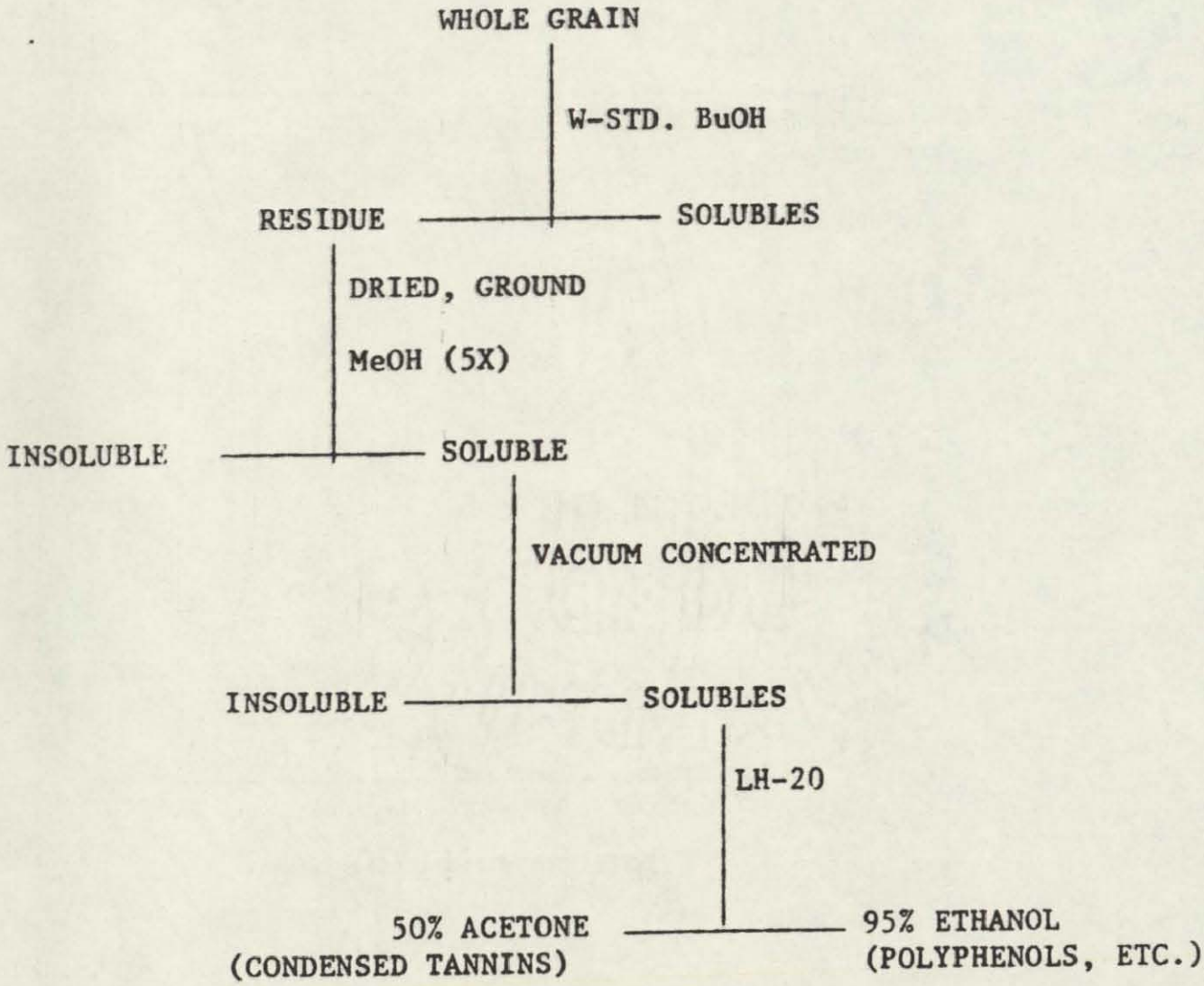

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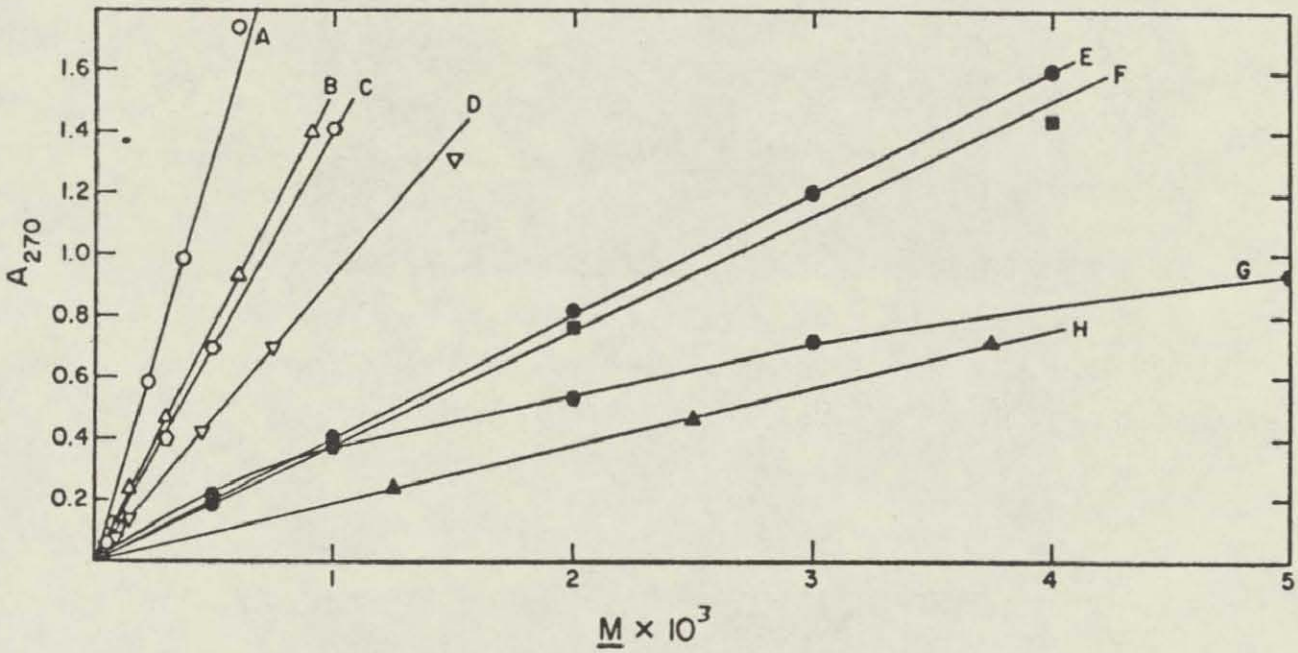

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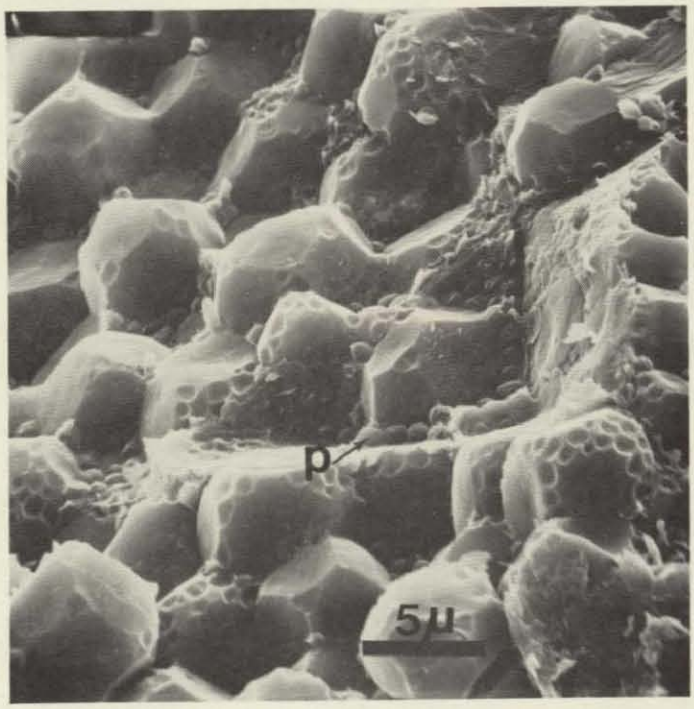

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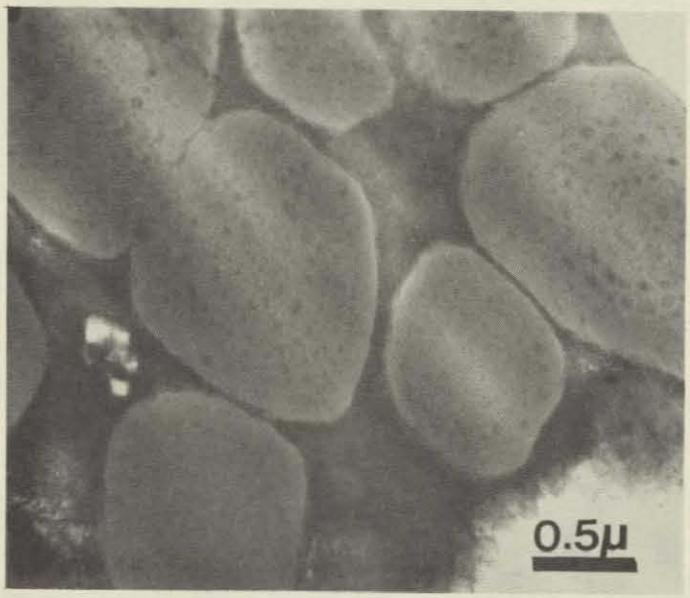

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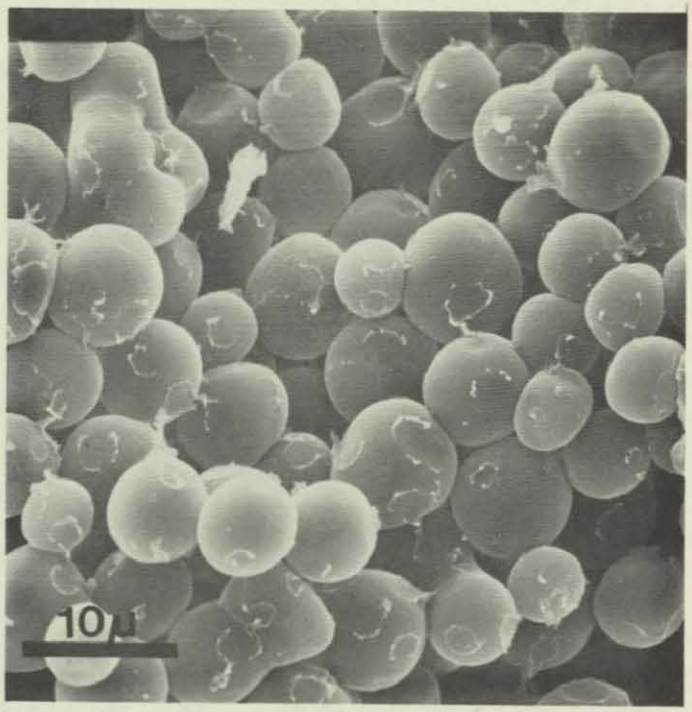

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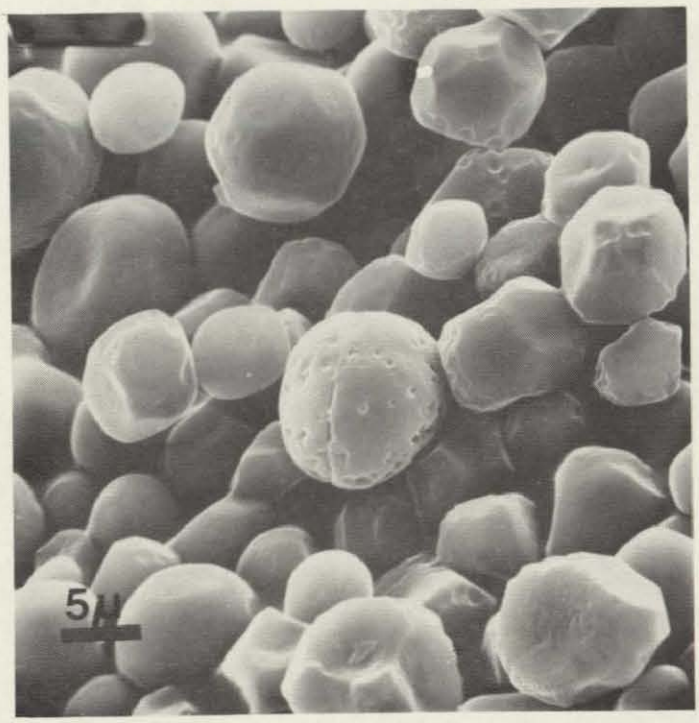

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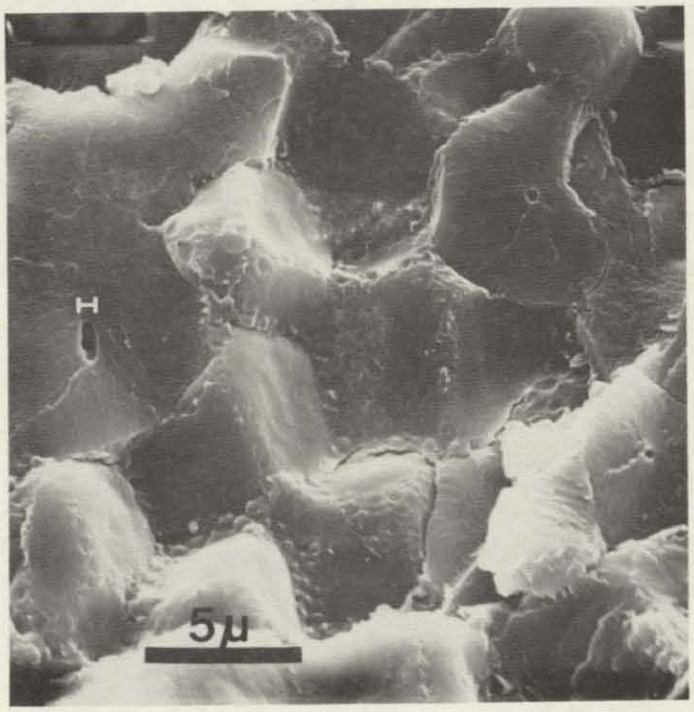

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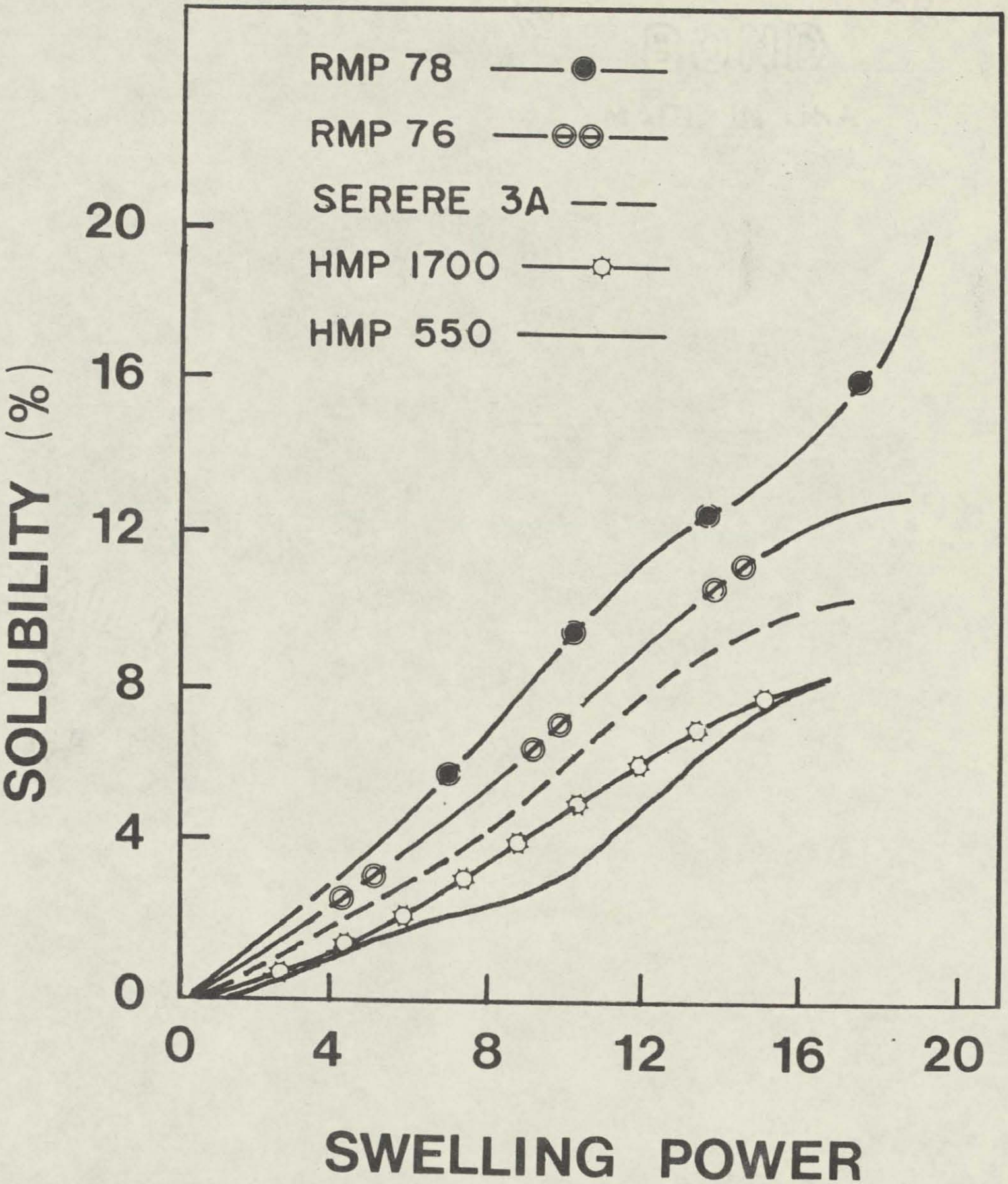

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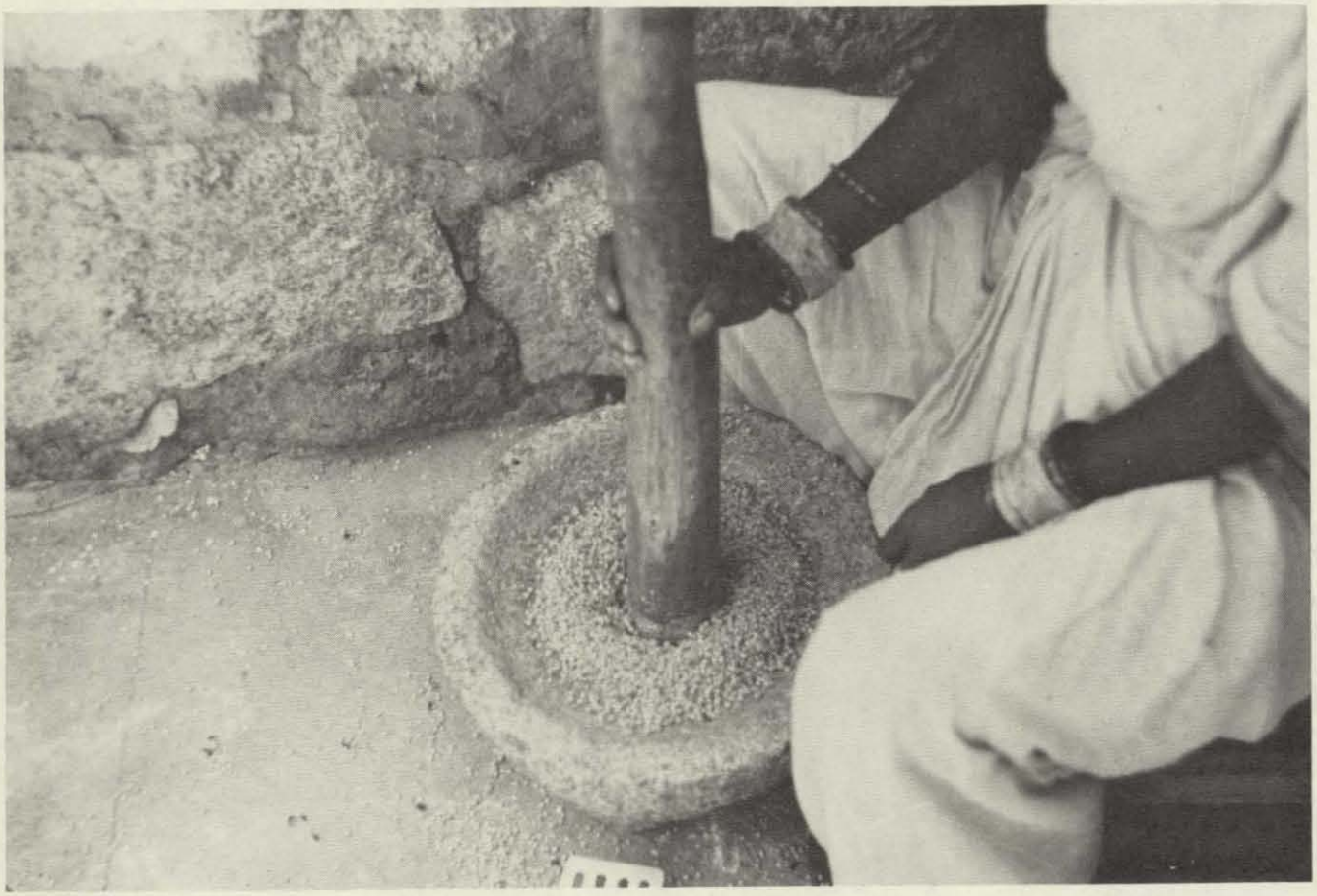

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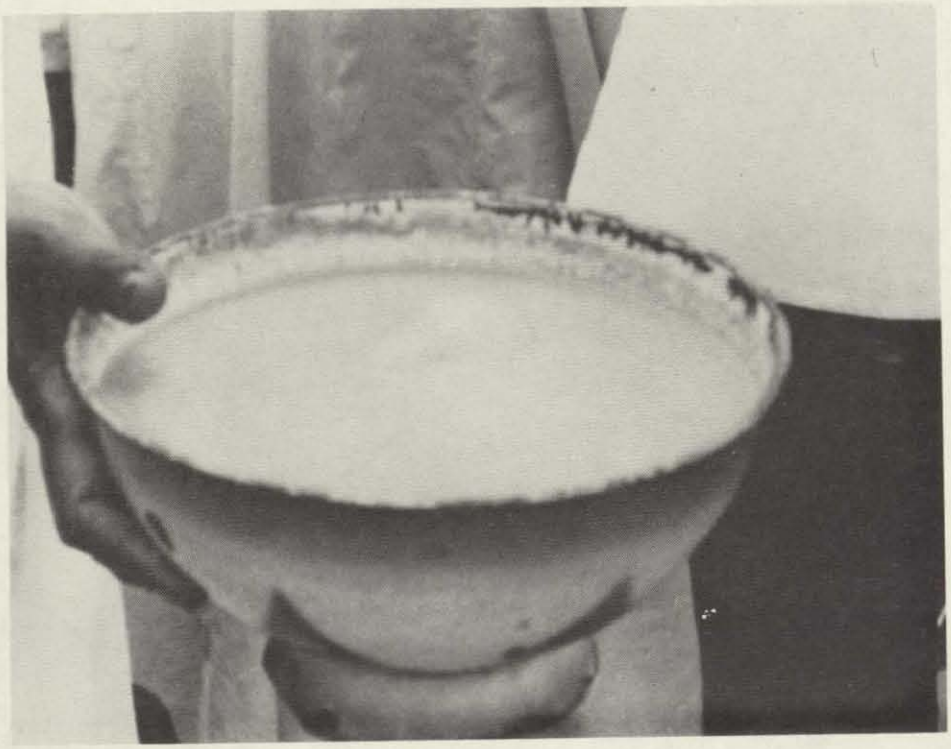

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LITERATURE CITED

Abhyander, V. S., Kotastane, W. V., And Naryana, N. 1939. The proteins of bajra (*Pennisetum typhoideum*). Proc. Indian Acad. Sci. B, 9:126-132.

Adams, C. A., and Liebenberg, N. V. D. W. 1975. Ultrastructure of storage protein in cereals. Verrigt.--Elecktronmikroskopiever. Suidelike Afr. 5:39-40.

Adams, C. A., and Novellie, L. 1975a. Composition and structure of protein bodies and spherosomes isolated from ungerminated seeds of *Sorghum Bicolor* (Linn.) Moench. Plant Physiol. 55:1-6.

Adams, C. A., and Novellie, L. 1975b. Acid hydrolases and autolytic properties of protein bodies and spherosomes isolated from ungerminated seeds of *Sorghum bicolor* (Linn.) Moench. Plant Physiol. 55:7-11.

Adams, C. A., Novellie, L., and Liebenberg, N. V. D. W. 1976. Biochemical properties and ultrastructure of protein bodies isolated from selected cereals. Cereal Chem. 53:1-12.

Adams, C. A., Watson, T. G., and Novellie, L. 1975. Lytic bodies from cereals hydrolyzing maltose and starch. Phytochem. 14:953-956.

Adrian, J., Goussault, B., Arnal-Peyrot, F., and Samson, M. F. 1975. Techniques de mouture du mil pennisetum et valeur protidique des semoules et des farines. Agronom. Tropicale 30:43-51.

Adrian, J. and Sayerse, C. 1957. Composition of Senegal millets and sorghums. Brit. J. Nutr. 11:99-105.

Adrian, Jean, Frangne, R., and Gerbaud, D. 1979. Attempts at supplementing African cereals (sorghum and pennisetum millet). Aliment. Vie 67: 167-174.

Agarwal, P. N., and Sinha, N. S. 1964. Chemical composition of the oil from seeds of *Pennisetum typhoideum* (bajra). Indian J. Agron. 9:288-296.

Ahuja, K. L., Sekhon, K. S., and Sehgal, K. L. 1979. Lipid composition of pearl millet flour. J. Fd. Sci. Technol. (Mysore) 16:32-33.

Alekseeva, L. V., Aleksandrova, N. E., Kovaleva, V. I., Kolosova, G. M., and Fomina, V. V. 1978. Biochemical characteristics of germinating millet grain and culinary properties of groats prepared from it. Tr. Vses. Nauchno-Issled. Inst. Zerna Prod. Ego Pererab. 89:105-109 (Russ) Chem. Abstracts 92:4909.

Ambegaokar, S. D., Raj, H., Shinde, V. P., and Radhakrishna Rao, M. V. 1965. Studies in nutritive value of Indian foodstuffs. II - Amino acid composition of certain leafy vegetables and millets. J. Nutr. Dietet. 2:14-16.

Anderson, P. A., Baker, D. H., and Mistry, S. P. 1978. Bioassay determination of the biotin content of corn, barley, sorghum and wheat. J. Animal Sci. 47:654-659.

Anderson, R. A. 1969. Producing quality sorghum flour on wheat milling equipment. The Northwestern Miller, Oct. p. 10-12, 14-15.

Anderson, R. A., and Burbridge, L. H. 1971. Integrated process for dry milling grain sorghum. The Northwestern Miller, July p. 24-28.

Anderson, R. A., Conway, H. F., and Burbridge, L. H. 1977. Yield and chemical composition of fractions from the dry milling of a high-lysine grain sorghum. Cereal Chem. 54:855-856.

Anderson, R. A., Montgomery, R. R., and Burbridge, L. H. 1969. Low-fat endosperm fractions from grain sorghum. Cereal Sci. Today 14:366-368.

Armanious, M. W., Britton, W. M., and Fuller, H. L. 1973. Effect of methionine and choline on tannic acid and tannin toxicity in the laying hen. Poult. Sci. 52:2160-2168.

Armstrong, W. D., Rogler, J. C., and Featherston, W. R. 1974a. Effect of tannin extraction on the performance of chicks fed bird resistant sorghum diets. Poult. Sci. 53:714-720.

Armstrong, W. D., Featherston, W. R., and Rogler, J. C. 1974 b. Effects of bird resistant sorghum grain and various commercial tannins on chick performance. Poult. Sci. 53:2137-2142.

Au, Paul. 1979. Study of fermentation of grain sorghum to improve its amino acid and vitamin content. Masters Thesis. University of Missouri-Columbia.

Aucamp, M. C., Grieff, J. T., Novellie, L., Papendick, B., Schwartz, H. M., and Steer, A. G. 1961. Kaffircorn malting and brewing studies VIII. Nutritive value of some kaffircorn products. J. Sci. Food Agric. 12:449-456.

Awadalla, M. Z. 1974. Native Egyptian millet as supplement of wheat flour in bread. II. Technological studies. Nutr. Report Int. 9:69-79.

Axtell, J. D. 1976. Nutritional quality research in sorghum--progress report and current status. Improv. Nutr. Qual. Cereals 2:183-192.

Axtell, J. D., Pickett, R. C., Oswalt, D. L., Jambunathan, R., and Srinivasan, G. 1972. Components of nutritional quality in grain sorghum. In: Inheritance and improvement of protein quality and content in *Sorghum bicolor* (L.) Moench. AID contract csd;1175. Report No. 9, 1-20.

Aykroyd, W. R., Gopalan, C., and Subramanian, S. C. 1965. The nutritive value of Indian foods and the planning of satisfactory diets (Special Report Series No. 42, 6th ed.). Nutr. Res. Lab., Hyderabad. Indian Council of Med. Res., New Delhi.

Badi, S. M., and Hoseney, R. C. 1976. Use of sorghum and pearl millet flours in cookies. Cereal Chem. 53:733-738.

Badi, S. M., Hoseney, R. C., and Casady, A. J. 1976a. Pearl millet. I. Characterization by SEM, amino acid analysis, lipid composition, and prolamine solubility. Cereal Chem. 53:478-487.

Badi, S. M., Hoseney, R. C., and Finney, P. L. 1976b. Pearl millet. II. Partial characterization of starch and use of millet flour in bread-making. Cereal Chem. 53:718-724.

Badi, S. M., Perten, H., and Abert, P. 1980. New food product "peral dura." ICC Symposium on sorghum and millet for human food. Vienna.

Badi, S. M., Perten, H., Mustafa, A. I., and Abert, P. 1978. Research and development of new sorghum food products. Abst. A5-2. Cereal Foods World 23:485.

Badi, Sitt. 1980. Food Research Center, Khartoum North, Sudan. Personal communication.

Baily, A. V., Piccolo, B., Sumrell, G., and Burton, G. W. 1980. Some effects of nitrogen fertilizer on the chemical composition of pearl millet grain. J. Agric. Food Chem. 28:866-870.

Bailey, A. V., and Sumrell, G. 1980. Preparation of protein concentrate from pearl millet. J. Agric. Food Chem. 28:475-477.

Bailey, A. V., Sumrell, G., and Burton, G. W. 1979. Pentosans in pearl millet. Cereal Chem. 56:295-298.

Baldwin, A. R., and Sniegowski, M. S. 1951. Fatty acid composition of lipids from corn and grain sorghum kernels. J. Amer. Oil Chem. Soc. 28:24-27.

Banigo, E. O. I., and Muller, H. G. 1972. Carboxyl acid patterns in Ogi fermentation. J. Sci. Fd. Agric. 23:101-111.

Baptist, N. G., and Perera, B. P. M. 1956. Essential amino acids of some tropical cereal millets. Brit. J. Nutr. 10:334-337.

Barham, H. N., Wagoner, J. A., Campbell, C. L., and Harclerode, E. H. 1946. Chemical composition of some sorghum grains and the properties of their starches. Kansas Agr. Expt. Sta. Tech. Bull. 61, 1-47.

Basse, Marie-Thérèse. 1978. We are trying to make local products as attractive as imported ones. Ceres May-June p. 38.

Bate-Smith, E. C. 1969. Luteoforol (3', 4, 4', 5, 7-pentahydroxyflavan) in sorghum vulgare L. Phytochem. 8:1803-1810.

Bate-Smith, E. C. 1973. Haemanalysis of tannins: The concept of relative astringency. Phytochem. 12:907-912.

Bate-Smith, E. C. 1977. Astringent tannins of Acer species. Phytochem. 16:1421-1426.

Bate-Smith, E. C., and Rasper, V. 1969. Tannins of Grain sorghum: Luteoforol (leucoluteolinidin), 3', 4, 4', 5, 7-pentahydroxyflavan. J. Food Sci. 34:203-209.

Bates, F. L., French, D., and Rundle, R. E. 1943. Amylose and amylopectin content of starches determined by their iodine complex formation. J. Amer. Chem. Soc. 65:142-148.

Becker, R., and Lorenz, K. 1978. Saccharides in proso and foxtail millets. J. Food Sci. 43:1412-1414.

Beckwith, A. C. 1972. Grain sorghum glutelin: Isolation and characterization. J. Agric. Food Chem. 20:761-764.

Belavady, B. 1975. Nutritive value of maize (*zea mays*) and sorghum (*Sorghum vulgare*). J. Scient. Ind. Res. 34:294-304.

Belavady, B., and Rao, P. Udayasekhara. 1979. Leucine and isoleucine content of jowar and its pellagragenicity. Indian J. Exp. Biology 17:659-661.

Belavady, B., Srinkantia, S. G., and Gopalan, C. 1963. The effect of the oral administration of leucine on the metabolism of tryptophan. Biochem. J. 87:652-655.

Beleia, A. 1980. Characterization of starch and α-amylase from pearl millet. Ph.D. Thesis. Kansas State University.

Beleia, A., Varriano-Marston, E., and Hoseney, R. C. 1980. Characterization of starch from pearl millets. Cereal Chem. 57:300-303.

Bhatia, I. S., Gumber, S. C., and Singh, R. 1980. Metabolism of free sugars in relation to starch synthesis in the developing *Sorghum vulgare* grain. Physiol. Plant. 49:248-254.

Bhatia, I. S., and Uppal, D. 1979. Free and sugar nucleotides in seedlings of *sorghum vulgare*. Plant Sci. Letters 16:59-66.

Bhatia, I. S., Singh, R., and Dua, S. 1972. Changes in carbohydrates during growth and development of bajra (*Pennisetum typhoides*), jowar (*Sorghum vulgare*) and kangni (*Setaria italica*). J. Sci. Food Agric. 23:429-440.

Bianchi, G., Avato, P., and Mariani, G. 1979. Composition of surface wax from sorghum grain. Cereal Chem. 56:491-492.

Bijttebier, R. P. J. 1980. Methodes standard de panification pour des farines tropicales sans valeur boulangere, dont sorgho et millet. ICC Symposium on sorghum and millet for human feed. Vienna.

Blakely, M. E., Rooney, L. W., Sullins, R. D., and Miller, F. R. 1979. Microscopy of the pericarp and the testa of different genotypes of sorghum. Crop Sci. 19:837-842.

Blessin, C. W., Anderson, R. A., Deatherage, W. L., and Inglett, G. E. 1971. Effect of alkali dehulling on composition and wet-milling characteristics of sorghum grain. Cereal Chem. 48:528-532.

Blessin, C. W., Van Etten, C. H., and Dimler, R. J. 1963. An examination of anthocyanogens in grain sorghums. Cereal Chem. 40:241-250.

Bornstein, S., and Lipstein, B. 1971. Comparison of sorghum grain (milo) and maize as the principal cereal grain source in poultry rations. 4. Relative content of available sulfur amino acids in milo and maize. Brit. Poul. Sci. 12:1-13.

Botes, D. P., Joubert, F. J., and Novellie, L. 1967a. Kaffircorn malting and brewing studies. XVIII. Purification and properties of sorghum malt α-amylase. J. Sci. Food Agric. 18:415-419.

Botes, D. P., Joubert, F. J., and Novellie, L. 1967b. Kaffircorn malting and brewing studies. XVII. Purification and properties of sorghum malt β-amylase. J. Sci. Food Agric. 18:409-415.

Bowden, B. N., and Williams, P. M. 1971. Sterols in grass seeds. Phytochem. 10:3135-3137.

Bressani, R., and Rios, B. J. 1962. The chemical and essential amino acid composition of twenty-five selections of grain sorghum. Cereal Chem. 39:50-58.

Briley, M. R., Tribble, L. F., and Starnes, W. L. 1979. Amino acids in sorghum hydrolysates. Cereal Chem. 56:359-361.

Brommelsiek, W. A., Shirley, R. L., Bertrand, J. E., and Palmer, A. Z. 1979. Effect of methionine hydroxy analog on energy utilization of a bird-resistant sorghum grain diet fed steers. J. Anim. Sci. 48: 1475-1482.

Brunken, Jere, De Wet, J. M. J., and Harlan, J. R. 1977. The morphology and domestication of pearl millet. Econ. Bot. 31:163-174.

Bullard, R. W., Garrison, M. V., Kilburn, S. R., and York, J. O. 1980. Laboratory comparisons of polyphenols and their repellent characteristics in bird-resistant sorghum grains. J. Agric. Food Chem. 28: 1006-1016.

Burleson, C. A., Cowley, W. R., and Otey, G. 1956. Effect of nitrogen fertilization on yield and protein content of grain sorghum in the Lower Rio Grande Valley of Texas. Agron. J. 48:524-525.

Burns, R. E. 1971. Method for estimation of tannin in grain sorghum. Agron. J. 63:511-512.

Burton, G. W., Rabson, R., and Axmann, H. 1980. Immediate effect of male and female gametes and nitrogen on five pearl millet grain characteristics. Crop Sci. 20:7-9.

Burton, G. W., Wallace, A. T., and Rachie, K. O. 1972. Chemical composition and nutritive value of pearl millet *Pennisetum typhoides* (Burm) Stapf and E. C. Hubbard grain. Crop Sci. 12:187-188.

Butler, L. 1980. Unpublished data.

Cannon, C., and Kummerow, F. A. 1957. A comparison of plant and grain wax from two varieties of sorghum. J. Am. Oil Chemists Soc. 34: 519-520.

Carnovale, E., and Quaglia, G. B. 1973. Influence of temperature and humidity controlled preservation on the chemical compostion of milling products from millet. Ann. Technol. Agric. 22:371-380.

Carr, W. R. 1961. Observations ont he nutritive value of traditionally ground cereals in Southern Rhodesia. Brit. J. Nutr. 15:339-343.

Casey, P., and Lorenz, K. 1977. Millet functional and nutritional properties. Bakers Digest 51(1):45-51.

Casier, J. P. J., de Paepe, G., Willems, H., Goffings, G., and Noppen, H. 1977. Bread from starchy tropical crops. II. Bread production from pure millet and sorghum flours, by using cereal endosperm-cellwall-pentosan as a universal baking factor. In: Proceedings of a symposium on sorghum and millets for human food. Ed. by D. A. V. Dendy, p. 127-123, Tropical Products Institute, London.

Chang, S. I., and Fuller, H. L. 1964. Effect of tannin content of grain sorghums on their feeding value for growing chicks. Poult. Sci. 43:30-36.

Chang, Y. O., and Chao, N. 1969. Influence of various levels of lysine intake on weight gain and body composition of rats. J. Agric. Food Chem. 17:48-50.

Chavan, J. K., Ghonsikar, C. P., Kadam, S. S., and Salunkhe, D. K. 1979a. Protein, tannin, and starch changes in developing seeds of low and high tannin cultivars of sorghum. J. of Food Bioch. 3:13-20.

Chavan, J. K., Kadam, S. S., Ghonsikar, C. P., and Salunkhe, D. K. 1979b. Removal of tannins and improvement of in vitro protein digestibility of sorghum seeds by soaking in alkali. J. Food Sci. 44:1319-1321.

Chevassus, J. A., and Agnes, S. 1979. Protein and lysine contents of some North Cameroon hybrids of sorghum grains. Cah. ONAREST 2(3): 5-16. Chem. Abs. 92:90919.

Chibber, B. A. K., Mertz, E. T., and Axtell, J. D. 1978. Effects of dehulling on tannin content, protein distribution, and quality of high and low tannin sorghum. J. Agric. Food Chem. 26:679-683.

Chibber, B. A. K., Mertz, E. T., and Axtell, J. D. 1980. In vitro digestibility of high-tannin sorghum at different stages of dehulling. J. Agric. Food Chem. 28:160-161.

Cluskey, J. E., Wu, Y. V., Wall, J. S., and Inglett, G. E. 1979. Food applications of oat, sorghum, and triticale protein products. J. Am. Oil Chemists Soc. 56:481-483.

Cohen, R. S., and Tanksley, T. D., Jr. 1973. Energy and protein digestibility of sorghum grains with different endosperm textures and starch types by growing swine. J. Anim. Sci. 37:931-935.

Connor, J. K., Hurwood, I. S., Burton, H. W., and Fuelling, D. E. 1969. Some nutritional aspects of feeding sorghum grain of high tannin content to growing chicks. Aust. J. Exp. Agric. Anim. Husb. 9: 497-501.

Crabtree, J., and Dendy, D. A. V. 1979. Comilling of four species of millet with wheat to produce composite flours. Cereal Foods World 24:103-107.

Cummins, D. G. 1971. Relationships between tannin content and forage digestibility in sorghum. Agron. J. 63:500-502.

Daiber, K. H. 1975. Enzyme inhibition by polyphenols of sorghum grain and malt. J. Sci. Food Agric. 26:1399-1411.

Dalby, A., and Shuman, A. C. 1978. Temperature-induced errors in the colorimetric determination of tannins. Anal. Biochem. 85:325-327.

Dalton, J. L., and Mitchell, H. L. 1959. Fractionation of sorghum grain wax. J. Agric. Food Chem. 7:570-573.

Damron, B. L., Prine, G. M., and Harms, R. H. 1968. Evaluation of various bird-resistant and non-resistant varieties of grain sorghum for use in broiler diets. Poult. Sci. 47:1648-1650.

Daniel, V. A., Leela, R., Doraiswamy, T. R., Rajalakshmi, D., Vankat Rao, S., Swaminathan, J., and Parpia, H. A. B. 1966. The effect of

supplementing a poor kaffir-corn (*sorghum vulgare*) diet with L-lysine and DL-threonine on the digestibility coefficient, biological value, and net utilization ofp roteins and retention of nitrogen in children. J. Nutr. Dietet. 3:10-18.

Daniel, V. A., Leela, R., Subramanyarajurs, T. S., Rao, S. V. Hariharas, K., Rajalakshmi, D., Swaminathan, M., and Parpia, H. A. B. 1965. Amino acid supplementation of proteins: II. The effect of supplementing kaffir corn and pearl millet and diets based on them with L-lysine and DL-threonine on the nutritive value of their protein. J. Nutr. Dietet. 2:134-137.

Danno, G., and Natake, M. 1980. Isolation of foxtail millet proteins and their subunit structure. Agric. Biol. Chem. (Tokyo) 44:913-918.

Dassenko, S. 1980. Effect of milling, fermentation and cooking on nutritive value of pearl millet (*Pennisetum americanum* (L.) Leeke). Ph.D. Thesis, Kansas State University, Manhattan, Kansas.

Davis, A. B. 1973. Scanning electron microscopy of monogastric and ruminant digestion sorghum grain. M.S. Thesis, Kansas State University.

Davis, A. B., and Harbers, L. H. 1974. Hydrolysis of sorghum grain starch by rumen microorganisms and purified alpha-amylase as observed by scanning electron microscopy. J. Anim. Sci. 38:900-907.

Davis, A. B., and Hoseney, R. C. 1979a. Grain sorghum condensed tannins. I. Isolation, estimation, and selective adsorption by starch. Cereal Chem. 56:310-314.

Davis, A. B., and Hoseney, R. C. 1979b. Grain sorghum condensed tannins. II. Preharvest changes. Cereal Chem. 56:314-316.

deMan, J. M., Banigo, E. O. I., Rasper, V. and Gade, H. 1973. Dehulling of sorghum and millet with the Palyi Compact Milling Systems. Can. Inst. Food Sci. Technol. J. 6:188-193.

Deatherage, W. L., MacMasters, M. M., and Rist, C. E. 1955. A partial survey of amylose content in starch from domestic and foreign varieties of corn, wheat, and sorghum and from some other starch-bearing plants. AACC Trans. 13:31-42.

Dendy, D. A. V., Clarke, P. A., and James, A. W. 1970. The use of blends of wheat and non-wheat flours in breadmaking. Tropical Sci. 12:131-141.

Dendy, D. A. V., and Pinson, L. S. 1979. Khartoum, Sudan, Personal communication.

Deosthale, Y. G., and Belavady, B. 1978. Mineral and trace element composition of sorghum grain: Effect of variety, location and application of nitrogen fertilizer. Ind. J. Nutr. Diet. 15:302-308.

Deosthale, Y. G., Krishnamachari, K. A. V. R., and Belavady, B. 1977. Copper, molybdenum and zinc in rice, sorghum and pearl millet grains from fluorosis and non-fluorosis areas of Andhra Pradesh. Indian J. Agric. Sci. 47:333-335.

Deosthale, Y. G., Mohan, V. S., Radhakrishman, M. R., and Bhat, S. 1969. Locational variations in β-carotene content of two yellow endosperm varieties of sorghum. J. Nutr. Diet. 6:224-228.

Deosthale, Y. G., Mohan, V. S., and Visweswara Rao, K. 1970a. Varietal differences in protein, lysine, and leucine content of grain sorghum. J. Agr. Food Chem. 18:644-646.

Deosthale, Y. G., Nagarajan, V., and Pant, K. C. 1970. Nutrient composition of some varieties of ragi (*Eleusine coracana*). J. Nutr. Diet. 7:80-83.

Deosthale, Y. G., Nagarajan, V., and Visweswar Rao, K. 1972. Some factors influencing the nutrient composition of sorghum grain. Indian J. Agri. Sci. 42:100-108.

Deosthale, Y. G., Rao, K. V., Nagarajan, V., and Pant, K. C. 1971. Varietal differences in proteins and amino acids of grain bajra (*Pennisetum typhoides*). Ind. J. Nutr. Dietet. 8:301-308.

Derman, D. P., Bothwell, T. H., Torrance, J. D., Bezwooda, W. R., MacPhail, A. P., Kew, M. C., Sayers, M. H., Disler, P. B., and Charlton, R. W. 1980. Iron absorption from maize (*Zea mays*) and sorghum (*Sorghum vulgare*) beer. Brit. J. Nutr. 43:271-280.

Desai, B. L. M., Daniel, V. A., Rao, S. V., Swaminathan, M., and Parpia, H. A. B. 1970. Studies on low cost balanced foods suitable for feeding weaned infants in developing countries: II Supplementary value of low cost balanced foods based on cereals, cottonseed or peanut flour and Bengal gram flour to poor Indian diets. J. Nutr. Diet. 7:21-26.

Desikachar, H. S. R. 1975. Processing of maize, sorghum, and millets for food uses. J. Scient. Ind. Res. 34:231-237.

Desikachar, H. S. R. 1977. Processing of sorghum and millets for versatile food uses in India. In: "Proceedings of a symposium on sorghum and millets for human food, "D. A. V. Dendy ed., p. 41-46. Tropical Products Institute, London.

Deyoe, C. W., and Robinson R. J. 1979. Sorghum and pearl millet foods. In: Tropical Foods, G. Inglett (ed.), Vol. I., p. 217-237. Academic Press, New York.

Deyoe, C. W., and Shellenberger, J. A. 1965. Amino acids and protein in sorghum grain. J. Agric. Food Chem. 13:446-450.

Deyoe, C. W., Shoup, F. K., Miller, G. D., Bathurst, J., Liang, D., Sanford, P. E., and Murphy, L. S. 1970. Amino acid composition and energy value of immature sorghum grain. Cereal Chem. 47:363-368.

Dube, S. K., and Nordin, P. 1961. Isolation and properties of sorghum α-amylase. Arch. Biochem. Biophys. 94:121-127.

Dube, S. K., and Nordin, P. 1962. The action pattern of sorghum α-amylase. Arch. Biochem. Biophys. 99:105-108.

Dyer, T. A., and Novellie, L. 1966. Kaffircorn malting and brewing studies. XVI. The distribution and activity of α- and β-amylases in germinating kaffircorn. J. Sci. Food Agric. 17:449-456.

Edwards, W. M., and Curtis, J. J. 1943. Grain sorghums, their products and uses. Northern Reg. Res. Lab., U.S. Dept. Agr., Peoria, Il., ACE-193, NM-229.

Earp, C. F., Akingbala, J. O., Ring, S. H., and Rooney, L. W. 1981. Evaluation of several methods to determine tannins in sorghums with varying kernel characteristic. Cereal Chem. In. Press.

Eastman, P. 1980. An End to Pounding. International Development Research Center, Ottawa, Canada.

El Tinay, A. H., Abdel, Gadir, A. M., and El Hidai, M. 1979. Sorghum fermented kisra bread. I. Nutritive value of kisra. J. Sci. Food Agric. 30:859-863.

El Tuhami, M. K., Cummins, D. G., and Burns, R. E. 1980. Extractant color as a factor in grain sorghum tannin analysis. Agron. J. 72:108-110.

Elkin, R. G., Featherston, W. R., and Rogler, J. C. 1978b. Investigations of leg abnormalities in chicks consuming high tannin sorghum grain diets. Poult. Sci. 57:757-762.

Elkin, R. G., Rogler, J. C., and Featherston, W. R. 1978a. Influence of sorghum grain tannins on methionine utilization in chicks. Poult. Sci. 57:704-710.

Fernandex, R., Lucas, E., and McGinnis, J. 1974. Comparative nutritional value of different cereal grains as protein sources in a modified chick bioassay. Poult. Sci. 53:39-46.

Filho, J. X. 1974. Trypsin inhibitors in sorghum grain. J. Food Sci. 39:422-423.

Fishman, M. L., and Neucere, N. J. 1980. Partial characterization of tannin-protein complexes in five varieties of grain sorghum by automated gel filtration chromatography. J. Agric. Food Chem. 28:477-480.

Fletcher, A. C., Porter, L. J., Haslam, E., and Gupta, R. K. 1977. Plant proanthocyanidins. Part 3. Conformational and configurational studies of natural procyanidins. J. C. S. Perkin I. 1628-1637.

Foo, L. Y., and Porter, L. J. 1980. The phytochemistry of proanthocyanidin polymers. Phytochem. 19:1747-1754.

Ford, J. E., and Hewitt, D. 1979. Protein quality in cereals and pulses. 2. Influence of polyethyleneglycol on the nutritional availability of methionine in sorghum (*Sorghum vulgare* Pers.), field beans (*Vicia foba* L.) and barley, Br. J. Nutr. 42:317-323.

Freeman, J. E., and Bocan, B. J. 1973. Pearl millet: A potential crop for wet milling. Cereal Sci. Today 18:69-73.

Freeman, J. E., Kramer, N. W., and Watson, S. A. 1968. Gelatinization of starches from corn (*Zea mays* L.) and sorghum (*Sorghum bicolor* (L.) Moench): Effects of genetic and environmental factors. Crop Sci. 8:409-413.

Freeman, J. E., and Watson, S. A. 1969. Peeling sorghum grain for wet milling. Cereal Sci. Today 14:10-15.

Frigg, M. 1976. Bio-availability of biotin in cereals. Poult. Sci. 55:2310-2318.

Galyean, R. D., Laney, J. A., Hardan, M., and Krieg, D. 1980. Water-soluble proteins of selected pearl millet genotypes. J. Food Sci. 45:1165-1167.

Ganapathy, S. N., and Chitre, R. G. 1976. Factors affecting the utilization of millet protein by rats. Ind. J. Nutr. Diet. 13: 67-71.

Garg, G. K., and Virupaksha, T. K. 1970a. Acid protease from germinated sorghum. 1. Purification and characterization of the enzyme. Eur. J. Biochem. 17:4-12.

Garg, G. K., and Virupaksha, T. K. 1970b. Acid protease from germinated sorghum. 2. Substrate specificity with synthetic peptides and ribonuclease. Eur. J. Biochem. 17:13-18.

Goldstein, J. L., and Swain, T. 1963. Changes in tannins in ripening fruits. Phytochem. 2:371-383.

Goldstein, J. L., and Swain, T. 1965. The inhibition of enzymes by tannins. Phytochem. 4:185-192.

Gopalan, C. 1968. Leucine and pellagra. Nutr. Reviews 26:323-326.

Gopalan, C., and Srikantia, S. G. 1960. Leucine and pellagra. Lancet 1:954-957.

Goswami, A. K., Sharma, K. P., and Gupta, B. K. 1969b. Chemical composition of bajra grains. 2. American entries. J. Nutr. Diet. 6:291-294.

Goswami, A. K., Sehgal, K. L., and Gupta, B. K. 1970a. Chemical composition of bajra grains. 3. Indian inbreds. Ind. J. Nutr. Diet. 7:5-9.

Goswami, A. K., Sharma, K. P., and Sehgal, K. L. 1970b. Chemical composition of bajra grains. 4. Indian varieties. Ind. J. Nutr. Diet. 7:67-70.

Goussault, B., and Adrian, J. 1977. The milling of *Pennisetum* millet and the value of the protein in the products. In: "Proceedings of a symposium on sorghum and millets for human food," (D. A. V. Dendy, ed.) p. 13-18. Tropical Products Institute, London.

Gurragossian, V., Chibber, B. A. K., Van Scoyoc, S., Jambunathan, R., Mertz, E. T., and Axtell, J. D. 1978. Characteristics of proteins from normal, high lysine, and high tannin sorghums. J. Agric. Food Chem. 26:219-223.

Gupta, D. N., Roy, M. K., Singh, J. N., Singhal, G. S., and Mehta, S. L. 1980. Changes in proteins and enzymes during grain development in pearl millet. Biochem. Physiol. Pflanz. 175:15-22. Chem. Abstract 92:72817.

Gupta, R. K., and Haslam, E. 1978. Plant proanthocyanidins. Part 5. Sorghum polyphenols. J. C. S. Perkin I. 892-896.

Hagerman, A. E., and Butler, L. G. 1978. Protein precipitation method for the quantitative determination of tannins. J. Agric. Food Chem. 26: 809-812.

Hahn, R. R. 1969. Dry milling of grain sorghum. Cereal Sci. Today 14:234-237.

Haikerwal, M., and Mathieson, A. R. 1971. The protein content and amino acid composition of sorghum grain. Cereal Chem. 48:690-699.

Hanh, P. P., and Rasper, V. 1974. The effect of nonstarchy polysaccharides from yam, sorghum, and millet flours on the rheological behavior of wheat doughs. Cereal Chem. 51:734-750.

Hansen, R. G. 1973. An index of food quality. Nutr. Rev. 31:1-7.

Harbers, L. H. 1975. Starch granule structural changes and amylolytic patterns in processed sorghum grain. J. Anim. Sci. 41:1496-1501.

Harbers, L. H., and Davis, A. B. 1974. Digestion of sorghum grain endosperm in the rat and pig observed by scanning electron microscopy. J. Anim. Sci. 39:1099-1105.

Harden, M. L., Stahland, R., Briley, M., and Yang, S. P. 1976. The nutritional quality of proteins in sorghum. J. Food Sci. 41:1082-1085.

Hariharan, K., Subramanyarajurs, T. S., Desai, B. L. M., Rao, S. V. Rajalakshmi, D., Swaminathan, M., and Parpia, H. A. B. 1965. Effect of supplementing poor Indian diets based on kaffir corn, pearl millet and maize with vitamins, minerals and fortified and unfortified groundnut flour on the nutritive value of the diets as judged by the growth of rats and on the protein efficiency ratio. J. Nutr. Diet. 2:196-201.

Harris, H. B., and Burns, R. E. 1970. Influence of tannin content on preharvest seed germination in sorghum. Agron. J. 62:835-836.

Harris, H. B., and Burns, R. E. 1973. Relationship between tannin content of sorghum grain and preharvest seed molding. Agron. J. 65:957-959.

Hart, M. R., Graham, R. P., Gee, M., and Morgan, A. I., Jr. 1970. Bread from sorghum and barley flours. J. Food Sci. 35:661-665.

Haslam, E. 1966. Chemistry of vegetable tannins. Academic Press, New York, NY.

Hemanalini, G., Umapathy, K. P., Rao, J. R., and Saraswathi, G. 1980. Nutritional evaluation of sprouted ragi. Nutr. Reports Int. 22: 271:277.

Heusdens, W., and King, J. G. 1962. Improvement of seed quality in sorghum. Sorghum Newsletter 5:70-71.

Hinman, D. D., and Johnson R. R. 1974a. Influence of processing methods on digestion of sorghum starch in high concentrate beef cattle rations. J. Anim. Sci. 39:417-422.

Hinman, D. D., and Johnson, R. R. 1974b. Influence of degree of micronization on the site and extent of sorghum starch digestion in beef cattle fed high concentrate rations. J. Anim. Sci. 39:958-963.

Hoff, J. E., and Singleton, K. I. 1977. A method for determination of tannins in foods by means of immobilized protein. J. Food Sci. 42:1566-1569.

Holmes, J. H., Drennan, M. J., and Garrett, W. N. 1970. Digestion of steam-processed milo by ruminants. J. Anim. Sci. 31:409-413.

Horan, F. E., and Heider, M. F. 1946. A study of sorghum and sorghum starches. Cereal Chem. 23:492-503.

Hoseney, R. C., Davis, A. B., and Harbers, L. H. 1974. Pericarp and endosperm structure of sorghum grain shown by scanning electron microscopy. Cereal Chem. 51:552-558.

Hoseney, R. C., and Varriano-Marston, E. 1980. Pearl millet: Its chemistry and utilization. p. 461-494. In: Cereals for foods and beverages. Ed. G. E. Inglett and Lars Munck. Academic Press, NY.

Hubbard, J. E., Hall, H. H., and Earle, F. R. 1950. Composition of the component parts of the sorghum kernel. Cereal Chem. 27:415-420.

Hulse, J. H., Laing, E., and Pearson, D. E. 1980. Sorghum and the Millets: Their composition and nutritive value. Academic Press: New York.

Ifon, E. T. 1980. Biological evaluation of the nutritive value of the millet porridge - a traditional Nigerian weaning food - before and after fortification with soya proteins. Nutr. Rep. Int. 22:109-116.

Ilori, J. O., and Conrad, J. H. 1976. The nutritive value of protein in selected sorghum lines as measured by rat performance. Nutr. Rep. Int. 13:307-314.

Indira, R., and Naik, M. S. 1971. Nutrient composition and protein quality of some minor millets. Indian J. Agric. Sci. 41:795-797.

Jambunathan, R., and Mertz, E. T. 1973. Relationship between tannin levels, rat growth, and distribution of proteins in sorghum. J. Agric. Food Chem. 21:692-696.

Jambunathan, R., Mertz, E. T., and Axtell, J. D. 1975. Fractionation of soluble proteins of high-lysine and normal sorghum grain. Cereal Chem. 52:119-121.

Jayatissa, P. M., Pathirana, R. A., and Sivayogasunderam, K. 1980. Malting quality of Sri Lankan varieties of sorghum. J. Inst. Brewing 86:18-20.

Jellum, M. D., and Powell, J. B. 1971. Fatty acid composition of oil from pearl millet seed. Agron. J. 63:29-33.

Jensen, A. H., Becker, D. E., and Harmon, B. G. 1965. Nutritional adequacy of milo for the finishing pig. J. Anim. Sci. 24:398-402.

Johari, R. P., Mehta, S. L., and Naik, M. S. 1977. Changes in protein fractions and leucine-(^{14}C) incorporation during sorghum grain development. Phytochem. 16:311-314.

Johnson, B. A., Rooney, L. W., and Khan, M. N. 1980. Tortilla - making characteristics of micronized sorghum and corn flours. J. Food Sci. 45:671-674.

Johnson, V. A., Schmidt, J. W., and Mattern, P. J. 1968. Cereal breeding for better protein impact. Econ. Botany 22:16-25.

Jones, R. W., and Beckwith, A. C. 1970. Proximate composition and proteins of three grain sorghum hybrids and their dry-mill fractions. J. Agr. Food Chem. 18:33-36.

Jones, R. W., Beckwith, A. C., Khoo, U., and Inglett, G. E. 1970. Protein composition of proso millet. J. Agric. Food Chem. 18:37-39.

Joseph, K., Kurien, P. P., Swaminathan, M., and Subrahmanyan, V. 1959. The metabolism of nitrogen, calcium and phosphorus in undernourished children. Brit. J. Nutr. 13:213-218.

Kaluza, W. Z., McGrath, R. M., Roberts, T. C., and Schroder, H. H. 1980. Separation of phenolics of *Sorghum bicolor* (L.) Moench grain. J. Agric. Food Chem. 28:1191-1196.

Kamath, M. V., and Belavady, B. 1980. Unavailable carbohydrates of commonly consumed Indian foods. J. Sci. Food Agric. 31:194-202.

Kapasi-Kakama, J. 1977. Some characteristics which influence the yield and quality of pearled sorghum grain. In: "Proceedings of a symposium on sorghum and millets for human food," D. A. V. Dendy ed., p. 21-26. Tropical Products Institute, London.

Kapustina, V. V., and Dudkin, M. S. 1972. Enzymatic hydrolysis of millet starch. Fermentnaia I. Spirtovaia Promyshlennost p. 34-36.

Karim, A., and Rooney, L. W. 1972a. Pentosans in sorghum grain. J. Food Sci. 37:365-368.

Karim, A., and Rooney, L. W. 1972b. Characterization of pentosans in sorghum grain. J. Food Sci. 37:369-371.

Karper, R. E., and Quinby, J. R. 1963. Sugary endosperm in sorghum. J. Heredity 54:121-126.

Kersting, J. F., Pauli, A. W., and Stickler, F. C. 1961. Grain sorghum caryopsis development. II. Changes in chemical composition Agron. J. 53:74-77.

Khan, M. N., Rooney, L. W., Rosenow, D. T., and Miller, F. R. 1980. Sorghums with improved tortilla making characteristics. J. Food Sci. 45:720-725.

Khangura, B. S., Gill, K. S., and Phul, P. S. 1980. Combining ability analysis of beta-carotene, total carotenoids and other grain characteristics in pearl millet. Theor. Appl. Genetics 56:91-96. Chem. Abstract 92:91080.

Kies, C., Fox, H. M., and Nelson, L. 1975. Triticale, soy-TVP and millet based diets as protein suppliers for human adults. J. Food Sci. 40:90-93.

Kneen, E. 1945. Sorghum amylase. Cereal Chem. 22:112-134.

Knox, G., Heller, V. G., and Sieglinger, J. B. 1944. Riboflavin, niacin, and pantothenic acid contents of grain sorghums. Food Res. 9:89-90.

Kumar, P. M. Harish, Virupaksha, Tumkur K., and Vithayathil, P. J. 1978. Sorghum proteinase inhibitors: Purification and some biochemical properties. Int. J. Peptide Protein Res. 12:185-196.

Kumar, P. M. Harish, Virupaksha, Tumkur K., and Vithayathil, P. J. 1979. Sorghum proteinase inhibitors. 2. Mode of interaction with serine proteinases. Int. J. Peptide Protein Res. 13:153-160.

Kurien, P. P. 1967. Nutritive value of refined ragi (*Eleusine coracana*) flour I. J. Nutr. Diet. 4:96-101.

Kurien, P. P., and Desikachar, H. S. R. 1966. Preparation of a refined white flour from ragi (*Eleusine coracana*) using a laboratory mill. J. Food. Sci. Technol. 3:56-58.

Kurien, P. P., and Doraiswamy, T. R. 1967. Nutritive value of refined ragi (*Eleusine coracana*) flour-II. J. Nutr. Diet. 4:102-109.

Kurien, P. P., Joseph, K., Swaminathan, M., and Subrahmanyan, V. 1959. The distribution of nitrogen, calcium and phosphorus between the husk and endosperm of ragi (*Eleusine coracana*). Food Science 8: 353-355.

Kurien, P. P., Narayanarao, M., Swaminathan, M., and Subrahmanyan, V. 1960. The metabolism of nitrogen, calcium and phosphorus in undernourished children. 6. The effect of partial or complete replacement of rice in poor vegetarian diets by kaffir corn (*Sorghum vulgare*). Brit. J. Nutr. 14:339-345.

Kurien, P. P., Swaminathan, M., and Subrahmanyan, V. 1961. The metabolism of nitrogen, calcium and phosphorus in undernourished children. Brit. J. Nutr. 15:345-347.

Lai, C. C., and Varriano-Marston, E. 1980a. Lipid content and fatty acid composition of free and bound lipids in pearl millets. Cereal Chem. 57:271-274.

Lai, C. C., and Varriano-Marston, E. 1980b. Changes in pearl millet meal during storage. Cereal Chem. 57:275-277.

Landry, J., and Moureaux, T. 1970. Heterogenite des glutelines du grain de mais: Extraction selective et composition en acides amines des trios fractions isolees. Bull. Soc. Chim. Biol. 52:1021-1027.

Leach, H. W., McCowen, L. D., and Schoch, T. J. 1959. Structure of the starch granule. I. Swelling and solubility patterns of various starches. Cereal Chem. 36:534-544.

Liang, Y. T., Morrill, J. L. Anstaett, F. R., Dayton, A. D., and Pfost, H. B. 1969. Effect of pressure, moisture, and cooking time on susceptibility of corn or sorghum grain starch to enzymatic attack. J. Dairy Sci. 53:336-341.

Lichtenwalner, R. E., Ellis, E. B., and Rooney, L. W. 1978. Effect of incremental dosages of the waxy gene of sorghum on digestibility. J. Anim. Sci. 46:1113-1119.

Lin, P. S., and Pi, C. P. 1964. The inheritance of amylose content in grain sorghum. Sorghum Newsletter 7:5-6.

Lindemann, E. 1951. Über die verschiedenen Sorghumvarietäten and die Eigenschaften der daraus gewinnbaren Stärken. Die Stärke 3:55-58.

Lineback, D. R., and Ponpipom, S. 1977. Effects of germination of wheat, oats, and pearl millet on alpha-amylase activity and starch degradation. Die Stärke 29:52-60.

Lorenz, K., and Dilsaver, W. 1980. Rheological properties and food applications of proso millet flours. Cereal Chem. 57:21-24.

Lorenz, K., Dilsaver, W., and Bates L. 1980. Proso millets. Milling characteristics, proximate compositions, nutritive value of flours. Cereal Chem. 57:16-20.

Lorenz, K., and Hinze, G. 1976. Functional characteristics of starches from proso and foxtail millets. J. Agric. Food Chem. 24:911-914.

Luce, W. G., Peo, E. R., Jr., and Hudman, D. B. 1967. Availability of niacin in corn and milo for swine. J. Anim. Sci. 26:76-84.

MacLean, W. C., Jr., and Graham, G. G. 1980. Evaluation of the protein quality and digestibility of sorghum in the diet of infants: supplementary report. p. 1-6. Progress Report--March 19, 1980. Research Contract AID/ta-C-1286.

MacMasters, M.M., and Hilbert, G. E. 1944. Glutinous corn and sorghum starches. Industrial Eng. Chem. 36(10):958-963.

Mahadevappa, V. G., and Raina, P. L. 1978. Sterol lipids in finger millet (*Eleusine coracana*). J. Am. Oil Chemists' Soc. 55:647-648.

Maki, Z., and Tashiro, M. 1978. Component polypeptides of alcohol-soluble protein from millet. Kyoto-furitsu Daigaku Gakujutsu Hokoku Rigaku Seikatsu Kagaku 29:21-25. Chem. Abstract 90:199165.

Maki, Z., and Tashiro, M. 1979. Polypeptide composition of foxtail millet prolamin. Eiyo to Shokuryo 32:317-320. Chem. Abstract 92:36302.

Malleshi, N. G., and Desikachar, H. S. R. 1979. Malting quality of new varieties of ragi (*Eleusine coracana*). J. Food Sci. Technol. 16(4):149-150.

Mangay, A. S., Pearson, W. N., and Darby, W. J. 1957. Millet (*Setaria Italica*): Its amino acid and niacin content and supplementary nutritive value for corn (maize). J. Nutr. 62:377-393.

Maxson, E. D., Fryar, W. B., Rooney, L. W., and Krishnaprasad, M. N. 1971. Milling properties of sorghum grain with different proportions of corneous to floury endosperm. Cereal Chem. 48:478-490.

Maxson, E. D., and Rooney, L. W. 1972. Evaluation of methods for tannin analysis in sorghum grain. Cereal Chem. 49:719-729.

Maxson, E. D., Rooney, L. W., Lewis, R. W., Clark, L. E., and Johnson, J. W. 1973. The relationship between tannin content, enzyme inhibition, rat performance, and characteristics of sorghum grain. Nutr. Rep. Int. 8:145-152.

McCance, R. A., and Widdowson, E. M. 1942. Mineral metabolism of healthy adults on white and brown bread dietaries. J. Physiol. 101:44-85.

McCollough, R. L. 1970. Feedlot comparisons and digestibility of four hybrid grain sorghums for beef cattle fed all-concentrate rations. M.S. Thesis, Kansas State University.

McCollough, R. L. 1973. Comparison of digestibility and feedlot performance of hybrid sorghum grains and corn fed to steers. Ph.D. Thesis, Kansas State University.

McGinty, D. D. 1968. Factors affecting the digestibility of varieties of sorghum grains by cattle. Ph.D. Thesis, Texas A & M University.

McMillian, W. W., Wiseman, B. R. Burns, R. E., Harris, H. B., and Greene, G. L. 1972. Bird resistance in diverse germplasm of sorghum. Agron. J. 64:821-822.

McNeil, J. W., Potter, G. D., Riggs, J. K., and Rooney, L. W. 1975. Chemical and physical properties of processed sorghum grain carbohydrates. J. Anim. Sci. 40:335-341.

Mejbaum-Kalzenellenbogen, W., and Kudrewicz-Hubica, Z. 1966. Application of urea, ferric ammonium sulfate and casein for determination of tanning substances in plants. Acta Biochem. Pol. 13:57 (original not seen, cited by Maxson and Rooney, 1972).

Mertz, E. T. 1975. Breeding for improved nutritional value in cereals. In: "Protein nutritional quality in foods and feeds," (M. Friedman, ed.), Part II. p. 1-12. Marcel Dekker, New York.

Miche, J. C. 1980. Comparison between two sorghum milling systems. ICC Symposium on sorghum and millet for human food. Vienna.

Miller, B. S., and Kneen, E. 1947. The amylase inhibitor of Leoti sorghum. Arch. Biochem. 15:251-264.

Miller, D. F. 1958. Composition of cereal grains and forages. Publication 585, National Academy of Sciences, NRC, Wash., D.C.

Miller, G. D., Deyoe, C. W., Walter, T. L., and Smith, F. W. 1964. Variations in protein levels in Kansas sorghum grain. Agron. J. 56:302-304.

Miller, O. H., and Burns, E. E. 1970. Starch characteristics of selected grain sorghums as related to human foods. J. Food Sci. 35:666-668.

Mohan, D. P., and Axtell, J. D. 1975. Proceeding of the Ninth Biannual Grain Sorghum Research and Utilization Conference, Lubbock, Texas.

Morton, J. F. 1970. Tentative correlations of plant usage and esophageal cancer zones. Econ. Bot. 24:217-226.

Monawar, L. Y. 1980. Personal Communication.

Narayamurti, D., and Aiyar, C. V. R. 1930. Vegetable proteins. II. Typhoidin--the alcohol soluble proteins of Pennisetum typhoideum. J. Indian Chem. Soc. 7:945-952.

Narayanaswamy, D., Desai, B. L. M., Daniel, V. A., Kurien, S., Swaminathan, M., and Parpia, H. A. B. 1970. Improvement of protein value of poor kaffir corn (*Sorghum vulgare*) diet by supplementation with limiting amino acids. Nutr. Rep. Int. 1:297-303.

Nawar, I. A., and Clark, H. E. 1970. Protein quality of selected lines of *sorghum vulgare* for the growing rat. Nutr. Rep. Int. 1:75-81.

Nechaev, A. P., Busareva, N. N., Denisenko, Y. I., and Kuznetsov, D. I. 1973. Changes in the fatty acid composition of millet lipids during storage. Prikl. Biokhim. Mikrob. 9:733-736.

Neihaus, M. H., and Schmidt, W. H. 1970. Evaluation of bird resistant grain sorghum in Ohio. Agron. J. 62:677-678.

Nelson, L. R., and Cummins, D. G. 1975. Effects of tannin content and temperature on storage of propionic acid treated grain sorghum. Agron. J. 67:71-73.

Nelson, T. S., Stephenson, E. L., Burgos, A., Floyd, J., and York, J. O. 1975. Effect of tannin content and dry matter digestion on energy utilization and average amino acid availability of hybrid sorghum grains. Poult. Sci. 54:1620-1623.

Neucere, N. J., and Sumrell, G. 1979. Protein fractions from five varieties of grain sorghum: Amino acid composition and solubility properties. J. Agric. Food Chem. 27:809-812.

Neucere, N. J., and Sumrell, G. 1980. Chemical composition of different varieties of grain sorghum. J. Agric. Food Chem. 28:19-21.

Newton, R. J., Baltuskonis, D. A., Goeschl, J. D., Meckenstock, D. H., and Miller, F. R. 1980. Distribution and transformation of soluble carbohydrates during germination growth of sorghum. Crop Sci. 20: 265-268.

Nip, W. K., and Burns, E. E. 1969. Pigment characterization in grain sorghum. I. Red varieties. Cereal Chem. 46:490-495.

Nip, W. K., and Burns, E. E. 1971. Pigment characterization in grain sorghum. II. White varieties. Cereal Chem. 48:74-80.

Noland, P. R., Campbell, Dr. R., Sharp, R. N., and Johnson, Z. B. 1977. Influence of pericarp and endosperm color and type on digestibility of grain sorghum by pigs. Animal Feed Sci. Tech. 2:219-224.

Nordin, P. 1959. Sorghum grain. The soluble sugars. Trans. Kansas Academy of Sci. 62:212-215.

Nordin, P., and Kim, Y. S. 1960. The reaction of amylases with starch granules. J. Amer. Chem. Soc. 82:4604-4607.

Normand, F. L., Hogan, J. T., and Deobald, H. J. 1965. Protein content of successive peripheral layers milled from wheat, barley, grain sorghum, and glutinous rice by tangential abrasion. Cereal Chem. 42:359-567.

Norris, J. R., and Rooney, L. W. 1970. Wet-milling properties of four sorghum parents and their hybrids. Cereal Chem. 47:64-69.

Novellie, L. 1959. Kaffircorn malting and brewing studies. III. Determination of amylases in kaffircorn malts. J. Sci. Food Agric. 10:441-449.

Novellie, L. 1960a. Kaffircorn malting and brewing studies. IV. The extraction and nature of the insoluble amylases of kaffircorn malts. J. Sci. Food Agric. 11:408-421.

Novellie, L. 1960b. Kaffircorn malting and brewing studies. V. Occurrence of β-amylase in kaffircorn malts. J. Sci. Food Agric. 11:457-463.

Novellie, L. 1962a. Kaffircorn malting and brewing studies. XI. Effect of malting conditions on malting losses and total amylase activity. J. Sci. Food Agric. 13:121-126.

Nwasike, C. C., Mertz, E. T., Pickett, R. C., Glover, D. V., Chibber, B. A. K., and Van Scoyoc, S. W. 1979. Lysine level in solvent fractions of pearl millet. J. Agric. Food Chem. 27:1329-1331.

Oberleas, D., and Prasad, A. S. 1970. The effect of zinc deficiency on growth and utilization of phytate containing proteins. Trace Element Metabolism in Animals, pp. 170-3. Mills, C. F. (ed.). E. and S. Livingstone, Edinburgh and London.

Obizoba, I. C. 1979. Utilization of sorghum, wheat, and navy beans by human adults: mineral and vitamin metabolism. Nutr. Rep. Int. 20: 777-786.

Obizoba, I. C., Ezekwe, M. O., and Akaigwe, B. N. 1979. Utilization of sorghum, wheat, and navy beans by human adults: Protein metabolism. Nutr. Rep. Int. 20:291-301.

Oh, H. I., and Hoff, J. E. 1979. Fractionation of grape tannins by affinity chromatography and partial characterization of the frac. tions. J. Food Sci. 44:87-89, 96.

Oh, H. I., Hoff, J. E., Armstrong, G. S., and Haff, L. A. 1980. Hydrophobic interaction in tannin protein complexes. J. Agric. Food Chem. 28: 394-398.

Oke, O. L. 1977. The potential of millet and sorghum as food in Nigeria. In: "Proceedings of a symposium on sorghum and millets for human food," (D. A. V. Dendy, ed.), p. 121-124. Tropical Products Institute, London.

Olifson, L. E., Pavlova, M.M ., Svistunova, L. V. 1979. Composition of millet lipids, Izv. Vyssh. Uchebn. Zaved,. Pishch. Tekhnol. 6: 109-111 Chem. Abs. 92:127202 (1980).

Oomah, B. D., Reichert, R. D., and Youngs, C. G. 1980. Development and testing of a small-sample tangential abrasive dehulling device (TADD). Cereal Chem. In Press.

Osman, H. F., Theurer, B., Hale, W. H., and Mehen, S. M. 1970. Influence of grain processing on in vitro enzymatic starch digestion of barley and sorghum grain. J. Nutr. 100:1133-1139.

Otterbacker, T. J., and Kite, F. E. 1958. The milo starches. Bakers Dig. 32(5):44-48.

Palmer, G. H. 1972. Morphology of starch granules in cereal grains and malts. J. Inst. Brew. 78:326-332.

Palmer, M. A., and Bowden, B. N. 1975a. The pentatcyclic triterpene esters and the free, esterified and glycosylated sterols of *Sorghum vulgare* grain. Phytochem. 14:1813-1815.

Palmer, M. A., and Bowden, B. N. 1975b. The sterols and triterpenes of *Sorghum vulgare* grains. Phytochem. 14:2049-2053.

Palmer, M. A., and Bowden, B. N. 1977. Variations in sterol and triterpene contents of developing *Sorghum bicolor* grains. Phytochem. 16:459-463.

Paramahans, S. V., and Tharanathan, R. N. 1980. Carbohydrate composition of the millet varagu. Die Starke 32:73-76.

Paul, Y., Sharma, B. N., and Bhatia, I. S. 1972. Note on lipids in sorghum. Indian J. Agric. Sci. 42:435-436.

Paulis, J. W., James, C., and Wall, J. S. 1969. Comparison of glutelin proteins in normal and high-lysine corn endosperms. J. Agric. Food Chem. 17:1301-1305.

Paulis, J. W., and Wall, J. S. 1979. Distribution and electrophoretic properties of alcohol-soluble proteins in normal and high-lysine sorghums. Cereal Chem. 56:20-23.

Pavlova, M. M., and Olifson, L. E. 1979. Activity of lipase in millet seeds. Prikl. Biokhim. Mikrobiol. 15:469-472 (Russ). Chem. Abs. 91:52748.

Perten, H. 1977. Specific characteristics of millet and sorghum milling. In: "Proceedings of a symposium on sorghum and millets for human food," D. A. V. Dendy ed., p. 47-52. Tropical Products Institute, London.

Pinta, M., and Busson, F. 1963. Chemical study on sorghum and African millet (mineral elements and minor elements). Ann. Nutr. Aliment. 17:103-126.

Pomeranz, Y. 1975. In: "Protein nutritional quality of foods and feeds," (M. Friedman, ed.), Part II, p. 13-78. Marcel Dekker, New York.

Pond, W. G., Hillier, J. C., and Benton, D. A. 1958. The amino acid adequacy of milo for the growth of rats. J. Nutr. 65:493-502.

Pore, M. S., and Magar, N. G. 1979. Nutrient composition of hybrid varieties of fingermillet. Indian J. Agric. Sci. 49:526-531.

Potter, D. K., and Fuller, H. L. 1968. Metabolic fate of dietary tannins in chickens. J. Nutr. 96:187-191.

Prasada Rao, K. E., and Murty, D. S. 1979. A basmati (scented) sorghum from Madhya Pradesh. Current Science 48:824-825.

Price, M. L., and Butler, L. G. 1977. Rapid visual estimation and spectrophotometric determination of tannin content of sorghum grain. J. Agric. Food Chem. 25:1268-1273.

Price, M. L., and Butler, L. G. 1978. Detoxification of high tannin sorghum grain. Nutr. Rep. Int. 17:229-235.

Price, M. L., Hagerman, A. E., and Butler, L. G. 1980. Tannin in sorghum grain: Effect of cooking on chemical assays and on anti-nutritional properties in rats. Nutr. Rep. Int. 21:761-767.

Price, M. L., Stromberg, A. M., and Butler, L. G. 1979. Tannin content as a function of grain maturity and drying conditions in several varieties of *Sorghum bicolor* (L.) Moench. J. Agric. Food Chem. 27:1270-1273.

Price, M. L., Van Scoyoc, S., and Butler, L. G. 1978. A critical evaluation of the vanillin reaction as an assay for tannin in sorghum grain. J. Agric. Food Chem. 26:1214-1218.

Price, P. B. 1975. Lipids of seven cereal grains. J. Amer. Oil Chem. Soc. 52:490-493.

Pruthi, T. D., and Bhatia, I. S. 1970. Lipids in cereals. I. *Pennisetum typhoideum*. J. Sci. Food Agric. 21:419-422.

Pushpamma, P., and Devi, C. A. 1979. Nutritional quality of sorghum and legume based food mixtures for infants and pre-school children. I. Nutr. Rep. Int. 19:635-641.

Pushpamma, S., Parrish, D. B., and Deyoe, C. W. 1972. Improving protein quality of millet, sorghum, and maize diets by supplementation. Nutr. Rep. Int. 5:93-101.

Pushpamma, P., and Reddy, M. U. 1979. Physico chemical changes in rice and jowar stored in different agro-climatic regions of Andhra Pradesh. Bull. Grain Tech. 17(2):97-108.

Pushpamma, P., Ratnakumari, A., and Geervani, P. 1979. Nutritional quality of sorghum and legume based food mixture for infants and pre-school children-II. Nutr. Rep. Int. 19:643-649.

Rabson, R., Hanna, W. W., Burton, G. W., and Axmann, H. 1979. Potential for improving the protein content of pearl millet grain using induced mutations. Seed Protein Improv. Cereals Grain Legumes, Proc. Int. Symp. 2:367-376, IAEA: Vienna, Austria.

Rachie, K. O. 1969. Sorghum grain: Its worldwide significance and potential. Cereal Sci. Today 14:271-276.

Rachie, K. O. 1975. The millets: Importance, Utilization and Outlook. Tech. Bull., 63p. International Crops Research Institute for the Semi-Arid Tropics, Hyderbad, India.

Rachie, K. O., and Peters, L. V. 1977. The eleusines, International Crops Research Institute for the Semi-arid Tropics, Hyderabad, India.

Radhakrishnan, M. R., and Sivaprasad, J. 1980. Tannin content of sorghum varieties and their role in iron bioavailability. J. Agric. Food Chem. 28:55-57.

Raghavendra Rao, S. N., and Desikachar, H. S. R. 1964. Pearling as a method of refining jowar and wheat and its effect on their chemical composition. J. Food Sci. Technol. 1:40-42.

Raghuramulu, N., Narasinga Rao, B. S., and Gopalan, C. 1965. Amino acid imbalance and tryptophan-niacin metabolism. I. Effect of excess leucine on the urinary excretion of tryptophan-niacin metabolities in rats. J. Nutr. 86:100-106.

Rahman, M. F. 1972. An evaluation of peeling bird resistant sorghum grains. M. S. Thesis, Kansas State University.

Rakhimbaev, I. 1968a. Amylose and amylopect in composition of millet starch. Prikl. Biokim. Mikrob. 4:125-127.

Rakhimbaev, I. 1968b. Composition of sugars in millet grain. Prikl. Biokim. Mikrob. 4:227-229.

Ramachandra, G., Virupaksha, T. K., and Shadaksharaswamy, M. 1977. Relationship between tannin levels and in vitro protein digestibility in finger millet (*Eleusine coracana* Gaertn.). J. Agric. Food Chem. 25:1101-1104.

Rao, S. Venkat, Swaminathan, M., and Parpia, H. A. B. 1964. Mutual supplementation of dietary proteins for meeting protein needs and overcoming protein shortage in developing countries. J. Nutr. Diet. 1:128-137.

Rasper, V. F. 1977. Palyi's compact system for debranning of sorghum and millet. In: "Proceedings of a symposium on sorghum and millets for human food," p. 59-68. Tropical Products Institute, London.

Reddy, Geervani. 1978. Home Science College, Hyderabad, India. Personal communication.

Reder, R. 1933. A method of vitamin assay and its application in a study of the vitamin B and G content of mung beans and the grain sorghums. Proc. Oklahoma Acad. Sci. 14:50-52.

Reichert, R. D. 1979. The pH-sensitive pigments in pearl millet. Cereal Chem. 56:291-294.

Reichert, R. D., Fleming, S. E., and Schwab, D. J. 1980. Tannin reduction and nutritional improvement of sorghum by anaerobic storage of water-, HCl-, or NaOH-treated grain. J. Agric. Food Chem. 28:824-829.

Reichert, R. D., and Youngs, C. G. 1976. Dehulling cereal grains and grain legumes for developing countries. I. Quantitative comparison between attrition- and abrasive-type mills. Cereal Chem. 53:829-839.

Reichert, R. D., and Youngs, C. G. 1977. Dehulling cereal grains and grain legumes for developing countries. II. Chemical composition of mechanically and traditionally dehulled sorghum and millet. Cereal Chem. 54:174-178.

Reichert, R. D., and Youngs, C. G. 1979. Bleaching effect of acid on pearl millet. Cereal Chem. 56:287-290.

Reiners, R. A., Hummel, J. B., Pressick, J. C., and Morgan, R. E. 1973. Composition of feed products from the wet-milling of grain sorghum. Cereal Sci. Today 18:378, 379, 383.

Ribéreau-Gayon, P. 1972. Plant Phenolics. Oliver and Boyd, Edinburgh, England.

Riggs, J. K., Sorenson, J. W., Jr., Adame, J. L., and Schake, L. M. 1965. Popped sorghum grain for finishing beef cattle. J. Anim. Sci. 30:634-638.

Rizley, N. F., and Suter, D. A. 1977. Sorghum tortillas: process and product attributes. J. Food Sci. 42:1435-1438.

Roofayel, R. L. 1967. A note on prediction of starch content in sorghum grain. Queensland J. Agric. Anim. Sci. 24:365-368.

Rooney, L. W. 1973. A review of the physical properties, composition and structure of sorghum grain as related to utilization. In Symposium Proceedings: Industrial uses of cereals. Y. Pomeranz, ed., American Association of Cereal Chemists, St. Paul, Minn., Chapter 9, p. 316-342.

Rooney, L. W. 1978. Sorghum and pearl millet lipids. Cereal Chem. 55:584-590.

Rooney, L. W., and Clark, L. E. 1968. The chemistry and processing of sorghum grain. Cereal Sci. Today 13:258-261, 264, 265, 285, 286.

Rooney, L. W., Fryar, W. B., and Cater, C. M. 1972. Protein and amino acid contents of successive layers removed by abrasive milling of sorghum grain. Cereal Chem. 49:399-406.

Rooney, L. W., Khan, M. N., and Earp, C. F. 1980. The technology of sorghum products. p. 513-554. In: Cereals for food and beverages. ed. Inglett and Munck. Academic Press. New York.

Rooney, L. W., and Sullins, R. D. 1969. A laboratory method for milling small samples of sorghum grain. Cereal Chem. 46:486-490.

Rooney, L. W., and Sullins, R. D. 1977. The structure of sorghum and its relation to processing and nutritional value. In: "Proceedings of a symposium on sorghum and millets for human food," (D. A. V. Dendy, ed.) p. 91-109. Tropical Products Institute, London.

Rostagno, H. S., Featherston, W. R., and Rogler, J. C. 1973a. Studies on the nutritional value of sorghum grains of varying tannin contents for chicks. Poult. Sci. 52:765-772.

Rostagno, H. S., Rogler, J. C., and Featherston, W. R. 1973b. Studies on the nutritional value of sorghum grains with varying tannin contents for chicks. 2. Amino acid digestibility studies. Poult. Sci. 52:772-778.

Runte, R. 1979. Personal communication.

Rusnak, B. A., Chou, C. L., and Rooney, L. W. 1980. Effect of micronizing on kernel characteristics of sorghum varieties with different endosperm type. J. Food Sci. 45:1529-1532.

Saba, J. J., Hale, W. H., and Theurer, B. 1972. In vitro rumen fermentation studies with a bird resistant sorghum grain. J. Anim. Sci. 35:1076-1082.

Sanders, E. H. 1955. Developmental morphology of the kernel in grain sorghum. Cereal Chem. 32:12-25.

Sarkar, S. K., and Howarth, R. E. 1976. Specificity of the vanillin test for flavanols. J. Agric. Food Chem. 24:317-320.

Sastry, L. V. S., and Virupaksha, T. K. 1969. Alcohol-soluble proteins of grain sorghum. Cereal Chem. 46:284-293.

Sawhney, S. K., and Naik, M. S. 1969. Amino acid composition of protein fractions of pearl millet and the effect of nitrogen fertilization on its proteins. Ind. J. Genetics Plant Breeding 29;395-406.

Schaffert, R. E., Lechtenberg, V. L., Oswalt, D. L., Axtell, J. D., Pickett, R. C., and Rhykerd, C. L. 1974. Effect of tannin on in vitro dry matter and protein disappearance in sorghum grain. Crop Sci. 14:640-643.

Schwarz, K., and Mertz, W. 1957. A glucose tolerance factor and its differentiation from factor 3. Arch. Biochem. Biophys. 72:515-518.

Seckinger, H. L., and Wolf, M. J. 1973. Sorghum protein ultrastructure as it relates to composition. Cereal Chem. 50:455-465.

Seit-Ablaeva, S. K., Nachaev, A. P., Denisenko, Y. I., and Yanotovskii, M. P. 1973. Tocopherols of millet and huskless-millet lipids and change in tocopherol content during grain storage. Prikl. Biokhim. Mikrobiol. 9:737-739.

Sietz, L. M. 1977. Composition of sorghum grain wax. Abst. 109. Cereal Foods World 22:472.

Shah, H. C., and Mehta, B. V. 1959. Magnesium-phosphorus-crude fat inter-relationships in the seed of pearl millet (*Pennisetum typhoideum* - Rich). Soil Sci. 87:320-324.

Sharma, K. P., and Bhatia, I. S. 1979. Composition of fructosyl oligomers isolated from ripening grains of *Sorghum vulgare*. India J. Biochem. Biophys. 16:38-40.

Sharma, K. P., and Bhatia, I. S. 1980. Sucrose metabolism in *Sorghum vulgare* at ripening. Physiol. Plant. 48:470-475.

Sharma, K. P., and Goswami, A. K. 1969. Chemical constants of lipid content of high yielding varieties and hybrids of Bajra (*Pennisetum typhoideum*) flour. J. Nutr. Diet. 6:316-318.

Sharp, R. N., Sharp, C. Q., and Kattan, A. A. 1978. Tannin content of sorghum grain by UV spectrophotometry. Cereal Chem. 55:117-118.

Sheorain, V. S., and Walge, D. S. 1973. Beta-amylase activity in germinated bajra and barley varieties. J. Food Sci. Technol. 10: 184-186.

Shepherd, A. D. 1979. Laboratory abrasive decorticating mill for small grains. Cereal Chem. 56:517-519.

Shoup, F. K., Deyoe, C. W., Campbell, J., and Parrish, D. B. 1969. Amino acid composition and nutritional value of milled sorghum grain products. Cereal Chem. 46:164-171.

Shoup, F. K., Deyoe, C. W., Farrell, E. P., Hammond, D. L., and Miller, G. D. 1970. Sorghum grain dry milling. Food Tech. 24:1028-1032.

Sikka, K. C., and Johari, R. P. 1979. Comparative nutritive value and amino acid content of different varieties of sorghum and effect of lysine fortification. J. Agric. Food Chem. 27:962-965.

Simmonds, D. H. 1974. Chemical basis of hardness and vitreosity in the wheat kernel. Bakers Digest 48(5):16-29.

Singh, R., and Axtell, J. D. 1973. High lysine mutant gene (hl) that improves protein quality and biological value of grain sorghum. Crop Sci. 13:535-539.

Singh, S. P. 1976. Modified vitreous endosperm recombinants from crosses of normal and high lysine sorghum. Crop Sci. 16:296-297.

Singleton, V. L., and Kratzer, F. H. 1973. Plant phenolics in toxicants occurring naturally in foods (2nd ed.). U. S. National Academy of Sciences, Washington, D. C.

Sisodia, B. S., Apte, B. G., and Solankey, B. S. 1979. Note on the tannin, protein and starch contents of some sorghum varieties. Indian J. Agric. Sci. 49:135-136.

Skoch, L. W., Deyoe, C. W., Shoup, F. W., Bathurst, J., and Liang, D. 1970. Protein fractionation of sorghum grain. Cereal Chem. 47: 472-481.

Shovron, J., and Lorenz, K. 1979. Enzymatic activities in proso millets. Cereal Chem. 56:559-562.

Smith, M. C. 1930. A quantitative comparison of the vitamin A content of yellow corn and the grain sorghums hegari and yellow milo. J. Agri. Res. 40:1147.

Srikantia, S. G. 1978. Endemic pellagra among jowar eaters. Indian J. Med. Res. 68(suppl):38-47.

Stickley, E. S. 1973. Sorghum products - current situation. AACC Symposium: Unique ingredients--Cereal flours. Feb. 1973, St. Louis, MO.

Stringfellow, A. C., and Peplinski, A. J. 1966. Air classification of sorghum flours from varieties representing different hardnesses. Cereal Sci. Today 11:438-455.

Strumeyer, D. H., and Malin, M. J. 1969. Identification of the amylase inhibitor from seeds of Leoti sorghum. Biochim. Biophys. Acta 184:643-645.

Strumeyer, D. H., and Malin, M. J. 1975. Condensed tannins in grain sorghum: Isolation, fractionation, and characterization. J. Agric. Food Chem. 23:909-914.

Subba Rao, G. N., Bains, G. S., Bhatia, D. S., and Subrahmanyan V. 1953. Processing of millets and cereals (other than rice) into rice substitutes. Trans. AACC 11:167-171.

Subramanian, V., and Jambunathan, R. 1980. Traditional methods of processing of sorghum (*Sorghum bicolor*) and pearl millet (*Pennisetum americanum*) grain in India. ICC Symposium on sorghum and millet for human food. Vienna.

Subramanian, V., Jambunathan, R., and Suryaprakash, S. 1980. Note on the soluble sugars of Sorghum. Cereal Chem. 57:440-441.

Subramanian, V., Jambunathan, R., and Suryaprakash, S. 1980. Sugars of pearl millet (*Pennisetum Americanum* (L.) Leeke), J. Food Sci. submitted.

Sullins, R. D., and Rooney, L. W. 1974. Microscopic evaluation of the digestibility of sorghum lines that differ in endosperm characteristics. Cereal Chem. 51:134-142.

Sullins, R. D., and Rooney, L. W. 1977. Pericarp and endosperm structure of pearl millet *Pennisetum typhoides*. In: "Proceedings of a symposium on sorghum and millet for human food," (D. A. V. Dendy, ed.), p. 79-89. Tropical Products Institute, London.

Swanson, A. F. 1928. Seed-coat structure and inheritance of seed color in sorghums. J. Agric. Res. 37:577-588.

Taira, H. 1968. Amino acid composition of different varieties of foxtail millet (*Setaria italica*). J. Agric. Food Chem. 16:102501027.

Takahashi, R., Chokki, S., Maekawa, A., Suzuki, T., Matsumoto, S., and Obara, T. 1978. Nutritive values in rats of the Italian millet protein concentrate prepared by α- and β-amylase treatment. Eiyo to Shokuryo 31:491-496. Chem. Abstract 91:209645.

Talwalkar, R. T., and Patel, S. M. 1970. Biological evaluation of proteins of ambadi (*Habiscus cannabinus*) and methi (*Trigonella foenumgraecum*) and their supplementary effect on jowar (*Sorghum vulgare*). Ind. J. Nutr. Diet. 7:13-16.

Tanner, F. W., Jr., Pfeiffer, S. E., and Curtis, J. J. 1947. B-complex vitamins in grain sorghums. Cereal Chem. 24:268-274.

Tashiro, M., and Maki, Z. 1979. Nutritive value of foxtail millet protein. Eiyo to Shokuryo 32:299-304. Chem. Abstract 92:57026.

Tharanathan, R. N., Paramahans, S. V., and Wankhede, D. B. 1980. Amylolytic susceptiblity of native groundnut and ragi starch granules as viewed by scanning electron microscopy. Die Stärke 32:158-161.

Thiam, A. A. 1980. Pilot plant production of weaning foods based on millet flour, groundnut flour, skim milk powder, full-fat soy flour and fortified with methionine, lysine and certain vitamins and minerals. Comparative feed efficiency ratio of Bal Amul, and these weaning foods. ICC Symposium on Sorghum and millet for human food. Vienna.

Thiam, A. A., Drapron, R., and Richard-Molard, D. 1976. Causes d' alteration des farines de mil et de sorgh. Ann. Technol. Agric. 25:253-271.

Tipton, K. W., Floyd, E. H., Marshall, J. G., and McDevitt, J. B. 1970. Resistance of certain grain sorghum hybrids to brid damage in Louisiana. Agron. J. 62:211-213.

Tovar, D., Liang, G. H., and Cunningham, B. A. 1977. Effect of the waxy gene on hydrolysis of sorghum starch. Crop Sci. 17:683-686.

Vaghefi, S. B., Makdani, D. D., and Mickelsen, O. 1974. Lysine supplementation of wheat protein. A review. Amer. J. Clinical Nutr. 27:1231-1246.

van der Maesen, L. J. G. 1978. Genetic resources at ICRISAT. International Crop Research Institute for the Semi-Arid Tropics, Hyderabad, India.

Van Sumere, C. F., Albrecht, J., Dedonder, A., De Pooter, H., and Pé, Irma. 1975. Plant proteins and phenolics. In: The chemistry and biochemistry of plant proteins. ed. Harborne, J. B. and Van Sumere, C. F. Academic Press., N.Y.

Varriano-Marston, E., and Hoseney, R. C. 1980. Note on mineral content and location in pearl millet. Cereal Chem. 57:150-152.

Viraktamath, C. S., Raghavendra, G., and Desikachar, H. S. R. 1971. Use of rice milling machinery for commercial pearling of grain sorghum (jowar) and culinary uses for pearled sorghum products. J. Food Sci. Technol. 8:11-13.

Viraktamath, C . S., Raghavendra, G., and Desikachar, H. S. R. 1972. Varietal differences in chemical composition, physical properties and culinary qualities of some recently developed sorghum strains. J. Food. Sci. Technol. 9:73-76.

Virupaksha, T. K., Ramachandra, G., and Nagaraju, D. 1975. Seed proteins of finger millet and their amino acid composition. J. Sci. Fd. Agric. 26:1237-1246.

Virupaksha, T. K., and Sastry, L. V. S. 1968. Studies on the protein content and amino acid composition of some varieties of grain sorghum. J. Agric. Food Chem. 16:199-203.

Vogel, S., and Graham, M. 1979. Sorghum and millets: Food production and use. International Development Research Center, Ottawa, Canada.

Vohra, P., Dratzer, F. H., and Joslyn, M. A. 1966. The growth depressing and toxic effects of tannins to chicks. Poult. Sci. 45:135-142.

Von Sniegowski, M. S., and Baldwin, A. R. 1950. Uber die Zusammensetzung der Fettsä uren der in Mai and Sorghumstärke vorkommenden Fette. Die Stärke 7:171-172.

Waggle, D. H., and Deyoe, C. W. 1966. Relationship between protein level and amino acid composition of sorghum grain. Feedstuffs 38(51): 18-19.

Waggle, D. H., Deyoe, C. W., and Smith, F. W. 1967. Effect of nitrogen fertilization on the amino acid composition and distribution in sorghum grain. Crop Sci. 7:367-368.

Waggle, D., Parrish, D. B., and Deyoe, C. W. 1966. Nutritive value of protein in high and low protein content sorghum grain as measured by rat performance and amino acid assays. J. Nutr. 88:370-374.

Wall, J. A., and Paulis, J. W. 1978. Corn and sorghum grain proteins. Adv. Cereal Sci. Tech. 2:135-219.

Wall, J. S., and Blessin, C. W. 1970. Composition of sorghum plant and grain. In: "Sorghum production and utilization," Wall, J. S. and Ross, W. M. (eds.), p. 118-166. Avi. Publishing Co., Westport, Conn.

Wall, J. S., and Bretz, J. A. 1980. Maximizing use of normal and high-lysine sorghums in foods. ICC Symposium on sorghum and millet for human food. Vienna, Austria.

Wang, Y-Y. D., and Fields, M. L. 1978. Germination of corn and sorghum in the home to improve nutritive value. J. Food Sci. 43:1113-1115.

Wankhede, D. B., Shehnaj, A., Raghavendra Rao, M. R. 1979a. Carbohydrate composition of finger millet (*Eleusine Coracana*) and foxtail millet (*Setaria Italica*). Qualita Plantarum 28:293-303.

Wankhede, D. B., Shehnaj, A., and Raghavendra Rao, M. R. 1979b. Preparation and physiocochemical properties of starches and their fractions from finger millet (*Eleusine coracana*) and foxtail millet (*Setaria italica*). Qualita Plantarum 28:293-303.

Wankhede, D. B., Shehnaj, A., and Raghavendra Rao, M. R. 1979b. Preparation and physiocochemical properties of starches and their fractions from finger millet (*Eleusine coracana*) and foxtail millet (*Setaria italica*). Die Starke 31:153-159.

Watson, S. A., and Hirata, Y. 1954. A method for evaluating the wet millability of steeped corn and grain sorghum. Cereal Chem. 31:423-432.

Watson, S. A., and Hirata, Y. 1955. The wet milling properties of grain sorghums. Agron. J. 47:11-15.

Watson, S. A., and Hirata, Y. 1960. Carbohydrates in grain sorghum kernels. Sorghum Newsletter 3:7.

Watson, S. A., Sanders, E. H., Wakely, R. D., and Williams, C. B. 1955. Peripheral cells of the endosperms of grain sorghum and corn and their influence on starch purification. Cereal Chem. 32:165-183.

Watson, S. A., Williams, C. B., and Wakely, R. D. 1951. Laboratory steeping procedures used in a wet milling research program. Cereal Chem. 28:105-108.

Watson, T. G., Daiber, K. L., and Novellie, L. 1974. Extraction of a salt-insoluble -glucosidase from *Sorghum vulgare* grain. Phytochem. 13:901-904.

Watson, T. G., and Novellie, L. 1974. Extraction of *Sorghum vulgare* and *Hordeum vulgare* -glucosidase. Phytochem. 13:1037-1041.

Watt, B. K., and Merrill, A. L. 1963. Composition of foods, Agricultural Handbook No. 8. Agricultural Research Service, USDA, Wash., D. C.

Weak, E. D., Miller, G. D., Farrell, E. P., and Watson, C. A. 1972. Rapid determination of germ damage in cereal grains. Cereal Chem. 49:653-663.

Wessels, J. P. H. 1970. Variation in amino acids in kaffir corn cultivars available to chickens. Agroanimalia 2(2):77-84.

Woolard, G. R., Novellie, L., and Van Der Walt, S. J. 1976a. Note on the isolation of sorghum husk polysaccharides and fractionation of hemicellulose B. Cereal Chem. 53:601-608.

Woolard, G. R., Rathbone, E. B., and Novellie, L. 1976b. Structural studies on a glucuronoarabinoxylan from the husk of sorghum grain. Carbohydrate Res. 51:239-247.

Woolard, G. R., Rathbone, E. B., and Novellie, L. 1976c. A hemicellulosic β-D glucan from the endosperm of sorghum grain. Carbohydrate Res. 51:249-252.

Woolard, G. R., Rathbone, E. B., and Novellie, L. 1977a. A heteroxylan from the husk of sorghum grain. Phytochem. 16:957-959.

Woolard, G. R., Rathbone, E. B., and Novellie, L. 1977b. Structural studies on three hemicellulose B fractions from the husk of sorghum grain. Carbohydrate Res. 59:547-552.

Woolard, G. R., Rathbone, E. B., and Novellie, L. 1977c. J. S. Afr. Chem. Inst. Cited in Woolard et al., 1977d.

Woolard, G. R., Rathbone, E. B., Novellie, L., and Ohlsson, J. T. 1977d. Structural studies on the water-soluble gums from the endosperm of sorghum grain. Carbohydrate Res. 53:95-100.

Worker, G. F., Jr., and Ruckman, J. 1968. Variations in protein levels in grain sorghum grown in the southwest desert. Agron. J. 60:485-488.

Wu, Y. V. 1978. Protein concentrate from normal and high-lysine sorghums: Preparation, composition, and properties. J. Agric. Food Chem. 26:305-309.

Wu, Y. V., and Wall, J. S. 1980. Lysine content of protein increased by germination of normal and high-lysine sorghums. J. Agric. Food Chem. 28:455-458.

Wyss, E. 1977. Millet and sorghum milling. In: "Proceedings of a symposium on sorghum and millets for human food," D. A. V. Dendy ed., p. 111-120. Tropical Products Institute, London.

Yasumatsu, K., Nakayama, T. O. M., and Chichester, C. O. 1965. Flavonoids of sorghum. J. Food Sci. 30:663-667.

Zammit, I. V. 1980. The nutritive value of sorghum beer. S. Afr. Food Rev. 7(1 Suppl.):73-75.

Zherebtsov, N. A., and Kosmacheva, L. S. 1980. Amylase complex of millet malt. Fermentn, Spirt. Prom-st: (3):32-35, (Russ.) Chem. Abs. 93:2838.

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SOLUBILITY OF PEARL MILLET PROTEINS

B. Mason and R. C. Hoseney

The classification of cereal proteins according to their solubility properties is helpful in understanding why certain cultivars vary in amino acid composition. The protein classes each have unique amino acid compositions. As the amount of protein in each class varies, then the amino acid composition of the grain varies. Reported here is a continuation of the work reported in the 2nd annual report.

As reported earlier (2nd annual report), a major problem was finding a series of solvents that would solubilize a high percentage of the pearl millet proteins. Since NaOH could have adverse effects on certain amino acids and thus on the proteins, we did not want to use it as a solvent.

With the solvent systems reported in the 2nd annual report, but without NaOH, a residual insoluble fraction amounting to about 20% of the total protein was obtained. That insoluble residue was found in about equal amounts, in both meal and flour samples and indicates that it comes from the endosperm and not from the bran. Amino acid analysis of the residue fraction showed it to be protein (good recovery of amino acids) that was similar in amino acid composition to that of total meal samples.

At this time our attention was focused on a report (Nwasike et al., 1979) showing 100% solubilization of pearl millet proteins using a Landry-Moureaux (1970) solvent system. We were unable to obtain 100% solubilization of pearl millet protein using their system, however, we did obtain 94% solubilization which was much better than the 80% obtained previously. An example of the data obtained with that solvent system is given in Table 1.

Interestingly, if the first extraction is made with isopropanol followed by dilute salt rather than dilute salt followed by isopropanol, the distribution of protein in the various fractions is quite different (Table 1). This shows the powerful effect of salt on the solubility of proteins and raises questions concerning the "best" solvent system for pearl millet proteins.

In addition to whole meal, the modified solvent system was used on an endosperm fraction. Pearl millet was decorticated with a Satake "grain testing mill". Following decortication the grain was reduced in an Alpine pin mill and then extracted. As shown in Table 2 the level of isopropanol soluble proteins increased and the level of the isopropanol + ME and insoluble residue protein both decreased for protein extracted from endosperm instead of the whole meal.

Table 1. Extraction of pearl millet meal with Landry-Moureaux solvents.

Solvent	% soluble	Solvent	% soluble
0.5M NaCl	31.6	70% Isopropanol	48.7
70% Isopropanol	21.1	0.5 M NaCl	11.8
70% Isopropanol + 0.5% M.E.[a]	22.4	70% Isopropanol + M.E.	4.8
pH 10[b] + 0.5% M.E.	4.7	pH 10 + M.E.	3.5
pH 10 + 0.5% M.E. + SDS[c]	14.9	pH 10 + M.E. + SDS	23.9
TOTAL	94.7	TOTAL	92.7

[a]mercaptoethanol

[b]borate buffer

[c]sodium dodecyl sulfate

Table 2. Extraction of protein from pearl millet endosperm with the modified solvent system.

Solvent	% soluble
70% Isopropanol	53.8
0.5 M NaCl	11.2
70% Isopropanol + M.E.	2.2
pH 10 + M.E.	3.9
pH 10 + M.E. + SDS	25.2
TOTAL	96.3

REFERENCES

Nwasike, C. C., Mertz, E. T., Pickett, R. C., Glover, D. V., Chiffer, B. A. K., and Van Scoyoc, S. W. (1979) Lysine levels in solvent fractions of pearl millet. J. Agric. Food Chem. 27:1329.

Landry, J., and Moureaux, T. 1970. Bull. Soc. Chem. Biol. 52:1021.

Objective 4. "Determine the storage stability of pearl millet grain and millet meal by determining the factors contributing to grain losses during storage and determining the factors contributing to the development of rancidity in millet meal."

Moisture Content/Relative Humidity Equilibrium of Pearl Millet (*Pennisetum americanum* (L.) Leeke)

Dansou Kossou

Four pearl millet lines (HMP 550, PI 295 157, Serere 3A, and RMPI (S)C_1) were compared for their moisture content (MC)/relative humidity (RH) equilibria. RH (30-90% at 15°, 25° and 40°C) was mainatained in desiccators with sulfuric acid solutions. Samples held at 90% RH during adsorption and all desorption samples were treated initially with 0.3% propionic acid as a fungistat. MC of whole kernels was determined in a forced-air oven at 120°C for 18 hours after 3-week equilibration period.

Adsorption isotherms of the four lines varied significantly (Figures 1-4). IMP 550 was significantly higher than all other lines at all temperatures. Serere 3A was significantly different from RMPI(S)C_1, but PI 295 157 was not significantly different from either of those lines. In contrast to the adsorption isotherms, no differences appeared in desorption curves.

Equilibrium moisture contents (EMC) for all samples at 30-90% RH and 15°, 25° or 40°C are shown in Table 1. Maximum EMC's at 70% RH were 13.5, 13.4 and 13.0% at 15°, 25° and 40°C for all lines when adsorbing. Desorption EMC's at the same conditions did not exceed 15.8, 14.5 and 14.0%.

Table . Adsorption and Desorption Moisture Content/Relative Humidity Equilibria for Four Pearl Millet Lines at 15, 25 and 40°C.

Temp °C	%RH	HMP 550		PI 295 157		Serere 3A		RMPI(S)C_1	
		Ads	Des	Ads	Des	Ads	Des	Ads	Des
		% Moisture Content (Wet Basis)							
15	IMC	-	21.14	-	21.17	-	21.29	-	21.17
	90	18.68	20.90	18.13	20.63	18.38	20.61	18.87	20.78
	80	15.60	17.77	15.23	17.76	15.33	17.64	15.49	17.66
	70	13.48	15.53	12.93	15.65	13.19	15.54	13.11	15.71
	50	10.42	13.33	9.53	13.29	10.17	13.26	9.96	13.21
	30	8.44	11.08	7.93	11.17	8.10	11.00	7.65	11.21
	IMC	7.19	-	7.17	-	7.26	-	7.14	-
25	IMC	-	21.14	-	21.17	-	21.29	-	21.17
	90	19.04	20.24	19.06	20.27	19.12	20.21	19.02	20.49
	80	15.81	16.67	15.58	16.64	15.42	16.56	15.71	16.73
	70	13.28	14.38	13.05	14.42	13.02	14.31	12.83	14.48
	50	10.47	12.23	10.10	12.14	10.18	12.06	9.94	11.93
	30	8.25	9.70	7.73	9.95	8.05	9.81	7.64	9.85
	IMC	7.19	-	7.17	-	7.26	-	7.14	-
40	IMC	-	21.14	-	21.17	-	21.29	-	21.17
	90	19.61	20.39	18.75	20.27	18.59	20.10	19.53	20.35
	80	15.30	16.33	14.86	16.09	14.75	16.02	15.17	16.13
	70	12.80	13.89	12.68	13.91	12.54	13.74	12.79	13.96
	50	10.19	11.65	10.09	11.67	10.07	11.62	9.91	11.47
	30	8.31	9.31	7.72	9.64	8.00	9.25	7.60	9.54
	IMC	7.19	-	7.17	-	7.26	-	7.14	-

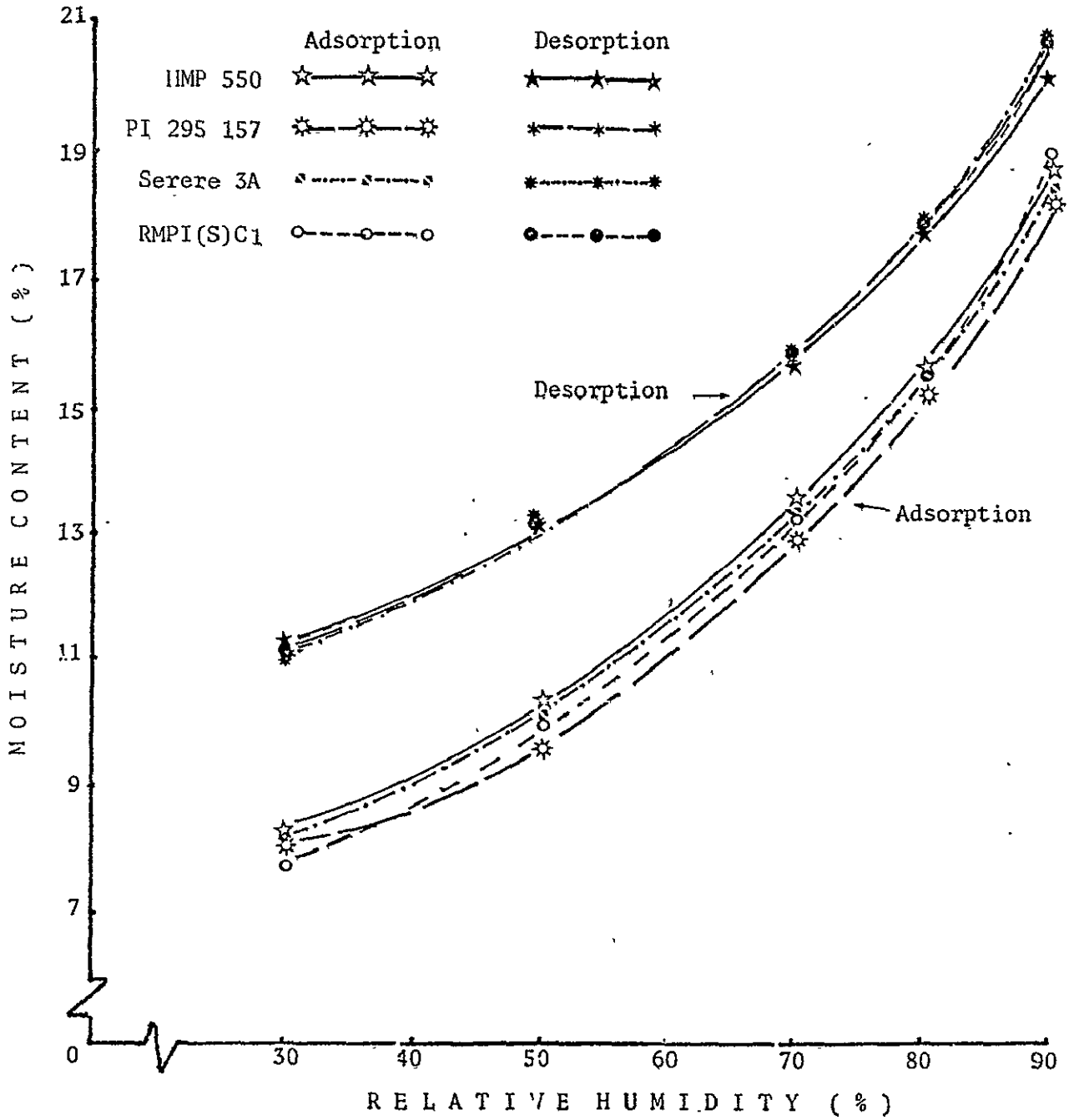

Fig. 1. Sorption isotherms for pearl millet (Pennisetum americanum (L.) Locke) lines HMP 550, PI 295 157, Serere 3A and RMPI(S)C_1 at 15°C.

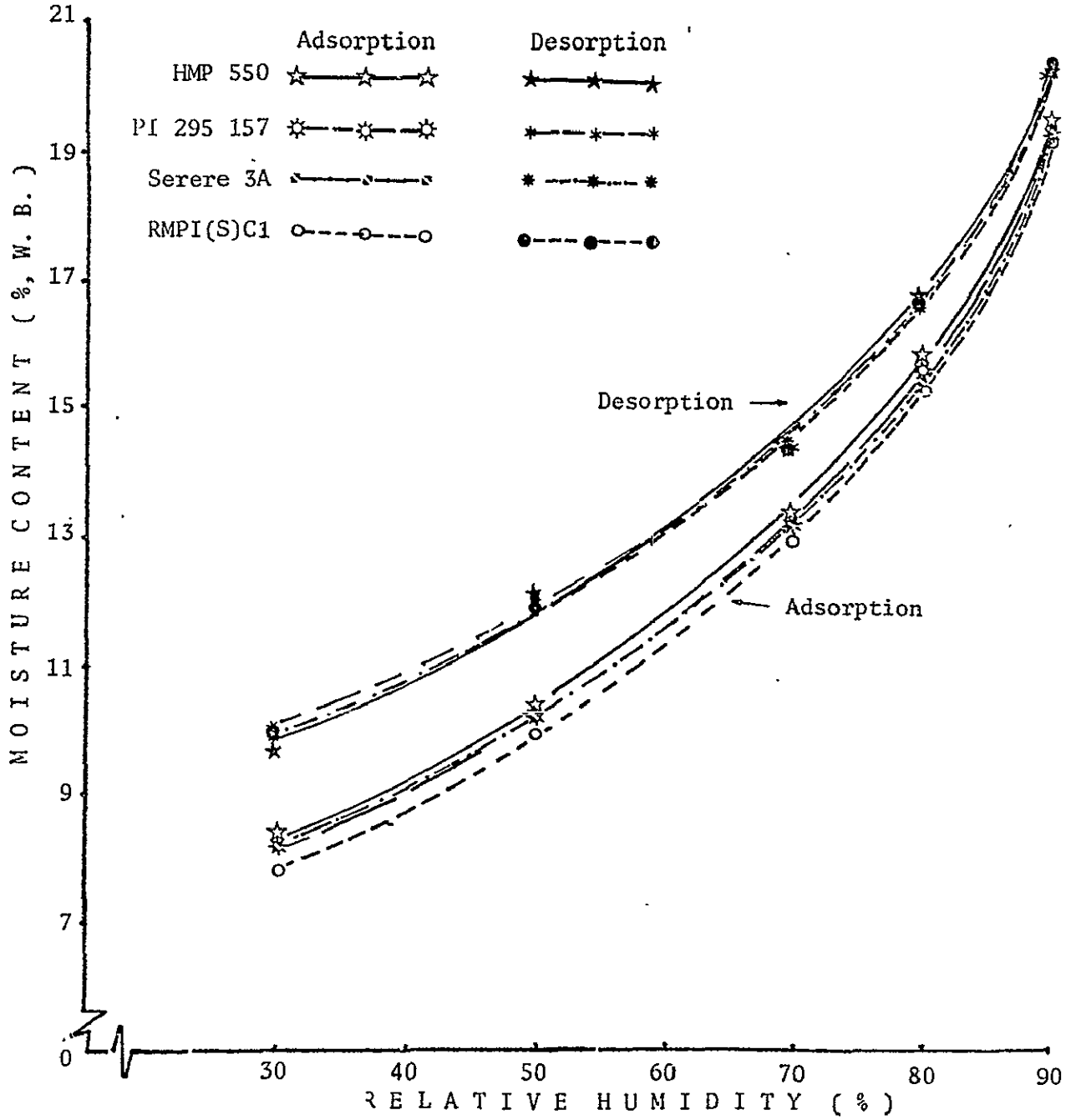

Fig. 2. Sorption isotherms for pearl millet (Pennisetum americanum (L.) Leeke) lines HMP 550, PI 295 157, Serere 3A and RMPI(S)C_1 at 25°C.

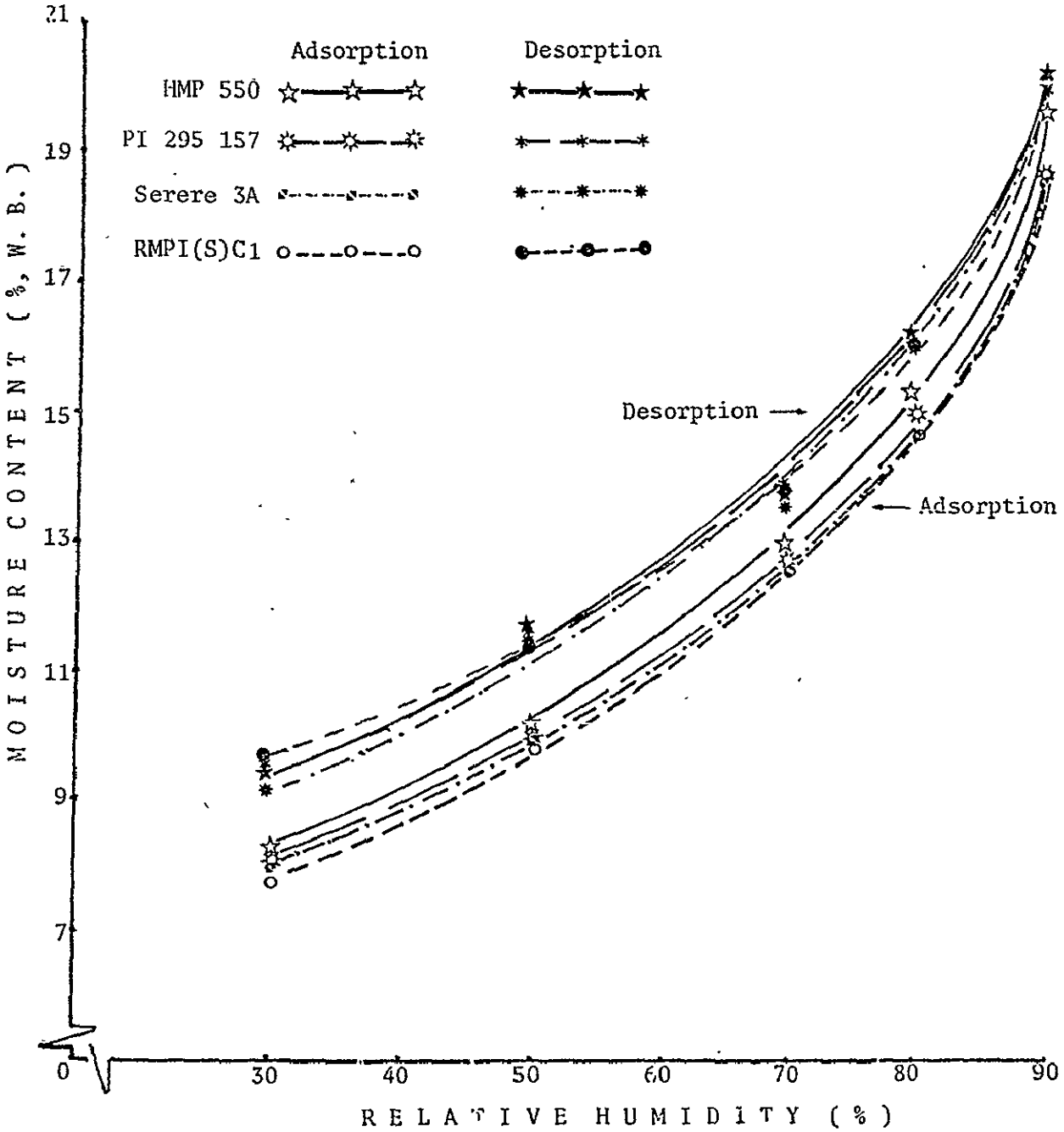

Fig. 3. Sorption isotherms for pearl millet (Pennisetum americanum (L.) Leeke) lines HMP 550, PI 295 157, Serere 3A and RMPI(S)C1 at 40°C.

VII. Financial Status

Year - 1 1 October 1977 - 30 September 1978

	AID - 3 yr funded	KSU Budget first year	Actual Expenditure
Salaries	290,170.00	89,260.00	54,797.54
Fringe Benefits	43,124.00	12,532.00	3,955.13
Indirect Costs	187,766.00	57,309.00	33,102.74
Travel & Per Diem	72,000.00	20,000.00	17,426.60
Equipment	51,000.00	51,000.00	37,040.90
Material & Supplies	100,246.00	25,246.00	10,117.47
Other Direct Costs	15,694.00	4,500.00	4,442.53
Publications	10,000.00	2,000.00	69.13
Grand Total	$770,000.00	$261,847.00	$160,952.04

Year - 2 1 October 1978 - 30 September 1978

	Budget-3 yr Funded	KSU-2 yr Budget	Actual Expenditure
Salaries	280,048.00	169,798.00	185,523.15
Fringe Benefits	19,310.00	11,397.00	13,376.32
Indirect Costs	172,824.00	104,162.00	111,192.36
Travel & Per Diem	83,126.00	53,126.00	37,552.72
Equipment	132,829.00	115,645.00	87,145.49
Material & Supplies	45,801.00	30,810.00	34,884.28
Other Direct Costs	27,443.00	15,943.00	20,097.24
Publications	8,619.00	4,119.00	2,243.14
Grand Total	$770,000.00	$505,000.00	$492,014.70

Year - 3 1 October 1979 - 30 September 1980

	Budget-3 yr Funded	Actual Expenditure
Salaries	280,048.00	294,278.30
Fringe Benefits	19,310.00	22,860.11
Indirect Costs	172,824.00	164,834.00
Travel & Per Diem	83,126.00	62,902.54
Equipment	132,829.00	117,741.17
Material & Supplies	45,801.00	62,255.45
Other Direct Costs	27,443.00	39,057.11
Publications	8,619.00	6,071.32
Grand Total	770,000.00	$770,000.00