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SECOND ANNUAL REPORT

October 1978 — September 1979

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

PROJECT OFFICE DS/AGR/FCP

Second annual report for the period October 1978 through September 1979 submitted to the Agency for International Development by Kansas State University, Manhattan, Kansas.

Richard L. Vanderlip
Principal Investigator
Professor of Agronomy
Kansas State University

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ANNUAL REPORT

October 1978 - September 1979

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I. Executive Summary

This section contains abstracts of research results in support of the four research objectives of the contract plus a brief narrative of other project activities. More detailed information is provided in other sections of the report.

Research Results. Detailed results see Section VI, page 39.

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
(Page 40)

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

(Page 51)

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

(Page 55)

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

(Page 63)

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

(Page 67)

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

(Page 72)

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

(Page 85)

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

(Page 97)

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

(Page 102)

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

(Page 108)

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

(Page 119)

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

(Page 127)

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

(Page 131)

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

(Page 144)

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

(Page 150)

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

(Page 180)

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

(Page 194)

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

(Page 205)

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.

Planning Meetings Four IN-PROGRESS-REVIEWS plus one special meeting with Dr. Robert C. McGinnis, Associate Director, Cooperative Programs and Training, ICRISAT, were attended by the principal researchers and graduate students working with pearl millet. During these meetings plans for research projects were coordinated among the various personnel and evaluations on the progress of the research were made. Minutes of these reviews were provided AID and the decision making personnel at KSU, and are in Section II, page 13.

International Travel There were two international travel coordination programs during the year. Dr. Richard L. Vanderlip and William D. Stegmeier visited Dr. John M. Peacock, Grassland Research Institute, Maidenhead, England. Dr. Peacock, a crop physiologist, was formerly stationed at the Dryland Research Scheme, Gaborone, Botswana where he worked with pearl millet. He has accepted a position as crop physiologist, ICRISAT. Cooperative projects were coordinated for the 1980 growing season between KSU and ICRISAT. They then traveled to Delhi, India, conferring with Dr. Fletcher Riggs, AID Agricultural Officer, U.S. Embassy.

They visited Punjab Agricultural University, Ludhiana and Haryana Agricultural University, Hissar conferring with the staff and visiting the research plots.

They then traveled to ICRISAT, Hyderabad, India. Here they conferred with the staff and principal researchers coordinating cooperative research and exchange of germplasm.

Their next stop was Hawaii. During their conferences at the University of Hawaii arrangements were made for the winter nursery program to be on Molokai, to eliminate several of the seed production problems encountered in Puerto Rico.

Dr. Edward T. Kanemasu visited his cooperative research plot ICRISAT located at Hissar, India. While there he also contacted research personnel at Haryana Agricultural University. His research at Hissar is a cooperative program with Francis Bidinger, Dave Andrews and Les Fessel of ICRISAT. Copies of the trip reports are in Section III, page 23.

Publicity News releases were prepared and sent to all Kansas newspapers. A taped interview for radio was distributed to all Kansas radio stations. The field day at the Agronomy Farm, Manhattan, Kansas and Ft. Hays Branch Experiment Station, Hays, Kansas included pearl millet as one of the stops on the tour.

Two papers on the results of research on pearl millet were presented at the Eleventh Biennial Grain Sorghum Research and Utilization Conference, Wichita, Kansas on 28 February - 2 March 1979. Two papers were presented at the 1979 Annual Meeting, American Society of Agronomy, Ft. Collins, Colorado, 5-10 August. One paper was presented at the International

Conference on Cereals for Food and Beverages; Recent Progress in Cereal Chemistry and Technology, American Chemical Society, sponsor, Copenhagen, Denmark, 14-17 August. Two papers were presented at the American Association of Cereal Chemists 29 October - 2 November, Washington, D.C.

The principal researchers have been the program for local civic and religious groups explaining this research program. Approximately four hundred copies of the First Annual Report were distributed to interested personnel. Four agronomy graduate students presented seven seminars on pearl millet research to the agronomy faculty and graduate students during the Agronomy Seminar Program, KSU.

Personnel There are seven principal research personnel assigned to this project. Other members of faculty and experiment station personnel provided input to the program. Undergraduate students who work for the project are employed on an hourly basis. A list of the personnel who assisted with this project is found in Section V, page 36.

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. The program utilized $492,014.70 the first two years. The remaining funds will be reprogrammed for effective utilization during the remainder of the contract. The financial statement is Section VII, page 208.

General The APHIS permits for the breeding program at Ft. Hays Branch Experiment Station and import of grain for the Grain Science program have been received and utilized. The winter nursery program was changed from Puerto Rico to Molokai, Hawaii to provide better coordination of this program.

II. Planning Meetings

Special meeting of personnel of "Improvement of Pearl Millet" Contract AID/ta-C-1458, Project 931-1040, Project Office DS/AGR/FCP and the Title XII proposal with Dr. Robert C. McGinnis, Associate Director, Cooperative Programs and Training, ICRISAT, 9 November 1978, 1330 hours, Room 106 Waters Hall, Kansas State University.

Attendees: Richard L. Vanderlip, R. Carl Hoseney, Elizabeth Varriano-Marston, Edward T. Kanemasu, Wm. D. Stegmeier, Herman A. Praeger, Jr., Frank L. Barnett, Robert B. Mills, John R. Pedersen, Rosemary Burroughs, the principal researchers; and graduate students Julius Okonkwo, John Palmer, Gallus J. Mwageni, Adilaide Beleia, Dansou Kossou, Bill Mason, Mithlesh Kumar, John Gardner, Christopher Lai, Piara Singh, and Cielo R. Sumayao.

Dr. Vanderlip discussed the current approved program and the proposed enlargement of the program upon approval of Title XII. Essentially, Title XII is the current program with an expansion of the breeding program to include breeding programs at Manhattan and Ft. Hays Branch Experiment Station. It will include a grain storage study to be conducted by the Department of Entomology and expansion of the grain storage study currently underway in the Department of Grain Science and Industry and a socio-economic program conducted by the Departments of Sociology and Economics.

Dr. Vanderlip then asked the various researchers to briefly discuss their programs.

The Grain Science program of Drs. Hoseney and Marston includes analysis of various grain samples for protein-amino acid content, lipids for quantity and types to determine what causes rancidity when the grain is milled, carbohydrate content and composition, vitamin and mineral content. They have a cooperative project with the Department of Foods and Nutrition to determine the digestibility of pearl millet; presently this is limited to the digestibility of protein. They are studying techniques and tests to determine food use and quality which at this time is not defined. The availability of grain samples from India, Sudan and West Africa was discussed with Dr. McGinnis. This should pose no problem as contacts have been made with the researchers of ICRISAT and grain can be shipped as soon as KSU obtains the APHIS permit for Grain Science. The size of sample desired was discussed. Grain Science prefers 5-10 kilogram samples as they would like to process and prepare the food for quality determinations.

Dr. Pedersen discussed the current research of grain storage. This project is studying storage in unthreshed head and grain to insect damage and the susceptibility of the grain to damage by microbial organisms, mold and the natural flora of the grain. Although not a part of this contract, they have a cooperative project on warehousing of pearl millet grain with Senegal to assist in their national grain storage program.

Dr. Mills, Entomology, discussed his proposed program under Title XII. This is a grain storage study of facilities and techniques to determine the susceptibility of the various varieties of pearl millet to stored grain insects. The study will include grain stored in the head and threshed grain and be oriented to the conditions in the Lesser Developed Countries. This is to be a cooperative study with the Food and Feed Grain Institute here at Manhattan, Kansas.

Bill Stegmeier, plant breeder, Ft. Hays Branch Experiment Station, discussed his program. The breeding program was started in Kansas during 1969 by Dr. Casady at Manhattan and in 1971 at Ft. Hays Branch Experiment Station. The program incorporates the D_2 height gene (dwarf) into the populations so the crop can be mechanically harvested. Selections are made for early maturity, response to day length, increase in seed size plus desirable agronomic characteristics. The B_1 male sterility gene is utilized in the development of parental lines for hybrid seed production. The glass houses at Hays and a winter nursery program with the Puerto Rico Agricultural Experiment Station are utilized to grow two generations each year. It is doubtful that any of the populations, varieties or hybrids developed by this program will be of immediate value to the Lesser Developed Countries as there is no way of knowing the tolerance or resistance to the diseases and insects of these areas. Seed of agronomically desirable types can be provided to the ICRISAT and national programs for testing. If found to be desirable they can incorporate the necessary resistance.

Dr. Vanderlip discussed the seedling vigor and seedling establishment studies. This is not a problem in the Lesser Developed Countries where they utilize hill planting, planting many seeds per hill and hand thinning. With machine planting of single seeds and lack of hand labor, field establishment is a significant problem in growth of pearl millet here. The standard laboratory germination test is poorly correlated to field establishment. Various seed stress tests prior to germination are better indicators of field establishment. We are studying the effect of seed density (specific weight) on seedling vigor and field establishment. The yield trial program was discussed. There will be pearl millet plots located at seven different experiment fields in Kansas next year. There is a study on herbicide susceptibility in the culture of pearl millet.

Dr. McGinnis discussed the ICRISAT program and the ICRISAT/KSU program.

A copy of Dr. McGinnis' itinerary while at KSU is provided.

The trip of Dr. McGinnis included stops at CIMMYT, Texas A&M, Kansas State University, University of Nebraska, Iowa State University, University of Minnesota and University of Manitoba.

ITINERARY

FOR

DR. ROBERT C. McGINNIS

ASSOCIATE DIRECTOR, COOPERATIVE PROGRAMS AND TRAINING
ICRISAT, HYDERABAD, INDIA

8 Nov.	1414 hours	Met at airport by Dr. Vanderlip, check-in at Ramada Inn
	1500-1600	Dr. Richard L. Vanderlip, Department of Agronomy, Room 105B Waters
	1600-1700	Meeting with Agronomy Graduate Students, Room 106 Waters
	Evening	As desired
9 Nov.	0815 hours	Met at Ramada Inn, Dr. Vanderlip
	0830-0900	Dr. Hyde S. Jacobs, Head, Department of Agronomy, Room 108 Waters
	0900-0930	Dr. Roger L. Mitchell, Vice-President for Agriculture, Room 115 Waters
	0930-1000	Coffee Break
	1000-1030	Dr. Charles W. Deyoe, Head, Grain Science & Industry, Room 202 Shellenberger
	1030-1100	Dr. Vernon C. Larson, Director, International Agricultural Programs, Room 14 Waters
	1100-1130	Dr. Richard Sauer, Head, Department of Entomology, Room 123 Waters
	Lunch	Dr. Elmer G. Heyne
	1330-1430	Conference with principal personnel, Room 106 Waters, "Improvement of Pearl Millet" and Title XII
	1430-1530	Conferences as desired
	1530-1630	Interviews by interested personnel, Room 106 Waters
	1630	Depart for airport

The sixth IN-PROGRESS-REVIEW of the project, "Improvement of Pearl Millet", was held 8 February 1979 at 1315 hours, Room 135, Waters Hall, KSU, Manhattan, KS.

Attendees: Richard L. Vanderlip, Wm. D. Stegmeier, R. Carl Hoseney, Elizabeth Varriano-Marston, Herman A. Praeger, Jr., the principal researchers; Francis L. Barnett of the Title XII millet breeding program; Carol Klopfinstein, Grain Science; and Agronomy graduate students John Palmer, John Gardner, and Mithlesh Kumar.

There was discussion of materials available to Dr. Barnett upon initiation of the Title XII breeding program at Manhattan. Frank will plan a trip to Ft. Hays to coordinate with Bill Stegmeier what plant material will be available for this year's plantings and the cooperative projects to be conducted at the two locations.

Dr. Vanderlip discussed the status of INTSORMIL, the Title XII program. Information from Bob Jackson, AID, and Jerry Eastin, University of Nebraska, is not definite; they are confident of approval but do not know when.

The APHIS permits were discussed. Entomology program of INTSORMIL requested Grain Science for use of their permit to obtain grain from LDC's for their grain storage studies. Carl Hoseney had discussed this program with Jack Pedersen. They concluded it would be advisable for entomology to obtain a separate APHIS permit for its use. This was considered proper to solve this problem. Bill Stegmeier discussed the grow out dates for pearl millet, 1 Nov - 31 March, are not optimal for seed production. The plants are small, with small heads, some infertile, with low grain yields. The introduced material must be grown one generation before it can be field planted for testing or seed increase. Do not expect seed increases in the first or glasshouse generation.

The sources of variability within the available germplasm were discussed. RMP 1 (S)C1 is Serere 3A, Serere 17 and Tift 239 DB_2. The Hays Millet Populations (HMP) have PI 185642, a dwarf early maturing large seeded introduction from Ghana, as one of the parents. It appears no one has adequate information on genetic variability of our seed. Al Praeger was assigned the task to ascertain the genetic background of the available seed and document in a convenient usable format.

The annual report was discussed. All the input has now been received. The format and draft was approved for all but Objective 1 which will be coordinated directly with Bill Stegmeier. The number of copies to print was discussed. AID wants 100 copies for their distribution. They also want a list of personnel to whom we send copies overseas. They do not require a list of distribution within the U.S. It was decided to print 500 copies.

The budget as developed by the various departments and submitted to AID for approval was approved by AID. Copies were provided to the principal researchers.

Grain requirements were discussed. Grain Science wants 5 lbs of Serere 3A grown at Hays in 1977 to complete their analysis of this population, location, growing season study. Bill Stegmeier will provide. Grain Science would like to study geographical differences of grain having the same genotype grown at least on four different locations in the state. They require five lbs of seed from each location. This will be organized for this growing season. The grain increase to provide grain and millet heads for the grain storage studies was discussed. The most productive grain last year was the plot on the south end of the irrigated sorghum rate and date study at Ashland. This study will be repeated this year. There will be adequate isolation to grow two populations for grain increase in that area this year.

Locations for the millet experiments and yield trials were discussed. Arrangements have been made for plantings on the north farm, Ashland, St. John, Minneola, Garden City, plus Hays. Specific area requirements have not been identified, but will be determined in the near future and coordinated with the field superintendents.

Presentations of the results of research of this project were discussed. Two papers are to be presented by Agronomy at the 11th Biennial Grain Sorghum Utilization Conference, Wichita, KS, 28 Feb-2 March 1979. Agronomy will present papers at the American Society of Agronomy meeting at Ft. Collins, Colorado, 5-10 Aug. 1979. Grain Science will present papers at their meeting during October 1979. Carl Hoseney has been invited to present a paper at Copenhagen, Denmark this summer.

Property control and maintenance records required by paragraph 17 of the contract were discussed. Forms to be completed with the required information were provided to the researchers who have serial numbered nonexpendable equipment purchased by the contract. These are to be completed and returned to Al Praeger for project file.

The visit of David Andrews, ICRISAT Pearl Millet Breeder, with his co-workers, Drs. Gupta and Kumar, 18-20 March was discussed. Itinerary to be developed at later date.

Dr. N. V. Sundaram, Cereal Pathologist, ICRISAT, located at IAR, Ahmahdu Bello University, Zaria, Nigeria, will be on home leave during April and wishes to visit KSU. Final arrangements have not been completed for this visit. There is a possibility his trip will include stops at the University of Nebraska and Texas A&M.

Meeting adjourned 1530 hours.

The seventh IN-PROGRESS-REVIEW for the project, "Improvement of Pearl Millet", was held 1315 hours 17 April 1979 in Room 106, Waters Hall, KSU.

Personnel attending: Richard L. Vanderlip, R. Carl Hoseney, Elizabeth Varriano-Marston, William D. Stegmeier, Herman A. Praeger, Jr., John Gardner and John Palmer.

The seed and grain requirement for this year's research was discussed. For the yield trials of John Palmer, Bill Stegmeier is to provide the hybrid seed for twenty entries. These trials are planned for five locations throughout the state. Size and design of the trials was discussed. It was decided the trials would be two row plots, thirty feet long with three replications. The seeds would be planted four per row foot requiring the seed to be packaged 120 per row packet for planting. Ten grams of seed each of nine hybrids developed by Dr. Burton were obtained and are to be included in as many trials as possible. Dr. Burton also indicated he had increased his Tifton #1 hybrid and has seed available. Two pounds of seed was requested. If received it is to be included in the trials.

Grain Science desires five pounds of grain per entry per location for their study. There was discussion whether the yield trials would provide adequate grain for both John Palmer and Grain Science. It was considered that there would be adequate grain for both if the entries from the three replications would be bulked for Grain Science.

The 10 lb of grain and 100 unthreshed heads per entry required for Entomology Title XII study could best be obtained by planting one extra replication of the yield trial at Ashland. Their requirement for 100 lbs of grain of RMP-1 and Serere 3A will be grown on the irrigated area south of the sorghum study at Ashland.

Input for the semi-annual report was completed for all sections except Objective #1, which will be completed by Bill Stegmeier, hopefully by the first of next week.

The financial status of the project was discussed. We have completed three-fourths of the first two year program. At the end of March we have spent 73% of the budget funded for salaries, fringe benefits and indirect costs; 60% of the travel; 47% of the equipment budget; 75% of material and supplies; 101% budgeted for other direct costs; and 4% for publications. Overall we have spent 66% of the two year budget. It was noted there are major items of equipment that have been approved for purchase and are on order but have not been paid. So we are on target in expending the budgeted amounts. All were cautioned to pay close attention to expenditures and don't overspend.

Title XII proposals to Nebraska were discussed along with the results of the visit to KSU by Dr. Bob Kleis, Nebraska Title XII coordinator.

International travel was discussed. Ed Kanemasu is planning on presenting papers at the Water Use and Irrigation in Semi-Arid Lands Conference, Cairo, Egypt 1-6 September and at the Evapotranspiration Symposium in Vienna, Austria 10-14 September. He will then visit Hissar, India where he has a cooperative study with Dave Andrews, Millet Breeder, ICRISAT. Vanderlip, Praeger, and Stegmeier will visit England and India. In India they will visit Hissar and Ludhiana which they could not visit last year due to the floods. These are the northern most areas for millet research in India and will be more closely aligned with Kansas growing conditions than the tropical regions. Then they will visit ICRISAT at Hyderabad to review the cooperative research with Dave Andrews and Dr. Fran Bidinger, Cereal Physiologist, ICRISAT.

Carl Hoseney and Liz Marston are to present a paper at Copenhagen, Denmark at the International Conference on Cereals for Food and Beverages; Recent Progress in Cereal Chemistry and Technology, American Chemical Society, sponsor. They plan to visit Senegal and coordinate their nutritional quality work with the Senegal Institute of Food Technology. There is a food preparation, nutritional quality program being developed by IDRC in Ouagadougou, Upper Volta. If it can be arranged, they will visit this IN-COUNTRY Workshop. They will then visit ICRISAT in Hyderabad, India to coordinate their work with Dr. R. Jambunathan, Biochemist.

Announced the visits to KSU of Dr. N. V. Sundaram, Cereal Pathologist, ICRISAT, IAR, and Ahmadu Bello University, Zaria, Nigeria on or about 7 May. A firm date will not be known until his visit to Texas A&M, then his schedule will be developed. Dr. R. Jambunathan, ICRISAT Biochemist, will visit KSU 2-3 May. Grain Science will develop his schedule.

The eighth IN-PROGRESS-REVIEW of the project "Improvement of Pearl Millet" was held 1300 hours 9 July in Room 106, Waters Hall, KSU.

Personnel attending: Richard L. Vanderlip, R. Carl Hoseney, Elizabeth Varriano-Marston, William D. Stegmeier, Edward T. Kanemasu, Francis L. Barnett, and Herman A. Praeger, Jr.

The financial status of the first eight months of the fiscal year was discussed. For the overall project we have completed 66.6% of the fiscal year and have spent 66.7% of the budgeted resources. However, Agronomy and Fort Hays Branch Experiment Station have overspent their budget and Grain Science and Industry has underspent.

Dr. Vanderlip discussed the status of Title XII INTSORMIL project. Nebraska has received a proposed contract from AID for INTSORMIL. The directors of the eight states involved are meeting in Kansas City 12 July to determine if the provisions of the contract are acceptable to all parties in the definition of the relationship with University of Nebraska, the base institution. Recommendations were made to Floyd Smith,

Director, KAES, for some changes and some areas for clarification that would be preferable to us. Apparently the University of Nebraska misinterpreted our input on the proposed budget as the figures in the contract are much less than required to support our proposed program. But then the proposed period of time the budget was to cover was not readily defined. More information will be available following the meeting.

The foreign travel program was discussed. Planning of the trips is progressing satisfactorily.

Grain Science has received two millet grain samples from Sudan. One is considered high quality and the other low quality. They will analyze the samples hoping to be able to define "quality".

The grain samples we have are identified by numbers. A system has to be devised to indicate the genetic makeup of these samples, so we will know what we are comparing. This task was postponed for the time being.

Grain requirement for the various projects was discussed. All the grain from the various experiments will be saved and properly identified. The yield trials have 27 entries and are planted at six locations. Grain Science requires samples of the entries from each location. This will have to be harvested from what is left after the yield trial samples are harvested. There are many requests for pearl millet grain. We need all the grain we can produce to fulfill the requests. Kellogg Co. has requested 200 lbs of grain for their research. Bill Stegmeier can furnish this from composite reminants.

The next IN-PROGRESS-REVIEW will be at Ft. Hays Branch Experiment Station when we return from international travel, probably early October.

The ninth IN-PROGRESS-REVIEW of the project, "Improvement of Pearl Millet", was held 0830 hours 10 October 1979 in the Auditorium Conference Room, Ft. Hays Branch Experiment Station, Hays, Kansas.

Personnel attending: Richard L. Vanderlip, Edward T. Kanemasu, Robert Mills, William D. Stegmeier, Elizabeth Varriano-Marston, Tom Harvey, Barry Michie, Francis L. Barnett, Herman A. Praeger, Jr., John Gardner, William Phillips, Director, Ft. Hays Branch Experiment Station, and David Andrews, Principal Millet Breeder, ICRISAT, on sabbatical, University of Nebraska.

International travel coordination was discussed. Dr. Kanemasu reported on his cooperative microclimate study with ICRISAT at Hissar, India. The Hissar site was selected because of the high temperature of the area and the availability of limited irrigation. This year there is a severe drought in the area. The limited irrigation was not adequate

to establish a uniform stand. The plants are stunted. It appears there will be so much variability in the stand and between the plants that the yield data will be of little or no value. The microclimate data should be useful. Dr. Cielo Romm, who is conducting the study, will be leaving as her husband is leaving the Ford Foundation position in New Delhi for a position on the faculty, University of California, Berkeley. Arrangements were made for a scientist on the ICRISAT staff at Hissar to conduct the study during the next growing season. Dr. Kanemasu feels this coordination during the growing season is a necessary part of the conduct of the study.

Dr. Vanderlip and Bill Stegmeier reported on their trip to Hissar, Ludhiana and ICRISAT, India. Using slides, they discussed the research plots they visited. They were especially impressed with the results that were being obtained in the disease nurseries. For example, the dwarf male sterile, the desired parent for hybrid production by plant breeders, 23 D_2B, developed by Dr. Glenn Burton, USDA, SEA, Tifton, Ga., is highly susceptible to downy mildew. They irradiated some seed with cobalt and found lines that were resistant to downy mildew. The change in the genetic makeup that created this resistance also rearranged the recombining ability of the male sterile, but the plant breeders are beginning to find solutions to this problem. While at ICRISAT arrangements were made for a graduate student of Dr. Vanderlip to conduct his research with Dr. Bidinger, Cereal physiologist, ICRISAT, on techniques to identify early seedling drought resistance. This is a problem in India and Africa as the pearl millet is planted after the first rain. If there is not a timely rain in the next few days, the plants will not survive. It is during the seedling stage that drought resistance is of primary importance. Dr. Bidinger and Seetharama, ICRISAT, in coordination with Dr. Vanderlip have initiated a project to develop a pearl millet growth and development model using the sorghum growth and development program of Vanderlip-Arkin as a basis for this project. During the return trip they stopped at the University of Hawaii where arrangements were initiated for the winter nursery for growing the second generation of breeding material. This arrangement will allow growing the breeding material on Molokai providing proper isolation as no pearl millet is grown there. There also will be no language barrier there as there was with the Puerto Rico program of the past.

Grain Science did not have an international coordination visit this year. They are planning on conducting visits next year.

The group then was taken on a tour of Bill Stegmeier's pearl millet project on the station. He has isolation seed increase plots, breeding nursery, yield trial, and recombining plots. This is an extensive program at the Ft. Hays Branch Experiment Station. The new personnel of the INTSORMIL program who had not visited this program before were impressed with the magnitude of the project and diversity of the plant material in the plots.

The group then returned to the conference room.

The yield trials at Tribune, Garden City, Minneola, St. John, and Manhattan have been harvested. The yield trial at Hays will be harvested next week. Threshing and recording data for the agronomic research will be completed as soon as possible. Then the grain will be made available to Grain Science for their analysis and will be provided for the new projects of INTSORMIL. It is anticipated each entry will yield four pounds of grain. By bulking the three replications we should have twelve pounds of grain from each of the six locations. This should be adequate for all the projects of "Improvement of Pearl Millet" and INTSORMIL. If there are requirements for heads of grain or any other plant material, the border rows or the unharvested plants in the plots are available. Recommend you obtain what you require at your earliest opportunity. We will combine the remaining pearl millet in about two weeks.

The annual report was discussed. As the research data is not completed, and will not be for some time, it was decided to prepare an interim annual report like we did last year. This to include a narrative of the ongoing research, list of personnel working on the project and financial status. The narrative is to be provided to Al Praeger for consolidation by 20 October. He will then prepare the report.

The target date for completion of the information to be included in the annual report was set as 15 December.

The financial status of "Improvement of Pearl Millet" and INTSORMIL was discussed. "Improvement of Pearl Millet" for the period of this fiscal year is underspent by approximately $30,000 of the $344,000 budgeted. However, some of the projects have overspent the budgeted amount. Upon receipt of the comptroller's report for the full fiscal year, a determination will be made if there should be a reallocation of budgeted funds. There has been no expenditures of INTSORMIL funds to date. The administration of how to spend them was discussed. Distribution of the indirect costs that develop the Sponsored Research Overhead funds was discussed. These are to be distributed in accordance with University policy, 55% of the total goes to the unallocated fund administered by Anderson Hall, 5% of the total goes to the Kansas Agricultural Experiment Station and the remaining 40% goes to the department that generates them. How this is handled within your department is to be determined by you and the Head of your department.

The INTSORMIL project requires a semi-annual and annual report. The semi-annual report is due 1 March. Further information will be provided at the next IN-PROGRESS-REVIEW.

The annual inventory of non-expendable equipment is due. Provide to Al Praeger the non-expendable equipment purchased this fiscal year by 20 Oct. so he can prepare the report.

Grain Science would like to obtain 150 lb samples of grain from known populations or hybrids to fulfill requests they have been receiving

for grain samples. It was considered that grain in this amount could be provided from at least four different populations.

The "Improvement of Pearl Millet" project has been invited to present a seminar to the Agronomy faculty and graduate students 11 Dec. It was decided to accept the invitation and each researcher is to present the scope of their work and results of the research. Fifteen minutes was thought to be adequate time for each researcher.

Since all personnel would be in Manhattan 11 December, the next IN-PROGRESS-REVIEW was scheduled 1300 hours 11 December, Room 106 Waters Hall.

Dr. Charles Francis and Dave Andrews visited Ft. Hays Branch Experiment Station 9 October for an overview of Bill Stegmeier's pearl millet program. Dave stayed over to attend the IN-PROGRESS-REVIEW. He was asked for his comments and suggestions for the improvement of our program. First of all, he was impressed with the breeding program, its organization and the amount of genetic material available. He had no idea the program would be of this magnitude. Also, he was amazed by the results that can be obtained by so few personnel working on the project. He had identified various lines having high potential for seed parents and combining ability and has arranged with Bill Stegmeier for seed to be provided ICRISAT. He was pleased that adequate seed was available for exchange of materials; although limited to grams this is all that is necessary. He did notice that similar lines grown at Hays tillered more than at Hyderabad, India. He would be interested in knowing what caused this to occur.

Dave Andrews accompanied us to Manhattan. On 11 October he had conferences with Dr. Kanemasu and Vanderlip. During this time preliminary arrangements were made for Dr. S. C. Gupta, pearl millet breeder, ICRISAT, to attend Kansas State University on sabbatical next year where he would be available for consultation for our breeding program in addition to his studies.

III. International Travel

Trip Report of Dr. Richard L. Vanderlip and William D. Stegmeier 30 Aug-23 Sep 1979, Contract AID/ta-C-1458, Project 931-1040, "Improvement of Pearl Millet"

Departed home station by air 30 August for Kansas City, Chicago and arrived London 0900 hours 31 August. They were met by Dr. John M. Peacock, staff member of the Grassland Research Institute, Maidenhead, England who escorted them on a tour of the Institute and organized conferences for them. Dr. Peacock, a crop physiologist, was formerly

stationed at the Dryland Farming Research Scheme, Gaborone, Botswana where he worked with pearl millet. Dr. Peacock has accepted the position of crop physiologist at ICRISAT, Hyderabad, India and will transfer there October 1979. While at Maidenhead, in addition to Dr. Peacock, they conferred with Dr. M. J. Hopper on his program of Soils and Plant Nutrition and with Dr. L. C. Chapas, Biometrics, concerning his growth and development computer modeling programs.

They departed London 0825 hours 3 September and arrived Delhi, India 0200 hours 4 September. After customs experience they arrived at their hotel. On 5 September they had a conference with Dr. Fletcher Riggs, AID agricultural officer, and Mr. M. A. Nair, AID, at the U.S. Embassy.

On 6 September they departed Delhi by car to Ludhiana for visit and conferences at Punjab Agricultural University. The conference was attended by Dr. Khem Singh Gill, Dean of the College of Agriculture, Dr. P. S. Pall, Head, Department of Plant Breeding, Dr. N. B. Singh, Bajra breeder, Dr. S. S. Chahal, pathologist, Dr. B. L. Bhardweig, geneticist and Manoj Srivcestava, Research Associate. They discussed the millet improvement program of the university and the state of Punjab. The next morning they visited the experiment fields. They have 8.1 hectares of plots. They are conducting research on development of hybrids, synthetics, and male steriles. They have a large program for disease testing. This program is emphasizing finding resistance to ergot. Ergot may be a greater problem to solve than the downy mildew problem.

That afternoon they traveled to Haryana Agricultural University at Hissar. They were met there by members of the Department of Plant Breeding. The members of the conference included Dr. P. S. Gill, Dr. R. L. Kahpoor, Dr. Faujdar Singh and Dr. D. P. Thakur of the university staff and Dr. R. P. Thakur, millet pathologist, ICRISAT. They discussed the millet improvement program of the university and its cooperative program with ICRISAT. They then visited the experiment fields to observe the developing crop.

The next day they returned to Delhi.

On 10 Sept. departed Delhi and arrived Hyderabad for their coordination visit with ICRISAT.

ICRISAT organized separate programs for Vanderlip and Stegmeier; plant physiology and agroclimatology for Dr. Vanderlip and millet breeding, germplasm collection and pathology for Stegmeier with two common conferences and tours on sorghum breeding and cropping systems.

These were well organized conferences with the talented ICRISAT staff with an opportunity to visit the experimental plot areas.

The personnel they conferred with included:

J. S. Kanwar, Associate Director
L. R. House, Principal Plant Breeder
F. R. Bidinger, Principal Physiologist
S. C. Gupta, Plant Breeder, Millets
K. Anand Kumar, Plant Breeder, Millets
S. Appa Rao, Genetic Resources
N. Seetharama, Plant Physiologist
G. Alagarswamy, Plant Physiologist
K. V. Seslv Reddy, Entomologist
K. N. Rao, Plant Pathologist
S. M. Virmani, Principal Agroclimatologist
D. L. Oswalt, Principal Training Officer
D. S. Murty, Sorghum Breeder
Dr. M. Natarajan, Agronomist, Cropping Systems
Dr. M. S. Reddy, Agronomist, Cropping Systems
Dr. R. J. Williams, Cereals Pathologist
B. L. Agrawal, Plant Breeder, Pest Resistance
Bhola Hath Varma, Plant Breeder, Populations
K. E. Prasada Rao, Botanist, Genetic Resources, Sorghum & Minor Millets
B. S. Talukdar, Plant Breeder

Tentative plans were made for Mr. Mithlesh Kumar to conduct a portion of his Ph.D. research at ICRISAT with Dr. Bidinger during March-August 1980.

The Indian Oil Company was on strike and there was no in-country air transportation so they had to drive from Hyderabad to Bombay to depart India 15 September.

They had conferences at the University of Hawaii in Honolulu September 18 and 19. Preliminary arrangements were made for growing winter nurseries of the random-mating recombination phase of S_1 selections of two populations and possibly an F_1 hybrid seed production nursery. It is believed that growing these materials in Hawaii will reduce or eliminate several of the seed production problems encountered in Puerto Rico.

Personnel interviewed in Hawaii included:

Dr. Peter Rotar, Head, Department of Agronomy and Plant Science
Dr. J. L. Brewbaker, Corn Geneticist, Horticulture Dept., College of Tropical Agriculture
University of Hawaii
Honolulu, Hawaii

P. H. Eichhorn, Nursery Manager
Hawaiian Research, Ltd., P.O. Box D
Kaunakakai, Molokai Island, Hawaii 96748

Trip Report of E. T. Kanemasu to India

I arrived in New Delhi on September 16, 1979. I was met by Dr. Cielo Sumayao Romm, a former student. Dr. Romm is in charge of our millet experiment at Hissar. We and Dr. K. N. Rai, a millet breeder from ICRISAT, drove to Hissar (about 100 miles northwest of Delhi - three hours drive). The Harayana Agricultural University is also located at Hissar. I visited with Dr. M. Singh (Director of Soil and Water Management Center), Dr. D. P. Singh (Professor of Plant-Water Relations), Dr. R. L. Kapoor (Professor of Millet Breeding). The Crops Department is well-equipped with radiometers, psychrometers, leaf area meters, and CO_2 analyzers. They are involved in crop modeling and drought resistance studies. We will cooperate with them in a sorghum and millet drought resistance study next year. Dr. Phool Singh will come to Kansas State University and work with us for several months next year (probably January 1980).

Our research in Hissar is in cooperation with Francis Bidinger, Dave Andrews and Les Fessel of ICRISAT. On July 21, 1979, four genotypes were planted (BJ104, ICH 118, Serere 39, and ICMS 7703) in 75 cm rows. Measurements of growth, development and leaf temperatures were obtained at periodic intervals. The lateness of the planting was due to heavy and frequent rains in July. However, since planting very little rain has fallen and irrigation water was not readily available. India is suffering from a widespread drought at this time. Last year was a very wet year and subsequently, the plots were graded to provide good drainage. The 3% slope is too great for uniform water application; thus, irrigation is not efficient in filling the soil profile. Our plots, therefore, are suffering from water stress--poor stand, poor developments, and stunted plants. They may recover depending on the availability of water--rain and irrigation. Harvest will occur in October.

IV. Contacts Established First Year

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Dr. W. Seibel, Director

Dr. W. Nierle, Chemist

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Dr. Bob Wiley, Intercropping Systems
Dr. R. Jambunathan, Biochemist
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Mr. K. E. Prasad Rao, Genetic Resources
Dr. L. J. G. van der Maesen, Pulse Germplasm
Dr. D. S. Murthy, Sorghum Breeder
Dr. M. von Oppen, Economist
Mr. Dave Andrews, Millet Breeder
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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 [*Pennisetum americanum* (L.) Leeke] is native to the dry tropics and is grown and consumed by peoples in nearly all of the dry tropical regions of the world. In order to be grown successfully in the dryer temperate zones at latitudes so far north as Kansas it is usually necessary to convert the tropical materials to photoinsensitive types that can flower and reproduce under the daylength, precipitation and temperature conditions and patterns of this area. And, when labor costs and culturing factors are considered, it is also beneficial to introduce dwarfness and increased seed size into the tropical materials to enable the material to be handled mechanically to the greatest extent possible. During the conversion of these materials efforts are made to maintain and improve nutritional and quality aspects of the grain. It is believed that the products of the Kansas pearl millet improvement program will be useful not only in Kansas but also in dryer areas of the tropics, in developing countries located in the mid-latitudes, and as germplasm for breeding programs in the lower latitudes.

The following report summarizes the current status and progress of this project.

Materials and Methods

Experimental designs used in the performance testing of S_1 progenies and F_1 hybrids were 9 x 9 triple lattices and randomized complete blocks with three replications. The initial statistical analysis of tests planted in a lattice design was conducted as though the tests were randomized complete block designs.

All of the materials in the program were planted with a four-row commercial planter equipped with cone seed feeders. Single-row plots were used in all yield tests with the exception of one test planted in two-row plots. All plots were 7.3 m long with rows 91 cm wide. Sowing rates were three to six times the desired stand and final stands were machine and hand thinned to populations of 35880 and 47840 plants/ha. Nitrogen fertilizer was applied at rates of 0 and 45 kg/ha depending on the objectives of the planting. Weeds were controlled with propazine and 2,4-D herbicides and cultivation. Performance test plots were harvested with a plot combine equipped with "Hesston Head-Hunters" to pick up lodged culms.

1. Population improvement

A recurrent selection scheme involving performance testing of S_1 selections followed by recombining superior selections has been imposed

on Hays millet populations HMP550 and HMP1700. A total of 204 HMP550 Cycle 2 S_1 selections were performance tested. Controls included HMP550 C_2S_0, HMP1700 C_1S_0, bulk hybrids 1166/HMP1700 and 1212/HMP1700, and sorghum hybrids DeKalb C42A+ and E-59+ for height and maturity comparisons.

The Cycle 2 recombination generation of HMP1700, containing remnant seeds of 21 Cycle 1 S_1 lines, was grown on the Corozal Experiment Station, Puerto Rico during the period of 9 February to 22 May 1979. Seeds harvested from the Corozal planting were planted to 0.4 ha 15 June on the Hays Experiment Station to form the Cycle 2 S_0 population. Between 1500 and 2000 plants were self-pollinated by bagging one to five heads per plant. Approximately 400 plants were harvested with selection based on plant type, conformation and tillering capacity, synchrony of heading, head size and exsertion, and apparent resistance to drought and lodging.

A tall, long-headed population, HMP559, was planted in the same isolated 0.8 ha field that the population occupied in 1978. This field has been continuously cropped for four years to induce and maintain a depleted soil fertility and moisture stress environment. Several hundred primary heads of phenotypically superior plants were harvested and threshed in bulk. Seeds were sized by screens and separated on a gravity table to obtain the larger, denser portion for replanting.

Seeds of 1500 self-pollinated early-maturing F_2 segregates of 1978 Series 2 were planted in an isolated 0.75 ha field. Primary heads of between 2000 and 3000 open-pollinated plants of D_2 height and several superior D_1 plants were harvested and threshed in bulk. Selection criteria were quite broad. Nearly all plants showing desirable agronomic characteristics were harvested unless they were lodged or had reduced seed set. This composite was formed in 1976 by interplanting PI185642 D_1B_1 and D_2B_1 lines within a planting of 233 Plant Introduction Station lines and random-mating the F_1 plants in 1977 on an isolated field.

1978 Series 5 was planted on a 0.4 ha field. Approximately 3000 D_2 height F_2 segregates were self-pollinated and between 2000 and 2500 were selected for harvest. This material was orignated by interplanting a bulk of PI185642 D_2B_1 lines within an isolated planting of the World Collection Composite and random-mating the F_1 progeny in 1977.

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_1B_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 $239D_2B_2$/2PI_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. This year 195 F_2 families derived from 31 PI's were planted to

1.7 ha. Desirable segregates were self-pollinated and will be selected for possible future use as hybrid parental materials.

The initial selection and inbreeding of materials to be used as possible male parents in hybrid combinations was conducted on upland soils. A 0.4 ha block of materials in F_3 to F_6 was grown in 1979. Several A_1 lines were interplanted in the block. Phenotypically superior plants were self-pollinated and advanced generation inbreds were crossed to one or more A_1 lines to produce experimental hybrids.

Emphasis continues to be placed on the development of early-maturing female lines with increased seed size. The development and maintenance by backcrossing procedures of cytoplasmic male-sterile and male-fertility maintainer lines was conducted on nonirrigated upland soils. About 200 A_1 and A_2 cytoplasmic male-sterile lines and their respective fertility maintainer lines and 100 B_1 and B_2 selections were grown in the 1979 nursery. The lines were advanced by backcrossing two or more selected plants from within a given maintainer line to its terile counterpart. Additional selection pressure was applied at harvest to eliminate materials that show excessive inbreeding depression, reproduction difficulties, and poor performance in hybrid combinations.

3. Production of F_1 hybrids

A crossing nursery containing 286 male-fertility restorer lines and 65 D_2A_1 lines was planted on a bottomland site. The R-line group includes the parent lines of F_1 hybrids that are being tested in performance trials and selections from superior R-lines undergoing additional inbreeding and crossing to a wider range of female lines. The group of A_1 lines included 50 advanced generation PI185641 D_2A_1 lines, Tift 23DA_1E, and 15 F_1 hybrid male-steriles. The F_1 steriles were combinations involving distantly related and unrelated PI185642 D_2A_1, B_1, T23DA_1E, and T23DB_1E lines. The crossing nursery received one irrigation at the late boot stage of plant development.

Five F_1 seed production crossing blocks were planted May 25 in isolated areas. Four of the blocks were abandoned because of herbicide damage and three of these were later replanted on new sites. Each block contained 39 to 48 PI185642 D_2A_1 lines including several male-sterile F_1 hybrids. The rows planted to female lines were 12 feet long. Several rows of a single male surrounded each block of females and the male was also interplanted between female rows. The male lines planted were:

Senegal Population
78-7024 Tift 239 D_2B_2/4*Serere 3A
78-7101 Tift 239 D_2B_2/3*Serere 3A/2/PI185642
79-4104 PI287049/Tift 239 D_2B_2/2/PI287049/PI185642

4. F_1 hybrid performance testing

Performance tests and observation nurseries of F_1 hybrids contained 230 entries. Pearl millet checks included Senegal population and three 78-7024 hybrids. DeKalb sorghum hybrids C42A+, E-59+ and F-67 provided maturity, height, and yield comparisons. With the exception of a few hybrids having the Tift $23DA_1E$ female all of the hybrids had PI185642 D_2A_1 derivatives as females. Male lines were derived from crosses involving Tift $23DB_1$, Tift $239DB_2$, PI185642, Serere 3A, and 15 Plant Introduction Station lines. Senegal Population S_2 selections were also used as male parents.

5. Insect resistance studies

Crosses were made in all combinations among the inbred parents of Georgia forage hybrid, Gahi 1 during the spring of 1979. The resulting F_1 hybrids were grown in a supplementally irrigated field during the summer and self-pollinated. Following threshing, the F_2 seeds will be grown in the spring 1980 greenhouse, exposed to the greenbug aphid, *Schizaphis graminum* (Rondani), and an attempt will be made to determine the mode of inheritance of resistance to this insect.

Results and Discussion

Weather conditions and precipitation amounts and patterns, as expected, continue to have a definite influence on the responses and performances exhibited by the millets. Total precipitation received in 1979 was 600 mm or 104 percent of the long time average, however, distribution throughout the year was abnormal. Very large amounts were received before and after the growing season but during the May 1 to October 15 growing season only 222 mm of rain or 54% of the long time average was received. Record precipitation in March puddled and compacted the soils and delayed seedbed preparation until late April and early May. Lack of rainfall during May made it impossible to till the upland soils into a firm, clod free seedbed, therefore, nearly all of the upland plantings had difficulty emerging to uniform stands because of rapidly drying soils. Several plantings from 25 to 29 May were replanted in mid-June because of poor stands. Planting dates of the majority of the millet material was delayed until 13 to 16 June following a period of several small showers that provided poor to fair surface soil moisture conditions. However, the seedbed remained in a cloddy condition, dried rapidly and final stands averaged 80 percent of desired. Stored subsoil moisture was abundant, extending to the six foot level of the soil profile, and vegetative development of the millets was excellent even though rainfall during this period was below average. Good rains were received during the last half of July corresponding to the floral initiation and early culm extension stages of development. Drought stressed areas, varying in severity, began appearing throughout the fields by mid-August, but the stress was moderated by mild ambient air temperatures. A rain of 24 mm recorded 27 August allowed the latest maturing millets and sorghums to produce larger yields and appeared to benefit test weights of

earlier maturing entries. Overall, the patterns of precipitation and drought stress periods favored the millets and sorghums that flowered in fewer than 60 days or later than 70 days after planting.

1. Population improvement.

A summary of the results obtained from the S_1 progeny performance trials of HMP550 C_2 is given in Table 1. Twenty-five S_1 progenies were selected for recombination to form the Cycle 3 population. These selections have been planted in a winter nursery on Molokai Island, Hawaii, by Hawaiian Research, Ltd. Because of variations in plant stands and drought stress visual appearance ratings were considered in the selection of superior lines for recombination. Included in this rating were characteristics such as plant conformation, tillering capacity, synchrony of heading, seed set and size, and head exsertion.

One of the objectives in the improvement of HMP550 is to maintain a ratio of D_1 to D_2 plant heights of 20:80. Height differences were difficult to determine in the selection of C_1S_0 plants to self pollinate in 1978 due to severe drought and in 1979 the C_2S_1 population approached a 50:50 ratio of D_1 to D_2 heights. Excessive lodging in progenies of D_1 height have eliminated all but four D_1 height S_1 selections in the group of 25 placed in the recombination nursery. However, with the advantage of height during pollination it is expected that more than 20 percent of the 1980 C_3S_0 population will exhibit D_1 height characteristics. Within the D_2 classification plant heights usually ranged from 61 to 127 cm, with the taller D_2 plants approaching heights found in the D_1 range. In the selection process the shortest D_2 heights were eliminated in preference to the taller plants.

Final stands of HMP1700 C_2S_0 were uniform, but thinner than desired with approximately 32,000 plants per ha. Plant growth and development was good and tillering was excellent because of reduced interplant competition. Over 1500 plants were self-pollinated and about 400 superior plants were selected for harvest. Further selection for seed size and visual quality will reduce the number to 200 for 1980 S_1 progeny performance testing.

HMP559, a tall, long-headed, medium-late maturing bulk population had good growth and development. Precipitation totaling 354 mm during the winter season provided sufficient subsoil moisture for good vegetative growth and timely rains during July and August allowed good seed production. Moderate drought stress was apparent in mid-August but recovery was good following a late August rain. Plant color was noticeably lighter indicating the beginning of nitrogen fertility stress in this field. This population will continue to be grown on this field in an effort to obtain drought and fertility stress. Harvesting was delayed until over 50 percent of the plants in the field have one or more lodged culms. Plants selected for harvest must have good seed set, acceptable head exsertion, above average seed size, and no lodged culms.

The severe drought conditions of 1978 had a major effect on height selection within 1978 Series 2 Composite. Drought induced stunting of tall plants to what is considered the D_1 and D_2 height range resulted in approximately 20 percent of the plants of the 1979 planting of this composite to be taller than D_1 and the proportion of D_1 height plants was about 40 percent rather than the desired 20 percent. During the next two years the composite will be random-mated with selection confined mainly to the D_2 height range. Tall and late maturing D_1 height plants will be removed before anthesis.

Growth and development of 1978 Series 5 was very good. About 3,000 F_2 segregates with D_2 height were easily identified and self-pollinated. Between 2,000 and 2,500 of these plants were harvested with the remainder discarded because of deficiencies in stalk strength, seed set or plant height. The harvested segregates will be grown as a random-mating bulk for two or three years. Following the period of random-mating there will be at least three avenues of use: selection of lines for inbreeding and use as parental materials in the production of hybrids and synthetics; backcrossing part of the population to the world collection composite to obtain additional variability; and placing part of the population in a recurrent selection improvement program.

2. Inbred line development

Nearly all of the pearl millet materials of tropical origin entering the breeding program have maturity requirements that limit their ability to produce seed under the day length and climatic conditions found in the central Great Plains area. Therefore, it has been necessary to cross these materials to sources of early maturity, increased seed size, D_1 and D_2 plant heights, and B_1 and B_2 male fertility maintainers of the A_1 and A_2 cytoplasmic male-sterility systems. A series of these crosses has been made with 56 plant introduction lines and as time and field space permit, the F_2 plants have been grown. This year, segregating F_2 families involving 31 plant introduction lines were grown. Since segregation occurs for both height and maturity the tall, early-maturing segregates and the D_1 and D_2 segregates with maturities ranging from early to medium-late were self-pollinated. In previous years the early-tall and dwarf-late selections from several crosses have yielded additional early-maturing dwarf F_3 and F_4 segregates. It should be mentioned that the factor conditioning early maturity in PI185642 is dominant to partly dominant in most crosses. There have been crosses between some PI lines and PI185642 where the early maturity characteristic segregates as a recessive.

The development of new male-fertility restorer lines was continued by selecting within 500 lines in F_3 to F_6 generations. Several of the more promising late generation materials have been crossed to A_1 lines in the field to produce experimental F_1 hybrids or have been planted in the greenhouse for crossing.

Growth and development of the materials in the male-sterilization backcross nursery was fair to good. Nearly all of the phenotypically

superior male-sterile lines were backcrossed to their respective maintainer lines in the field. Male-sterile lines that appeared to have good combining ability in hybrid combination have been planted in the greenhouse for additional backcrossing and to be crossed to restorer lines.

3. Production of F_1 hybrids

Several hundred pollinations were made among the 286 R lines and the 66 A_1 lines and hybrids planted in the bottom land crossing nursery. The F_1 male-sterile hybrids involving widely related and unrelated lines of PI 185642D_2A_1 and B_1 and Tift 23DA_1E and B_1 will be used as female parents of 3-way hybrids to explore the possibility of improving seedling emergence and stand establishment.

Production of F_1 hybrid seeds from combinations involving 4 male lines with 39 to 48 female lines was successful in several respects. Yields of F_1 seeds ranged from less than 50 grams to over 1,300 grams with the majority of the female lines producing 200 to 500 grams of seed. Three of the female lines were found to be pollen shedders and were destroyed, but not before adjacent females were exposed to their pollen. The F_1 seeds produced will be used in yield trials, agronomic studies, and a heterosis study.

4. F_1 hybrid performance testing

Evaluation of 230 F_1 hybrids was adversely affected by variable drought stress and stand deficiencies in several plots causing nonsignificant differences upon statistical analysis. Pearl millet grain yields ranged from less than 1,000 to 5,090 kg/ha. Sorghum checks produced yields of 3770 to 8200 kg/ha. Tables 2 and 3 summarize the results obtained from several of the higher yielding hybrids. While it was not possible to obtain a complete set of data describing maturity requirements it was noted that the sorghums required from 56 to 77 days to reach the half-bloom stage and the millets ranged from 51 to over 70 days. Precipitation patterns affected yields with the largest millet grain yields obtained from millets flowering in less than 60 days and from a few flowering at about 68 to 70 days. In previous years, fertility restoration of F_1 hybrids in the A_1-B_1 cytoplasmic male-sterile system was good with only occasional plants or hybrids showing male-sterility. This year a large number of hybrids showed incomplete fertility restoration and several hybrids were completely male-sterile, even though some of those hybrids had been classified as fertile hybrids in 1977 and 1978. The cause of the reduced fertility restoration has not been determined at this time.

Another form of sterility was very prevalent and apparently was caused by the chromosome translocation associated with the A_2-B_2 system. Although several hybrids and lines with T239D_2B_2 in their background had good seed set, a much larger proportion of these materials in the 1979 program had seed set of only 10 to 50 percent as compared to previous years. This is unfortunate because breeding materials derived from

$T239DB_2$ have had excellent agronomic performance in regard to lodging resistance, head exsertion, and grain yield. Plant heights of hybrids having $T239DB_2$ in their parentage are usually in the taller portion of the D_2 height range.

5. Insect resistance studies (cooperative work with Dr. Tom Harvey)

F_2 seeds of all combinations of the four inbred parents of Gahi 1, a Georgia forage hybrid, were produced in 1979 following production of the F_1 seeds in the spring 1979 greenhouse. The F_2 seedlings will be tested for greenbug aphid resistance and segregation during the spring of 1980. The parental lines were grown and self-pollinated in the 1978 field because of excess variation in previous studies. Indications from observations of the 1979 crop of F_1's are that the variation noted earlier has been reduced but not eliminated. Therefore, it is quite possible that the results to be obtained this spring may not be as good as desired.

Table 1. Combined results of the HMP 550 Cycle 2 S_1 population improvement performance trials, Hays, 1979. 1/

Kind	Visual appearance score 1-9 2/	Plant height cm	Lodged culms at harvest score 0-9 3/	Crude protein %	Test weight kg/hl	Grain yield kg/ha
Average of 25 Cycle 2 S_1 selections to be recombined	3.0	104	0.3	16.8	80.1	2663
HMP 550 C_2 S_0 (1979 recombination)	5.2	119	0.5	17.0	79.8	2373
HMP 1700 C_1 S_0 (1976 random-inated crop)	4.2	96	0.6	16.8	79.6	2054
1166 X HMP 1700 Bulk F_1	4.5	87	0.3	16.4	79.0	1785
1212 X HMP 1700 Bulk F_1	4.7	86	0.2	16.7	78.6	1623
Sorghum hybrid DeKalb C 42 A+	3.6	105	0.6	13.8	78.8	4663
Average of all entries	4.9	109	0.7	16.8	78.9	2030

1/ Results are averages of three trials containing a total of 204 S_1 selections.

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

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

Table 2. Agronomic data of pearl millet hybrids that produced grain yields within 80 percent of the yields of sorghum hybrid DeKalb C 42 A+ in millet performance test number 6, 1979.

1979 Series number of Hybrid	1978 Series numbers of parent lines Female	Male	Pedigree Female	Male	Visual appearance score 1-9 1/	Plant height cm	Lodged culms at harvest score 0-9 2/	Crude protein %	Test weight kg/hl	Grain yield kg/ha
905	2078	7088	PI185642D_2A_1/2/Tift 239D_2B_2/4*Serere 3A		2.6	99	2.0	14.7	80	4880
907	2197	7088	PI185652D_2A_1/2/Tift 239D_2B_2/4*Serere 3A		3.0	102	0.7	14.9	81	5090
948	2270	7140	PI185642D_2A_1/3/PI287049/T239D_2B_2/2/ PI287049/PI185642		3.3	107	1.6	16.1	82	4800
950	2240	7141	PI185642D_2A_1/3/PI287049/T239D_2B_2/2/ PI287049/PI185642		2.3	119	1.3	16.6	81	4950
964	2279	7024	PI185642D_2A_1/2/Tift 239D_2B_2/4*Serere 3A		4.5	94	0.1	15.4	81	4880
937			Senegal population check		4.3	119	2.0	15.8	79	3570
910			Sorghum hybrid DeKalb C 42 A+		5.0	104	0.3	12.8	80	5920
919			Sorghum hybrid DeKalb E-59+		4.2	104	0.1	12.8	79	6760
928			Sorghum hybrid DeKalb F-67		3.0	117	0	11.4	79	8200
			Test average of 81 entries		4.3	102	0.9	15.5	79	3340

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

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

Table 3. Agronomic data of pearl millet hybrids that produced grain yields equal to the yield of sorghum hybrid DeKalb C 42 A+ in millet performance test number 7, Hays, 1979.

1979 Series number of Hybrid	1978 Series numbers of parent lines Female	Male	Pedigree	Visual appearance scores 1-9 1/	Plant height cm	Lodged culms at harvest score 0-9 2/	Crude protein %	Test weight kg/hl	Grain yield kg/ha
1004	2051	7032	PI185642D_2A_1/3/PI286998/2/PI185642/Tift 23D_2B_1	1.8	117	0.5	15.2	81	4280
1007	2112	7032	PI185642D_2A_1/3/PI286998/2/PI185642/Tift 23D_2B_1	2.0	130	0.5	15.8	81	4910
1010	2251	7032	PI185642D_2A_1/3/PI286998/2/PI185642/Tift 23D_2B_1	3.0	119	2.5	15.4	82	4110
1020	2251	7181	PI185642D_2A_1/3/PI185642/2/PI286998/Tift 23D_2B_1	5.0	107	0.1	16.2	81	3920
1037	2426	7305	PI185642D_2A_1/3/PI185642//Tift 239D_2B_2/2*Serere 3A /2/PI287057/Tift 23D_2B_1	5.0	122	1.0	14.9	81	3860
1045	2092	7216	PI185642D_2A_1/3/PI185642/Tift 23D_2B_1/2/PI295141	2.0	114	0.5	15.8	83	3810
1056	2326	7338	PI185642D_2A_1/3/PI295147/PI185642/2/PI295147/ Tift 23D_2B_1	4.5	112	0.5	14.5	83	4140
1059	2315	0043	PI185642D_2A_1/BMP 561	4.0	99	0.1	15.3	82	3810
1036	2224	7024	PI185642D_2A_1/2/Tift 239D_2B_2/4*Serere 3A	4.0	102	0	15.1	80	4370
1042	2090	7024	PI185642D_2A_1/2/Tift 239D_2B_2/4*Serere 3A	3.0	91	0.5	14.6	79	4190
1024			Senegal population check	3.5	124	2.5	15.8	81	3610
1048			Sorghum hybrid DeKalb C 42 A+	4.5	107	0.1	12.6	80	3770
1054			Sorghum hybrid DeKalb E-59+	3.0	104	0.1	12.1	79	4860
			Test average (60 entries)	4.1	114	0.8	15.1	81	3160

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

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

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

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

INTRODUCTION

Heterosis has been demonstrated in a number of crops including pearl millet (1,2,3). A heterosis study conducted in 1978 was repeated for a second year, to aid in the identification of pearl millet inbreds possessing superior combining ability for yield and other characteristics, as well as to learn more about heterosis of pearl millet in general. Inbreds and hybrids developed by A. J. Casady* at Kansas State University were used in this study.

MATERIALS AND METHODS

The experiment was conducted at the Ashland Experiment Field, Manhattan, Kansas. Three pearl millet inbreds (used as female parents), six pearl millet inbreds (used as male parents), and eighteen F_1 hybrids from all possible crosses of these parents were planted in two-row plots, 9.1 m long. Row spacing was 75 cm and seeding depth was 2.5 cm. Thirteen seeds were planted per meter of row. The experiment was a randomized complete block design in three replications. From each plot the best 9.1 m of row was harvested. Data obtained on each entry included grain weight (adjusted to 12.5% moisture), plant height, one-thousand seed weight, head number per unit area, and plant population.

RESULTS AND DISCUSSION

Results are shown in Table 1. In each of the hybrids, heterosis was clearly demonstrated. All hybrids outyielded both their male and female parents, and sixteen hybrids had yields higher than the combined yields of their parents.

In Table 2, average results for all parents and hybrids are shown. Increases in plant height, seed weight, head number, and plant population (indicating better seedling emergence in hybrids) were observed in addition to substantial yield increases.

LITERATURE CITED

1. 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.

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2. Tewari, S. N. 1970. Heterosis studies in *Pennisetum typhoides* S and H - II (grain yield components). Agra Univ., J. of Research (Science) Vol. 19, Part 3; 7-12.

3. Tewari, S. N. 1972. Studies on heterosis and combining ability for some yield characters in pearl millet (*Pennisetum typhoides* S and H). Agra Univ. J. of Research (Science), Vol. 21, Part 3:21-34.

Table 1. Heterosis Study, Manhattan

Entry	Yield (kg/ha)	Plant Ht. (cm)	1000 Seed Wt. (g)	Heads/ha (thous.)	Plants/h (thous.)
4050 x 4054	5708 a*	177	7.9	348	132
4051 x 4055	5491 ab	167	8.3	273	78
4049 x 4055	4511 a-c	158	6.9	203	85
4050 x 4053	4502 a-c	165	7.9	259	108
4050 x 4055	4415 a-d	156	6.5	220	72
4051 x 4054	4374 a-d	159	7.9	167	80
4049 x 4059	4256 a-d	152	7.7	245	88
4050 x 4059	4223 a-d	147	7.7	230	112
4051 x 4059	4151 a-d	142	8.6	270	88
4051 x 4053	4024 a-e	165	8.3	198	122
4051 x 4057	3626 a-f	157	8.4	231	141
4049 x 4058	3620 a-f	151	6.8	201	131
4051 x 4058	3563 a-f	157	7.8	226	86
4049 x 4053	3482 a-f	142	7.7	185	69
4050 x 4058	3470 b-f	153	7.3	241	129
4050 x 4057	3434 b-f	159	7.2	233	88
4049 x 4057	3414 b-f	167	7.5	182	105
4049 x 4054	3246 b-f	144	7.5	166	73
4053 (♂)	2430 c-g	124	6.5	187	57
4054 (♂)	2248 d-g	123	6.1	243	75
4055 (♂)	1907 e-g	115	4.3	191	92
4059 (♂)	1565 e-g	128	7.0	185	89
4049 (♀)	1266 fg	106	5.9	202	160
4058 (♂)	913 g	113	5.6	195	57
4057 (♂)	887 g	114	6.7	143	79
4051 (♀)	861 g	103	5.0	124	47
4050 (♀)	706 g	75	5.2	209	36

* Duncan's Multiple Range Test for yield. Values with the same letter are not significantly different, (α = .05).

Table 2. Results for all parents and hybrids.

	Yield (kg/ha)	Plant Ht. (cm)	1000 Seed Wt.(g)	Heads Thous./ha	Plants Thous./ha
Female parents	944	95	5.4	178	81
Male parents	1658	120	6.0	191	75
Hybrids	4084	157	7.7	227	99

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

PART I

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

It has been previously reported that pearl millet hybrids can yield as well as grain sorghum hybrids (1). Unfortunately, these millets displayed a number of undesirable agronomic characteristics including excessive plant height (which contributes to lodging) and small seed size. Considerable effort has been made by plant breeders to improve these and other characteristics while maintaining or increasing grain yield. In order to assess progress toward these goals, pearl millet hybrids developed at the Fort Hays Branch Experiment Station, Hays, Kansas, were evaluated in yield trials at several locations. Commercial sorghum hybrids and open pollinated populations of pearl millet were included for comparison.

MATERIALS AND METHODS

Six locations were selected in Kansas for the planting of hybrid yield trials, 1) Ashland Experiment Field, Manhattan; 2) Garden City Branch Experiment Station, Garden City; 3) Fort Hays Branch Experiment Station, Hays; 4) Southwest Kansas Experiment Field, Minneola; 5) Sandyland Experiment Field, St. John; and 6) Tribune Branch Experiment Station, Tribune.

At each location, ten F_1 pearl millet hybrids, five open pollinated populations of pearl millet, and three commercial sorghums, DeKalb vars. C42A+, E59+, and F67), were planted in two row plots, 9.1 m long. (At Hays, one additional pearl millet hybrid and three additional pearl millet populations were included). Row spacing was 75 cm and seeding depth was 2.5 cm. Thirteen seeds were planted per meter of row. The experiment was a randomized complete block design in three replications (four replications at Hays). From each plot the best 9.1 m of row was harvested. Data obtained on each entry included: grain weight (adjusted to 12.5% moisture), one thousand seed weight, plant height, number of heads, and (at Manhattan only) number of plants.

RESULTS AND DISCUSSION

Results of the hybrid yield studies are shown in Tables 1 through 6.

At all locations except Manhattan, pearl millet hybrid yields often were not significantly different than grain sorghum hybrid yields. At Manhattan high rainfall may have favored higher sorghum yields. But in the drier regions of the state, millet did perform admirably in comparison with sorghum, and these results are encouraging. It should be noted that the E59+ and F67 sorghums are substantially later in maturity than most of the millets in this study, and as such cannot be used fairly in comparison. In future studies, earlier maturing sorghums will be included.

Also listed in the tables are average plant heights, thousand seed weights, and head numbers.

The data indicate that short statured millet hybrids were the highest yielders. Shortness should reduce lodging and increase the feasibility of machine harvest.

Millet seed weights were less than sorghum seed weights but were slightly higher than the seed weights reported for millets tested in 1978, (1). This apparent increase may be the result of better growing conditions in 1979 than in 1978, but some genetic gain may have been made in the selection for larger seeded types.

There was no apparent relationship between head numbers per hectare and yield. High head numbers were found in association with high, medium, and low yielding millets. This relationship was further examined at Manhattan. Plant numbers, head numbers per plant, yield per head, and yield per plant are shown in Table 1. Differences in plant populations between hybrids were not significant. There was no apparent relationship between the number of heads per plant and yield. However, higher yielding millets tended to produce greater yields per head as well as greater yields per plant. Future studies will be necessary to confirm these relationships.

LITERATURE CITED

1. 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.

Table 1. Hybrid Study, Manhattan

Hybrid	Yield (Kg/ha)	Plant Ht. (cm)	1000 Seed Wt.(g)	Heads Thous./ha	Plants Thous./ha	Heads/ Plant	Yield/ Head (g)	Yield/ Plant (g)
C42A+ Sorghum	6891 a*	-	22.0	134	86	1.6	51	80
F67 Sorghum	6842 a	-	26.1	141	60	2.4	49	114
E59+ Sorghum	6642 a	-	26.2	130	67	1.9	51	99
2118 x 7101	4063 b	139	10.0	304	95	3.2	13	43
HMP 559	3981 bc	280	8.2	154	88	1.8	26	45
2224 x 7101	3770 b-d	116	9.9	212	84	2.5	18	45
2090 x 7101	3751 b-d	113	10.9	189	37	5.1	20	101
2279 x 7101	3662 b-d	121	10.9	232	82	2.8	16	45
2224 x 7024	3470 b-d	91	10.1	237	84	2.8	15	41
2279 x 7024	3442 b-d	108	9.9	222	138	1.6	16	25
HMP 550	3351 b-d	171	9.8	233	103	2.3	14	33
HMP 557A	3345 b-d	147	9.3	252	101	2.5	13	33
2090 x 7024	3266 b-d	101	10.7	243	112	2.2	13	29
2118 x 7024	3245 b-d	88	8.9	224	105	2.1	14	31
HMP 1700 ('77)	2957 b-d	125	7.4	262	138	1.9	11	21
HMP 561	2876 cd	162	9.8	215	99	2.2	13	29
1166 x 1700	2777 d	100	6.4	275	101	2.7	10	27
1212 x 1700	1402 e	105	5.8	209	97	2.2	7	14

*Duncans Multiple Range Test for yield. Values with the same letter are not significantly different, (α - .05).

Table 2. Hybrid Study, Garden City

Hybrid	Yield (kg/ha)	Heads (thous./ha)
F67 Sorghum	4598 a*	121
C42A+ "	3587 ab	108
E59+ "	3395 bc	101
2224 x 7024	3306 b-d	185
2224 x 7101	3029 b-e	198
2118 x 7024	2952 b-e	179
2279 x 7024	2920 b-e	193
2279 x 7101	2841 b-e	170
HMP 550	2424 b-f	191
2090 x 7024	2388 b-f	147
HMP 557A	2228 c-f	190
2090 x 7101	2188 d-f	135
2118 x 7101	2159 d-f	180
HMP 1700 ('77)	2120 d-f	204
HMP 561	2032 ef	187
1166 x 1700	1606 fg	183
1212 x 1700	1389 fg	208
HMP 559	844 g	96

* Duncan's Multiple Range Test for yield. Values with the same letter are not significantly different, (α = .05).

Table 3. Hybrid Study, Hays

Hybrid	Yield (kg/ha)	Plant Ht. (cm)	1000 Seed Wt. (g)	Heads (thous/ha)
F67 Sorghum	5316 a*	111	25.2	113
E59+ Sorghum	5047 a	106	27.6	116
C42A+ Sorghum	4619 ab	97	28.5	130
Tift 1	3848 bc	143	8.6	352
2090 x 7024	3679 b-d	86	11.6	242
2279 x 7101	3603 b-d	99	10.2	274
2090 x 7101	3311 c-e	106	10.8	230
HMP 02	3100 c-f	123	10.2	288
2118 x 7024	3087 c-f	83	9.6	238
2279 x 7024	3060 c-f	92	9.8	237
2224 x 7024	3035 c-f	90	10.7	213
HMP 550	3025 c-f	124	9.7	293
HMP 561	2947 c-g	113	9.1	303
HMP 557A	2794 c-g	96	9.0	252
HMP 1700 ('77)	2785 c-g	102	8.4	372
2224 x 7101	2725 c-g	88	9.7	211
2118 x 7101	2538 d-h	95	8.5	269
1166 x 1700	2113 e-h	86	7.4	349
1212 x 1700	1912 f-h	83	7.8	236
HMP 1700 ('79)	1881 f-h	95	8.8	172
Senegal Bulk	1756 gh	115	7.2	176
HMP 559	1176 h	240	7.7	121

* Duncan's Multiple Range Test for yield. Values with the same letter are not significantly different, ($\alpha = .05$).

Table 4. Hybrid Study, Minneola

Hybrid	Yield (kg/ha)	Heads (thous./ha)
C42A+ Sorghum	3862 a*	132
E59+ Sorghum	3620 ab	131
2224 x 7024	3394 a-c	163
2090 x 9024	3026 a-d	163
F67 Sorghum	2921 b-e	104
2118 x 7024	2858 b-f	142
2279 x 7024	2836 b-f	165
2224 x 7101	2834 b-f	194
HMP 561	2634 c-f	218
1166 x 1700	2539 c-f	214
2090 x 7101	2438 c-f	149
2279 x 7101	2430 d-f	179
2118 x 7101	2421 d-f	193
HMP 550	2346 d-f	166
HMP 557A	2042 ef	171
HMP 1700 ('77)	1985 f	188
1212 x 1700	1974 f	184
HMP 559	1062 g	90

* Duncan's Multiple Range Test for yield. Values with the same letter are not significantly different, (α = .05).

Table 5. Hybrid Study, St. John

Hybrid	Yield (kg/ha)	1000 Seed Wt. (g)	Heads (thous./ha)
2224 x 7024	2574 a*	10.2	272
2279 x 7024	2477 a	9.6	294
F67 Sorghum	2426 a	23.7	116
C42A+ Sorghum	2280 ab	25.9	135
2118 x 7101	2208 ab	9.7	256
2090 x 7024	2199 ab	11.1	186
HMP 550	2034 a-c	9.2	216
HMP 561	1941 a-d	9.1	247
2118 x 7024	1860 a-e	9.1	195
E59+ Sorghum	1816 a-e	26.3	127
2224 x 7101	1791 a-e	9.1	229
HMP 557A	1607 b-e	8.2	187
2090 x 7101	1535 b-e	10.5	134
HMP 559	1505 b-e	6.8	114
2279 x 7101	1502 b-e	9.7	169
HMP 1700 ('77)	1286 c-e	7.1	222
1212 x 1700	1209 de	7.1	261
1166 x 1700	1089 e	7.3	225

* Duncan's Multiple Range Test for yield. Values with the same letter are not significantly different, (α = .05).

Table 6. Hybrid Study, Tribune

Hybrid	Yield (kg/ha)	1000 Seed Wt. (g)	Heads (thous./ha)
C42A+ Sorghum	5666 a*	21.7	148
E59+ Sorghum	5442 a	25.6	179
2224 x 7024	4598 ab	10.7	298
F67 Sorghum	4576 ab	20.9	139
2279 x 7024	4319 ab	10.3	337
2090 x 7024	4286 a-c	11.0	368
2118 x 7101	4202 a-d	10.3	398
2224 x 7101	3953 a-d	10.4	309
2090 x 7101	3521 b-d	10.9	234
HMP 1700 ('77)	3334 b-d	8.5	340
HMP 561	3316 b-d	9.9	352
2279 x 7101	3309 b-d	10.7	261
HMP 557A	3165 b-e	10.1	338
2118 x 7024	3151 b-e	11.3	357
1212 x 1700	2894 b-e	8.6	293
HMP 550	2497 c-e	10.5	269
1166 x 1700	2470 de	9.0	282
HMP 559	1444 e	9.0	153

* Duncan's Multiple Range Test for yeild. Values with the smae letter are not significantly different, (α = .05).

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

PART II

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

Pearl millet breeding ongoing at the Coastal Plains Station, Tifton, Georgia* has resulted in the development of several important pearl millet forage varieties. In recent years, however, attention has been given in part to the development of pearl millet hybrids for grain production. Several of the more promising hybrids from this program were tested in yield trials in Kansas. Two open pollinated populations of pearl millet and two commercial sorghum hybrids were included for comparison.

MATERIALS AND METHODS

Hybrid yield studies were conducted at two locations in Kansas, the Ashland Experiment Field, Manhattan, and the Fort Hays Branch Experiment Station, Hays. Nine pearl millet F_1 hybrids, two open pollinated populations of pearl millet, and two commercial sorghum hybrids (DeKalb vars.C42A+ and C46+) were planted in two-row plots 7.6 m long at Manhattan and in single row plots 9.1 m long at Hays. Row spacing was 75 cm and seeding depth was 2.5 cm. Thirteen seeds were planted per meter of row. The experiment was a randomized complete block design in three replications. The best 6.1 m and 4.6 m of row was harvested at Manhattan and Hays, respectively. Data obtained on each entry included grain weight (adjusted to 12.5% moisture), plant height, number of heads, and at Manhattan only, plant population.

RESULTS AND DISCUSSION

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

At Manhattan, millet yields were not significantly different than sorghum yields in all but two cases. However, at Hays sorghum yields were significantly higher than millet yields. Millet yields were similar at both locations, however, sorghum yields were higher at Hays than Manhattan. Localized variations in soil type or texture may have been responsible for depressed sorghum yields at Manhattan.

Also listed in the tables are average plant height, head number per hectare, and at Manhattan only, plant number per hectare, head number per plant, yield per head, and yield per plant. At both locations, taller millets produced higher yields. At Hays, a large number of heads per hectare was also characteristic of higher yields though this was not found at Manhattan. At Manhattan, there was no apparent relationship between yield and plant population, head number per plant, yield per plant, yield per head, nor yield per plant.

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Table 1. Hybrid Study, Manhattan

Hybrid	Yield (kg/ha)	Plant Ht. (cm)	Heads (thous./ha)	Plants (thous./ha)	Heads/ Plant	Yield/ Head (g)	Yield/ Plant (g)
C42A+ Sorghum	4153 a*	-	127	52	2.4	33	80
Tift 2	3938 ab	216	429	95	4.5	9	41
C46+ Sorghum	3800 ab	-	100	42	2.4	38	90
Tift 15	3625 ab	183	355	129	2.8	10	28
Tift 1	3536 ab	239	388	141	2.8	9	25
Tift 9	3498 a-c	242	420	34	12.4	8	103
Tift 8	3426 a-c	192	180	113	1.6	19	30
RMP-1	3412 a-c	184	280	125	2.2	12	27
Tift 12	2805 a-c	213	414	111	3.7	7	25
Serere 3A	2697 a-c	245	136	105	1.3	20	26
Tift 7	2595 a-c	240	408	99	4.1	6	26
Tift 3	2541 bc	129	420	136	3.1	6	19
Tift 11	1960 c	149	223	99	2.3	9	20

* Duncan's Multiple Range Test for yield. Values with the same letter are not significantly different, (α = .05).

Table 2. Hybrid Study, Hays

Hybrid	Yield (kg/ha)	Plant Ht. (cm)	Heads (thous/ha)
C42A+ Sorghum	5985 a*	110	195
C46+ Sorghum	5959 a	121	131
Tift 2	3920 b	165	440
Tift 12	3887 b	163	500
Tift 9	3658 b	139	580
Tift 1	3613 b	188	424
Tift 3	3580 b	100	460
Tift 7	3529 b	175	842
Tift 15	3493 b	118	297
RMP-1	3362 b	114	296
Serere 3A	3211 b	185	274
Tift 11	1156 c	113	265
Tift 8	327 c	127	214

* Duncan's Multiple Range Test for yield. Values with the same letter are not significantly different, (α = .05).

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 SELECTED HERBICIDE APPLICATIONS AND DELAY IN PLANTING

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

INTRODUCTION

Large scale production of pearl millet is possible only if selective herbicides are used to control weeds. Research pertaining to use of herbicides in pearl millet production is very limited at the present time. Initial efforts to test herbicides for weed control in millet should focus on herbicides used in grain sorghum [*Sorghum bicolor* (L.) Moench] production. Grain sorghum and pearl millet are found in adjoining or overlapping geographical regions and are botanically similar (1).

The objectives of this research were: 1) to determine if herbicides used in sorghum production are tolerated by pearl millet, 2) to determine if herbicides not tolerated by sorghum are also phytotoxic to pearl millet, and 3) to determine if tolerance in pearl millet can be increased if planting is delayed after herbicide applications.

METHODS AND MATERIALS

Tolerance of pearl millet to selected herbicides was re-examined at the same site at Manhattan, KS in 1979 as in 1978 (2). Conventional methods for seedbed preparation were utilized on a Reading silt loam soil with 2.6 percent organic matter content and a pH of 6.3. Herbicides were applied by a tractor-mounted sprayer equipped with tapered flat fan nozzles with water as carrier at a volume of 1.87 L/ha and a pressure of 1.2 kg/cm^2. Treatments included triazine herbicides (atrazine, propazine, cyanazine, or terbutryn), a diphenylether herbicide (bifenox), an acetanilide herbicide (propachlor) and a substituted urea herbicide (linuron) at approximately the same rates used in grain sorghum production. Thiocarbamate herbicides (EPTC or butylate) in combination with protectant (R-25788) were also applied to determine their efficacy in volunteer millet control. Herbicides were immediately incorporated to a depth of 7.6 cm with a power-driven rotary tiller. Simultaneous planting of 'RMP1' pearl millet and furrow application of the insecticide carbofuran (2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate) occurred within eight hours after herbicide application.

The plots consisted of four rows each measuring 9 meters long and 76 cm wide and were kept weed free by occasional hand hoeing. Data were collected from the center two rows of each plot and consisted of visual injury ratings, plant height and number of heads harvested. Grain yields were obtained after millet heads were harvested by hand, dried and threshed.

Data reported from the field study represent means of three replications in a randomized complete block design.

Effect of delay in planting after herbicide application on pearl millet growth was investigated in the greenhouse. A Haynie very fine sandy loam soil with 8.6% clay, 34.6% silt and 56.8% sand, a pH of 7.0 and 0.7% organic matter was sifted through a 2mm screen. Atrazine, propazine, terbutryn and metolachlor, an acetanilide herbicide at 2.2 kg/ha and propachlor and xylachlor, another acetanilide herbicide at 3.4 kg/ha were applied to the soil with a moving nozzle pot sprayer, delivering 234 L/ha at 1.75 kg/cm^2 pressure. The soil was mixed immediately to uniformly distribute the herbicide and then placed to a depth of 5 cm in flats measuring 15 by 30 cm. 'RMP1' pearl millet was planted at a density of 30 seeds per flat and at a depth of 0.6 cm. Live plants were counted and height measured 25 days after planting. Top growth was then removed and weighed on a dry matter basis.

The greenhouse temperatures were 25 to 35 C without supplemental lighting. Treatments were replicated three times in a completely randomized design. Data presented are means of two experiments.

RESULTS AND DISCUSSION

Atrazine, propazine, terbutryn and bifenox applications caused only slight injury in pearl millet seedlings at Manhattan, Kansas in 1979 (Table 1). Cyanazine applications caused significantly greater injury in seedlings as compared to other triazine herbicide applications. Propachlor applied alone or in combination with other herbicides or EPTC plus protectant essentially prevented emergence while butylate plus protectant severely injured pearl millet. Triazine herbicides or bifenox did not significantly reduce height, number of heads or yield of treated millet. Susceptibility of pearl millet to propachlor treatments was substantially reduced when a 3-week delay occurred between herbicide application and planting. Effect of herbicide applications on pearl millet in 1979 was similar to the effect observed in 1978 (2).

A greenhouse study revealed that a significant interaction occurred between herbicide application and delay in planting in respect to plant survival or growth. Pearl millet tolerance to selected triazine herbicides generally was not affected by delay between herbicide application and planting (Table 2). Number of live plants averaged across planting dates was significantly reduced by atrazine but not propazine or terbutryn applications. All triazine applications significantly reduced height and dry weight per plant of pearl millet; propazine applications caused the least effect. Phytotoxicity of triazine herbicides could be attributed to the high pH and low organic matter content of the soil used in this study.

Tolerance of pearl millet to acetanilide herbicides was dependent on delay between herbicide application and planting. Number of live plants, height and dry weight per plant were significantly increased if a 2-week delay occurred between herbicide application and planting. Generally, survival or growth did not increase if planting was delayed four weeks as compared to two weeks after application. Number of live

plants averaged across planting dates was not significantly different among acetanilide herbicide applications. Metolachlor applications caused a greater reduction in height and dry weight per plant than did propachlor or xylachlor applications.

LITERATURE CITED

1. Martin, J. H., W. H. Leonard and D. L. Stamp. 1976. Principles of field crop production. 3rd Edition. MacMillan Publishing Co., Inc., New York. 1118 pp.

2. Ndahi, W. B., O. G. Russ, and M. C. Lundquist. 1979. Herbicide susceptibility of pearl millet [*Pennisetum americanum* (L.) K. Schum]. In Improvement of pearl millet: first annual report. Kansas State University, Manhattan, KS.

Table 1. Seedling injury and growth of pearl millet treated with selected herbicides at Manhattan, KS in 1979.

Herbicide	Rate (kg/ha)	Injury rating[a,b]	Height[a,c] (cm)	Heads[a,c] (number/ha X10^3)	Yield[a,c] (kg/ha)
Atrazine	2.4	0.10 C	160 A	375 AB	3218 A
Propazine	2.7	0.03 C	163 A	331 A-C	2984 AB
Cyanazine	1.7	0.50 B	135 A	326 A-C	2863 AB
Terbutryn	2.7	0.10 C	157 A	319 A-D	2836 AB
Bifenox	1.4	0.03 C	166 A	369 A-C	3138 A
Propachlor	3.4	0.98 A	76 BC	164 E	1048 CD
Propachlor + Atrazine	3.4 + 1.4	1.00 A	89 B	240 B-E	1915 A-C
Propachlor + Bifenox	3.4 + 1.4	1.00 A	76 BC	224 B-E	1841 A-C
Propachlor + Linuron	3.4 + 1.1	1.00 A	91 B	155 DE	1116 CD
EPTC + R-25788	6.7 + 0.6	1.00 A	0 D	0 G	0 E
Butylate + R-25788	6.7 + 0.3	0.83 A	30 C	6 F	280 D
None	----	0.00 C	170 A	423 A	2997 AB

[a] Means followed by common letters are not significantly different at the 5% level according to Duncan's Multiple Range Test.

[b] Injury ratings taken 10 days after treatment. Rating scale: 0 = no injury, 1.0 = complete death.

[c] Plots treated with propachlor alone or in combination with other herbicides were replanted 21 days after application.

Table 2. Effect of delay in planting after herbicide application on pearl millet growth in the greenhouse.

Herbicide	Rate (kg/ha)	Delay in planting	Live Plants	Height	Dry weight/plant
			% check[a]		
Atrazine	2.2	0 weeks	71 C-E	65 D	32 G-J
Propazine	2.2		116 A	98 AB	69 B-F
Terbutryn	2.2		97 A-C	77 CD	42 E-I
Metolachlor	2.2		31 F	7 F	5 J
Xylachlor	3.4		47 EF	25 E	18 H-J
Propachlor	3.4		3 G	7 F	23 H-J
None	---		100 A-C	100 A	100 AB
Atrazine	2.2	2 weeks	83 B-D	72 D	47 D-H
Propazine	2.2		82 B-D	90 A-C	73 B-E
Terbutryn	2.2		93 A-D	80 CD	64 C-G
Metolachlor	2.2		67 DE	16 F	11 IJ
Xylachlor	3.4		72 C-E	72 D	86 BC
Propachlor	3.4		88 A-D	92 A-C	124 A
None	---		100 A-C	100 A	100 AB
Atrazine	2.2	4 weeks	80 B-D	67 D	38 F-J
Propazine	2.2		104 AB	83 A-D	80 B-D
Terbutryn	2.2		101 A-C	79 A-C	64 C-G
Metolachlor	2.2		74 C-E	23 E	28 H-J
Xylachlor	3.4		80 B-D	83 A-D	95 A-C
Propachlor	3.4		92 A-D	91 A	102 AB
None	---		100 A-C	100 A	100 AB
Means					
Atrazine	2.2	-------	78 B	68 D	39 D
Propazine	2.2	-------	101 A	90 B	74 BC
Terbutryn	2.7	-------	97 A	79 C	56 C
Metolachlor	2.2	-------	57 C	15 E	15 E
Xylachlor	3.4	-------	66 BC	60 D	66 BC
Propachlor	3.4	-------	61 C	63 D	83 B
None	---	-------	100 A	100 A	100 A

[a] Means within columns followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range Test. Interaction between planting date and herbicide application was significant at 5% level for all three parameters.

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

Pearl millet [*Pennisetum americanum* (L.) Leeke] is grown in the hot semi-arid areas of Africa and India, especially in dry and infertile areas where it seems better adapted than other cereal grains. While its ability to overcome drought and other marginal environmental conditions during its growth cycle has been recognized, seedling establishment remains a major problem with the crop.

Varieties and hybrids with improved seed and seedling vigor are being developed. Present cultivars could be improved if selection could be made within a seedlot for the most vigorous seeds. To allow this selection physical characteristics of the pearl millet seed which are related to vigor would have to be identified.

During 1979 seedlots of two varieties and two inbreds of pearl millet were separated on the basis of seed size and seed density. Field performance of the seed fractions was based upon seedling establishment and grain yield. Kiesselbach (8) found that small seeds of winter wheat, spring wheat, and oats yielded only 81.4%, 82.1%, and 82.6% as much as the same number of large seeds within the same seedlot. Plants from small seeds were shorter, tillered less, and were slightly later in maturity. When put on a practical scale, planting a bushel of large seeds or a bushel of small seeds, the yield differences narrowed. The increased number of plants from the small seeds made up for what they lacked in individual productivity.

Three barley varieties were separated into three sizes and planted at three different seeding rates (4). The large seeds produced significantly more tillers and yielded the highest over all seeding rates. Emergence counts were found to be similar among sizes. Boyd et al.(3) found seed size to be positively related to seedling vigor in F_3 lines of barley.

In soybeans, Smith and Camper (18) screened large and small seeds from the same seedlot and compared them with the original seedlot. The large seeds resulted in taller plants, especially at early stages of growth, and tended to outyield both the small seeds and the original seedlot.

Sorghum seed size, as studied by Abdullahi and Vanderlip (1), was found to be a vigor factor. In laboratory stress tests large seeds produced higher germination percentages than the small seeds. When placed under field conditions, although the difference was not as great, the larger seeds continued to produce more plants.

Physiologically, why does the larger seed have more vigor? One hypothesis found in the literature is that the large seed has more carbohydrate reserve for the nourishment of the young plant (7, 8, 10, 18). With this added reserve, leaf area is larger in the first few leaves. In barley (7) the first two leaves produced by large seeds were both longer and wider than plants from small seed regardless of temperature. The floret count from these same plants was found to be more closely related to the area of the first two leaves than to the flag leaf, implying that early leaf area was more important than flag leaf area in determining this yield component. Nadrornik (14), however, found higher germination and vigor in ryegrass seedlings resulting from large seeds even when the endosperm was partially removed.

Ries and Everson (16), studying wheat seedling vigor, found protein content to be positively related to seed size. Seedlots with higher protein contents resulted in more vigorous seedlings and often higher yields. Ries et al. (15) showed that increasing protein with foliar nitrogen application at anthesis improved seedling vigor. Similar studies have shown both high protein seeds and large seeds to be highly correlated with seedling dry weight at 20 days (11).

Though protein content can be sampled for and selected for, the ease and utility of size as a selection tool makes it more attractive. It also allows selection within a single seedlot which is more often needed both here and abroad.

Density has the ability to distinguish fully filled, mature kernels from premature seeds as indicated by embryo:total seed weight ratios (2). Seeds high in density have more organic and inorganic material available to the seedling regardless of the size.

In soybeans there was a slight positive correlation between the size and density (17). Density was more strongly related to protein content (positively) than to size.

In sorghum, size and density both seem to be factors related to the vigor of individual seeds (12). Though no yield differences were apparent if enough viable seeds are planted, selection by either parameter was suggested to improve seedling vigor in questionable seedlots.

Vigor of rice seed in terms of emergence percent, rate of germination, and germination percent were all closely related to the density of the seed (19). In developing countries, where hand harvesting is predominant, density becomes critical as a seed quality characteristic. Modern combines are fairly efficient at density separation, thus low density seeds may be eliminated at harvest. In parts of Taiwan and Japan farmers separate their seed in ammonium sulfate solutions, use for seed those that sink to the bottom, then fertilize with the solution (19).

The problem of seed size in pearl millet was compared to that of alfalfa by Misra and Kumar (13). The physical relationship between the seed and soil particles puts the small seed at a disadvantage. The small seed must be planted shallow to emerge. Millet growing regions, however, typically have sandy soils where shallow planting results in low moisture problems because of the rapid drying of sands.

Hybrid pearl millets do offer heightened seedling vigor (9). When hybrids were compared to the parental lines, however, increased vigor, as measured by dry matter produced, only occurred for ten days after germination. After that parents and hybrids advanced at nearly the same rate.

Use of seed size or density separations seems appropriate with pearl millet. Garg et al.(5)found a positive relationship between the two characters over 41 varieties of pearl millet. Selection of large seed would improve seed:soil relations and may increase the average density of the seeds. High density could also be a selection tool. Immature seeds may also be eliminated.

MATERIALS AND METHODS

Seed size 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.

In 1979, Serere 3A and RMP1 along with two inbred lines from Fort Hays were utilized to observe both wide and narrow based genetic material.

Seed size was determined by running a portion of each of the seedlots through a series of round hole sieves. The four size categories were those seeds retained on a 7/64", through a 7/64" but retained on a 6½/64", through a 6½/64" but retained on a 5½/64", and through a 5½/64".

Density separations were made by placing a portion of each original seedlot in sucrose solutions with densities resulting in dividing the seedlot into three fractions (Table 1).

Table 1. Solution densities used to separate seedlots.

Variety	Solution densities	
	1	2
Serere 3A	1.241	1.275
RMP-1	1.241	1.275
Inbred 771240 (A)	1.219	1.275
Inbred 772043 (B)	1.156	1.219

Seeds were washed in distilled water and allowed to air dry after the sucrose soak. To eliminate possible effects of the density separation technique, an additional portion of each original seedlot was soaked in the sucrose solutions and allowed to come to equilibrium. These check seeds were then removed without regard to their density, washed and air dried.

Depletion of the source (leaf area) and sink (heads) was done to produce three seedlots in which the effect of seed size could be tested directly. In 1978 Serere 3A and inbred B were grown in isolation and at anthesis plants were given one of the following treatments: 1) approximately half of the area of each leaf removed, 2) approximately the top half of each head cut off, and 3) left as a control. Seed from these plants was also planted in the 1979 study.

Protein (Kjeldahl-N determination x 6.25) was determined on each seedlot by size, density, sucrose check, and the original seedlot.

All the varieties had the sizes, densities, sucrose check, and original seedlot planted 50 seeds/row in two row plots, 76 cm between rows and 4.6 m long, with a vacuum planter. Experimental design was a randomized complete block with four replications and two planting dates per location. The Manhattan studies were planted on 16 May and 12 June 1979 and St. John on 15 May and 6 June. Emergence counts were made 10 to 30 days after planting.

RESULTS AND DISCUSSION

Manhattan

Date of planting did not affect emergence or head production, but did affect yield. Date x variety interactions were found significant for yield, due mostly to the magnitude of differences between the varieties (Fig. 1).

Though the date x treatment interaction was significant for yield (Fig. 2), it is consistent with the final hypothesis that small and low density seeds were associated with poor field performance.

St. John date of planting could not be analyzed. Both dates were planted in good conditions, however, the second planting was on ground which had both varied fertilizer and herbicide carryover. After emergence counts were taken on the second date, it was decided that too many other factors would result in yield variation and the date was abandoned. The first planting was carried on to harvest though it showed nitrogen stress

Seed Size

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.

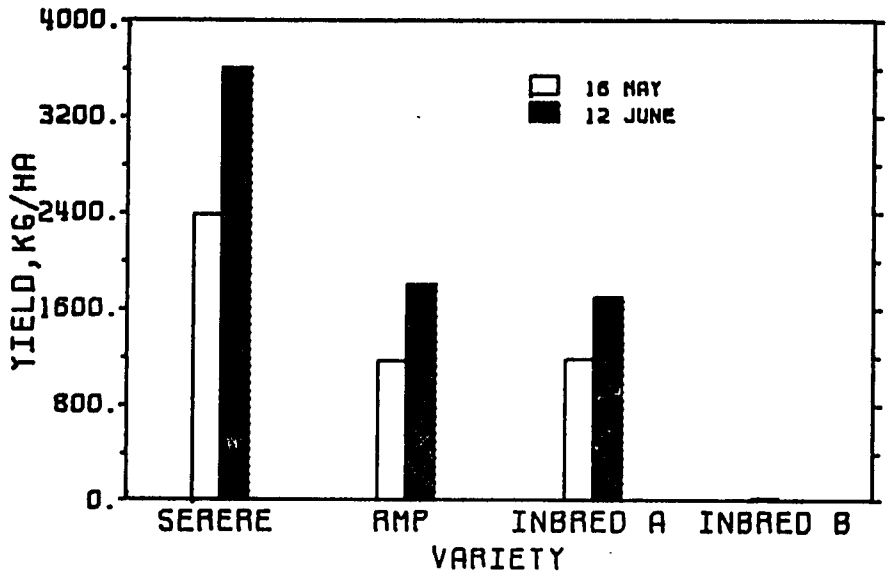

Figure 1. Grain yield at Manhattan in 1979 by variety and planting date.

Varietyxtreatment interactions were significant at both locations for emergence (Figs. 3 and 4). As in 1978, the smallest seed size resulted in poorest stands. Emergence data with all the varieties show the tendency for the largest seed also to emerge poorly.

The ability of seed size to bring about seedling vigor was affected by the seedlot which had been sieved. Serere 3A and RMP both had the two largest size categories produce the most seedlings. The largest seed of Inbred A performed almost as poorly as the smallest seed. Inbred B, the seedlot lowest in vigor, had size directly related to emergence performance. Even with the significant interaction the smallest seeds consistantly were lowest in vigor.

Grain yield was significantly affected by seed size. At St. John there was a positive relationship between size and grain yield (Fig. 5). At Manhattan in 1979 a significant datextreatment effect was found (Fig. 6). The Manhattan location was infested with chinch bugs and varietal preferences were apparent.

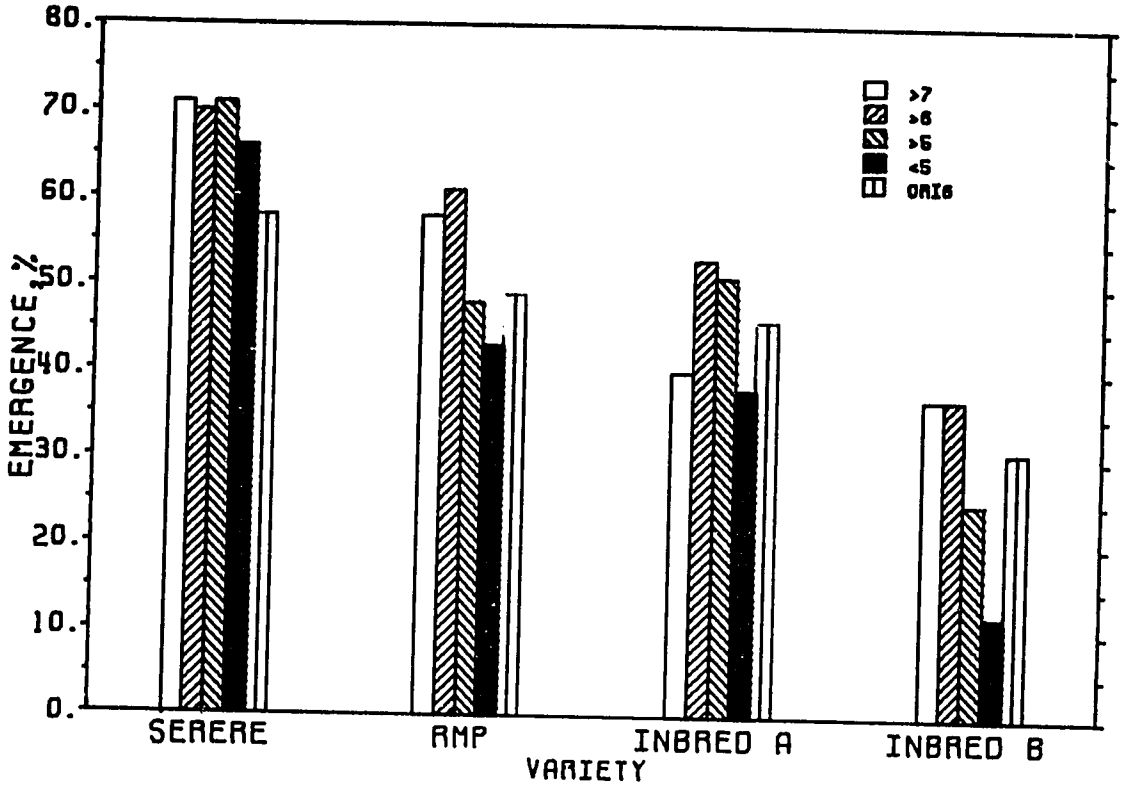

Figure 3. Emergence percentages at St. John in 1979 for the size treatments by variety.

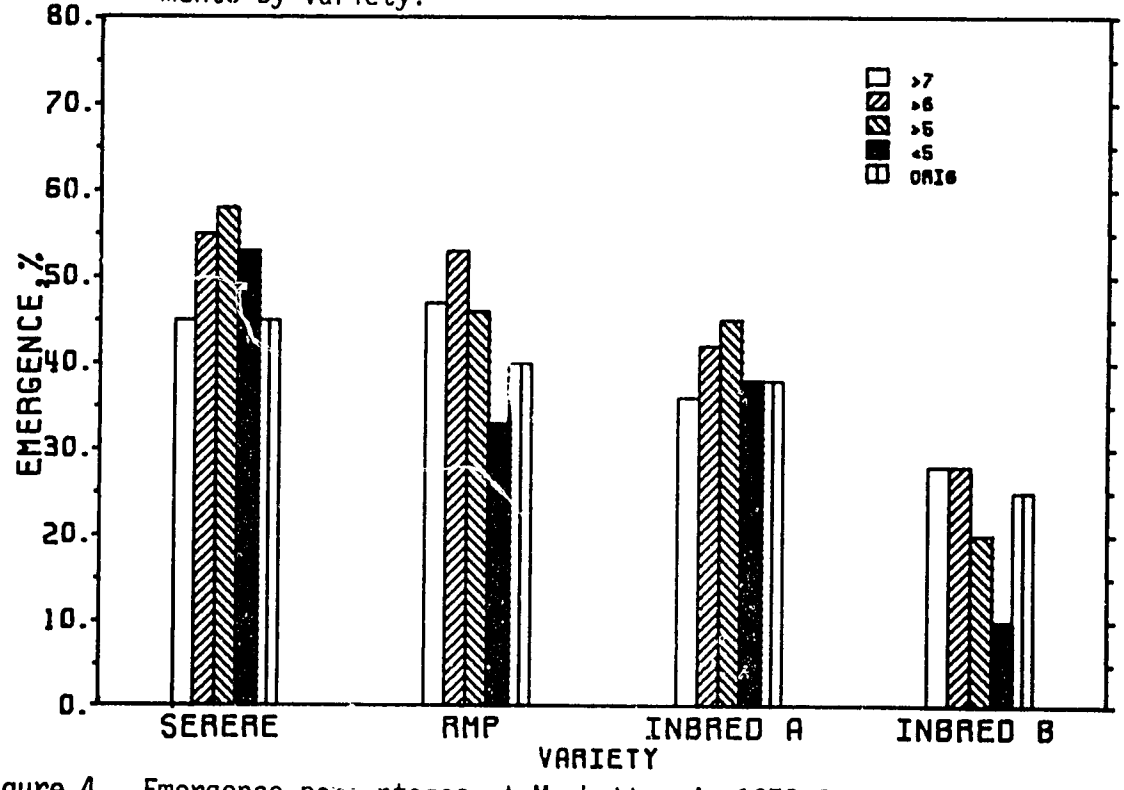

Figure 4. Emergence percentages at Manhattan in 1979 for the size treatments by variety.

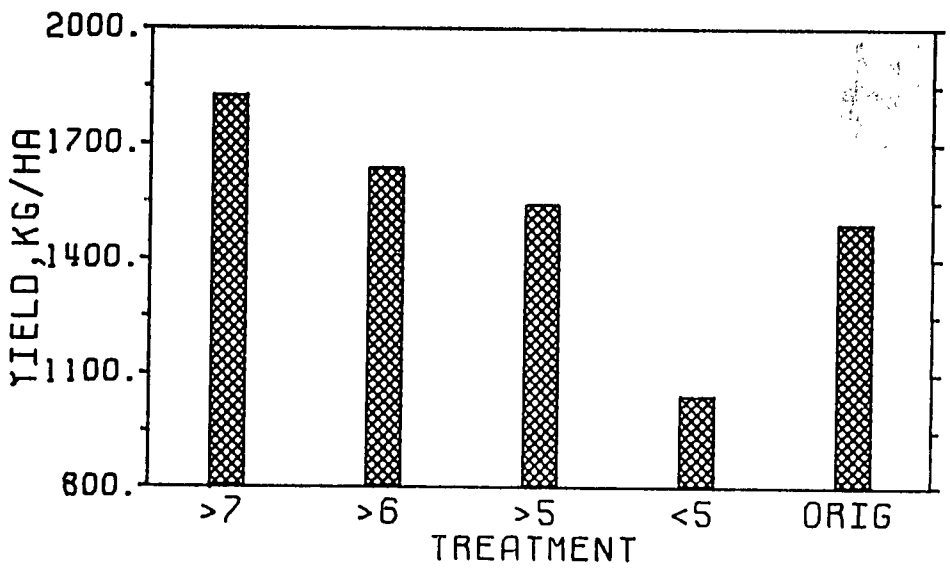

Figure 5. Grain yield at St. John for the size treatments averaged over all varieties in 1979.

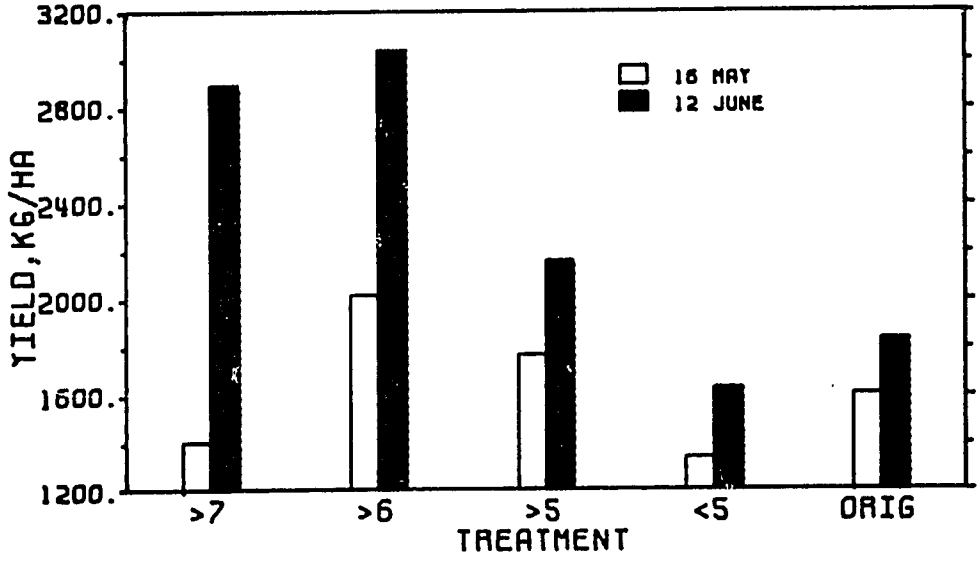

Figure 6. Grain yield at Manhattan in 1979 for the size treatments by planting date.

Density separations were made regardless of seed size. The effect of high density seeds upon emergence was positive. At Manhattan though a significant varietyxtreatment interaction was found (Fig. 7), the general effect of density was consistent in both varieties and inbreds. At St. John (Fig. 8) similar relationships were found. 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.

At St. John in 1979 the average emergence rate for the smallest seed size was 56.6% while the lowest density was 46.5%. Head production for the same two treatments, however, was 91,454/ha and 103,289/ha, respectively. The low density treatment went on to yield an average of 408 kg/ha more grain than the small seed size, and not significantly different from the high density treatments.

At Manhattan the density effect did not influence heads/plant but, as at St. John, size did. Heads/ha was affected by a varietyxtreatment interaction which shows a general trend different from that of St. John with higher densities producing more heads/ha. Yield was affected by a datextreatment interaction in which density was a factor (Fig. 9). Again, yield and heads were affected by stress from migrating chinch bugs which could be at least partially responsible for the yield and yield component variability between locations.

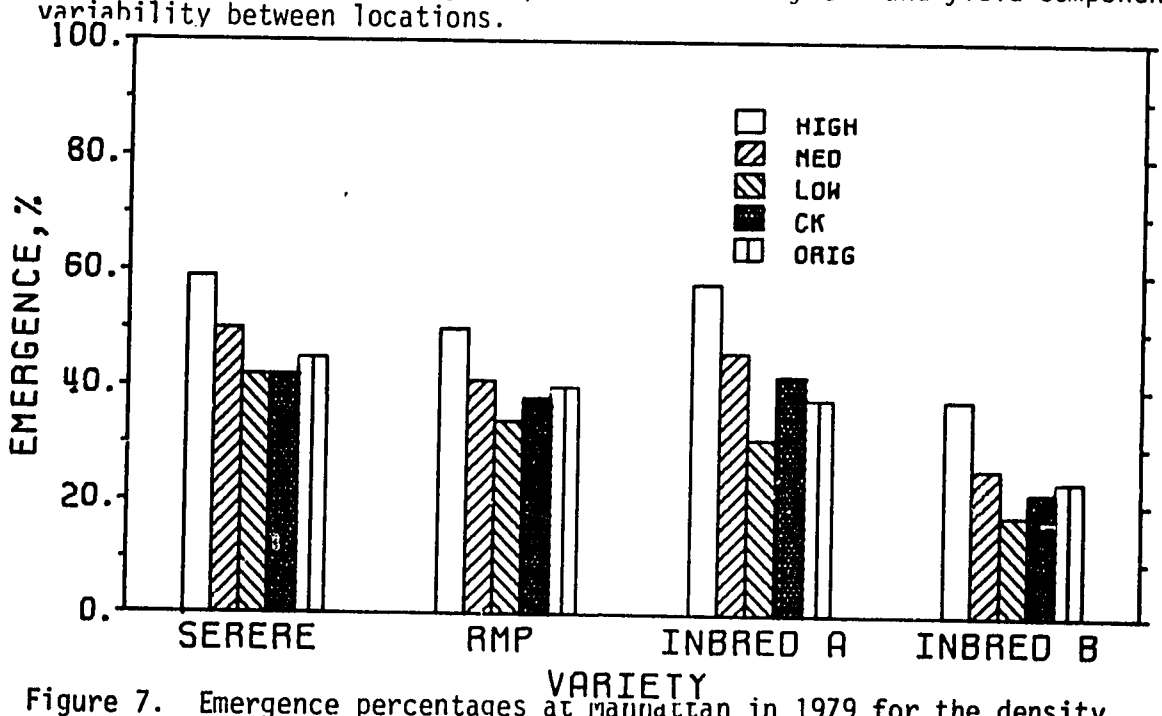

Figure 7. Emergence percentages at Manhattan in 1979 for the density treatments by variety.

Seed density was shown to be a consistent and effective criteria for improving seedling vigor but it does not discriminate against plants able to tiller and produce grain under varied plant populations. Small seeds, however, do 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.

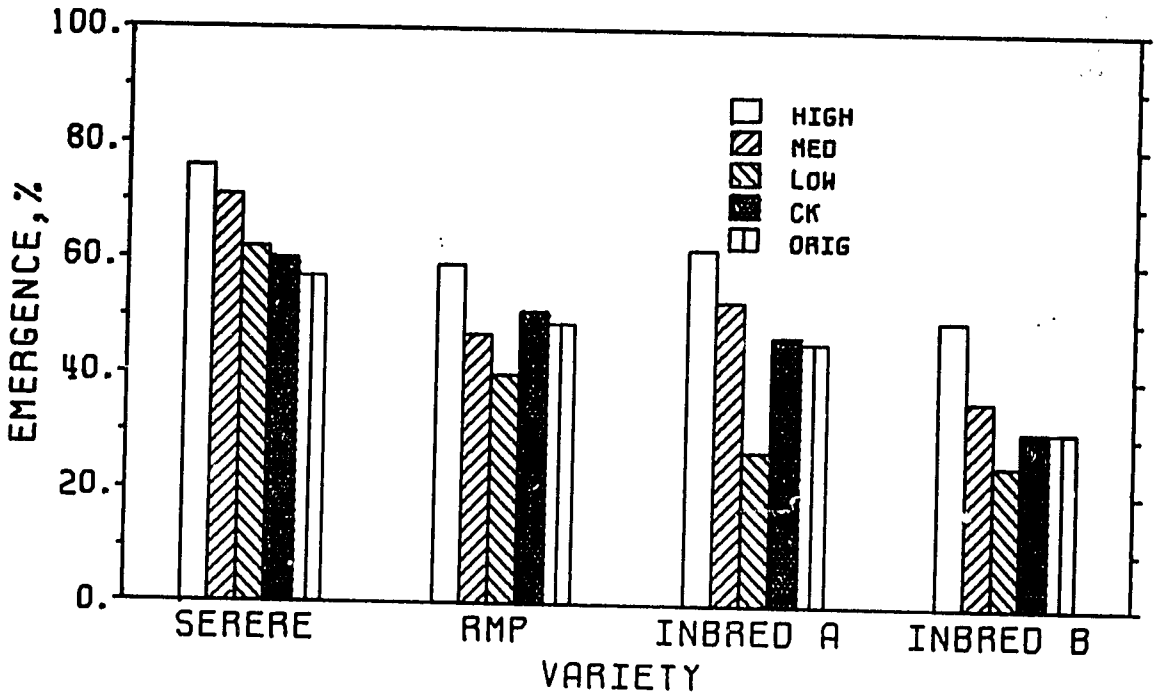

Figure 8. Emergence percentages at St. John in 1979 for the density treatments by variety.

Protein content has been reported to be positively related to both seed size and seed vigor. Protein percentages for the 1979 seedlot treatments were determined and correlated with emergence rates for each date at both locations (Table 2).

Seedlots differed in protein content, but there were similarities between inbreds and between populations. In both populations the largest seed contained a higher percentage of protein than any other fraction. The smallest seed contained the highest percentage protein in the inbreds (Fig. 10).

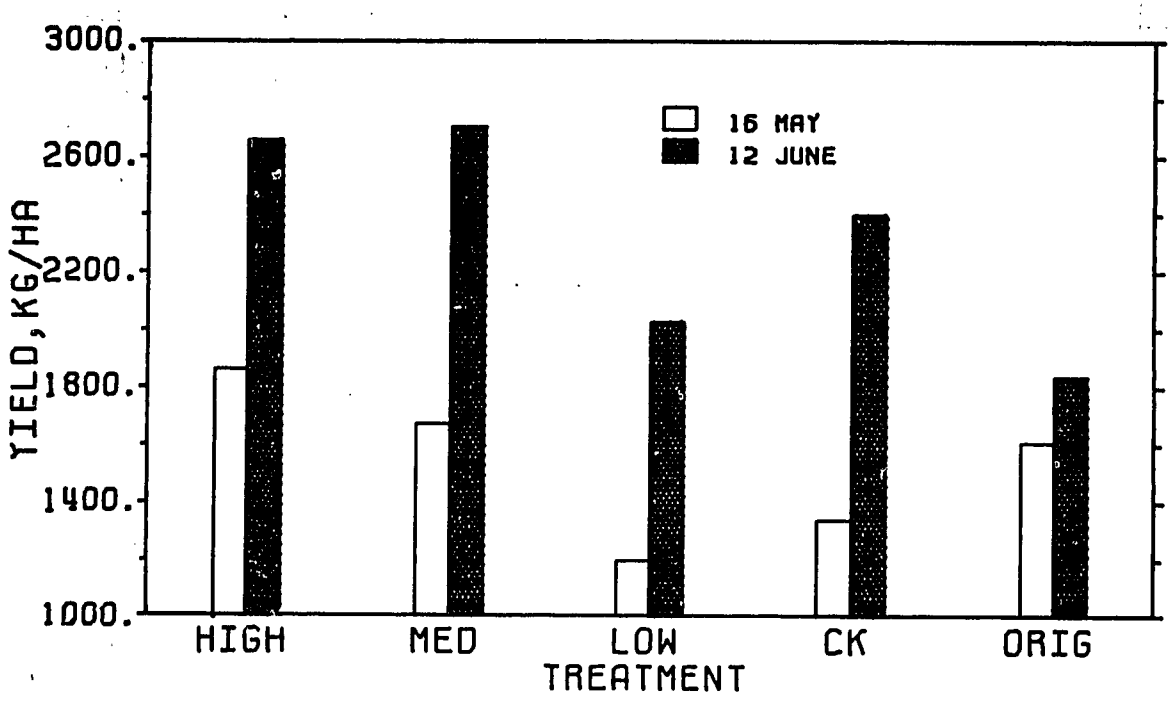

Figure 9. Grain yield at Manhattan in 1979 for the planting dates by density treatments.

Table 2. Correlation of emergence and percent protein, 1979.

Location and Date	Variety				Combined overall
	Serere 3A	RMP	Inbred A	Inbred B	
St. John-1	-.189	.472	-.553	-.773*	0.538**
St. John-2	-.242	.615	-.585	-.687*	0.546**
Manhattan-1	-.776*	.614	-.468	-.696*	0.416*
Manhattan-2	-.671*	.329	-.758*	-.769*	0.382

** Significant at 1%
* Significant at 5%

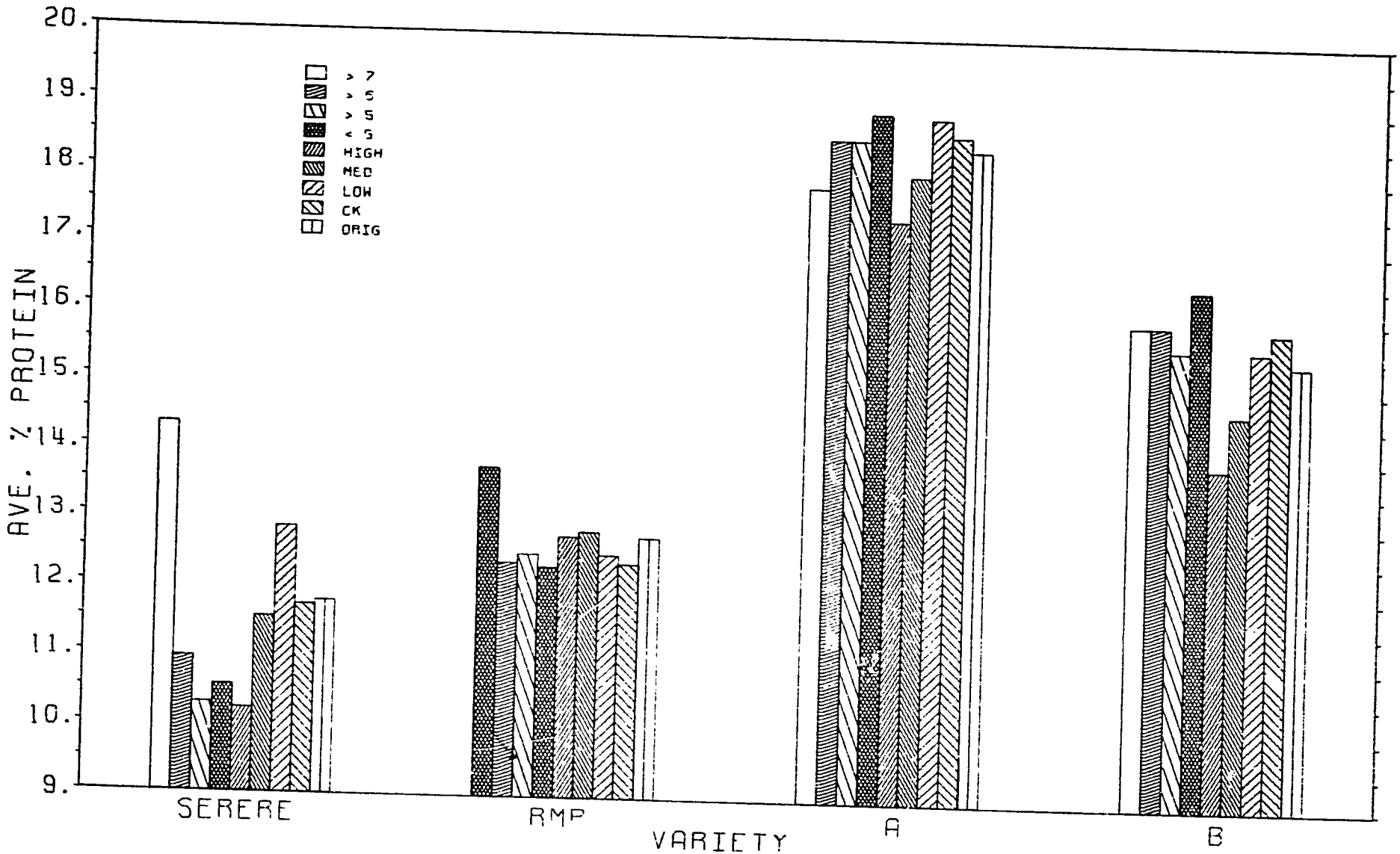

Figure 10. Average percent protein for the 1979 seedlot treatments by variety.

REFERENCES

1. Abdullahi, A., and R. L. Vanderlip. 1972. Relationships of vigor tests and seed source and size to sorghum seedling establishment. Agron. J. 64:143-4.
2. Bartee, S. N., and D. R. Krieg. 1974. Cottonseed density: Associated physical and chemical properties of ten cultivars. Agron. J. 66:433-35.
3. Boyd, W. J. R., A. G. Gordan, and L. J. LaCroix. 1971. Seed size, germination resistance and seedling vigor in barley. Can. J. Plant Sci. 51:93-9.
4. Demirlicakmak, A., M. L. Kaufmann, and L. P. V. Johnson. 1963. The influence of seed size and seeding rate on yield and yield components of barley, Can. J. Plant Sci. 43:330-37.
5. Garg, 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):21-4.
6. Isely, D. 1957. Vigor tests. Proc. Assoc. Offc. Anal. 47:176-81.
7. Kaufmann, M. L. 1967. The effect of seed size on early plant development in barley. Can. J. Plant Sci. 47:73-8.
8. Kiesselbach, T. A. 1924. Relation of seed size to the yield of small grains. Agron. J. 16:670-82.
9. Kittock, D. L. 1967. Investigations on seedling vigor in pearl millet. Proc. Indian Acad. Sci. Sect. B:66:87-91.
10. Kneebone, W. R. and C. L. Cremer. 1955. The relationship of seed size to seedling vigor in some native grass species. Agron. J. 47:472-7.

11. Lowe, L. B., G. S. Ayers, and S. K. Ries. 1972. Relationship of seed protein and amino acid composition to seedling vigor and yield of wheat. Agron. J. 64:608-11.

12. 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. 69:329-30.

13. Misra, D. K., and V. Kumar. 1964. Influence on depth of seeding on emergence, growth, crop stand, and yield of pearl millet in arid zone. A. Arid Zone 2 #2 11?-222.

14. Nadvernik, J. 1927. Lipoids des graines des gramines fourageres et son influence sur la germination. (French summary of Czech. paper.) Bulletin de L Ecole Supericure d Agronomie. Num. 23 Brno.

15. Ries, S. K., G. Ayers, V. Wet, and E. H. Emerson. 1976. Variation in protein, seed and seedling vigor with position of seed in head of winter wheat cultivars. Can. J. Plant Sci. 56:823-7.

16. Ries, S. K., and E. H. Everson. 1973. Protein content and seed size relationships with seedling vigor of wheat cultivars. Agron. J. 65:884-6.

17. Smith, R. R. and C. R. Weber. 1968. Mass selection by specific gravity for protein and oil in soybean populations. Crop Sci. 8:373-7.

18. Smith, T. J., and H. M. Camper. 1975. Effects of seed size on soybean performance. Agron. J. 67:681-4.

19. Sung, T. Y. and J. C. Delouche. 1962. Relation of specific gravity to vigor and viability of rice seeds. Proc. Assoc. Off. Seed Anal. 52:162-4.

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

P. Singh and E. T. Kanemasu

INTRODUCTION

Pearl millet is primarily grown in areas and in periods of low precipitation. It is recognized as one of the most drought resistant cereals (1). In 1979, we studied the water use, water depletion pattern and water use efficiency of various millet genotypes under rainfed conditions.

METHODS AND MATERIALS

Six genotypes namely HMP-600, HMP-1700, Senegal Bulk, Serere-3A, Tall Bulk (HMP-559) and HMP-550 were planted in plots of size 7m x 10m at the Evapotranspiration Research Field near Manhattan, Kansas. Each plot had 8 rows, 76 cm apart, and intrarow spacing of 10 cm. All the plots were laid out in a randomized complete block design and replicated four times. Each block had six genotypes of millet. The genotypes were planted on 29 May, 1979 and irrigated on 6 and 8 June to encourage germination. Fertilizer was broadcasted to supply 68 kg N/ha prior to planting. Eleven days after emergence, fertilizer (28-14-0) was side dressed to supply an additional 23 kg N/ha. Insecticide was applied to control chinch bugs.

Neutron probe access tubes were installed in the center of plots mid-way between rows. The tubes were read weekly at every 15-cm depth interval from 15 to 150 cm profile. Moisture content in the top 0-15 cm was determined gravimetrically.

RESULTS AND DISCUSSION

Dry Matter Production: The results on total dry matter production are presented in Fig. 1. Tall Bulk produced the greatest dry matter but the lowest in grain yield. Therefore, the harvest index was the lowest. The ranking of the harvest index (grain yield/total dry matter) from high to low was .347, .347, .312, .306, .282, and .122 for HMP-550, Serere-3A, HMP-1700, Senegal Bulk, HMP-600 and Tall Bulk, respectively.

Leaf area Index: LAI results are presented in Fig. 2. The maximum LAI of 7.0 was achieved by Tall Bulk which was not significantly different from that of Senegal Bulk. Minimum LAI was achieved by HMP-1700 which was 3.7. Serere-3A and HMP-550 achieved their maximum LAI much earlier than other cultivars. Senegal Bulk retained higher LAI as compared to other cultivars as it approached maturity showing less senescence. There was no relationship between maximum LAI achieved and the total dry matter produced.

Total water use: Cumulative water use data are presented in Table 4. Genotypes did not differ significantly in their water use for the first 40 days after emergence which was nearly the final leaf stage of all the

genotypes. However, later differences in water use were observed. HMP-1700 was the lowest and Tall Bulk was the highest in water use. Since the rainfall was relatively uniformly distributed over the season and water was not limiting for crop growth, there were no significant differences in water use among genotypes.

Water use and soil water extraction patterns: Total water use both from the top and sub-soil during the period between 17 and 93 days after emergence is presented in Table 5. Data show that genotypes did not differ in water use from 0 to 60 cm layer; but significant differences in water use were observed in the 60 to 150 cm layer. Tall Bulk used greatest amount of water from layers below 60 cm (9.4 cm) and HMP-1700 used the least (4.7 cm). This could be attributed to the differences in their rooting densities.

Figure 3 shows the cumulative water use from the layers below 60 cm from the period 17 and 93 days after emergence. Differences in water use were evident from the beginning of the crop growth and were emphasized with time.

Water use efficiency (WUE): Results on the water use efficiency both for total dry matter and grain yield are presented in Table 6. Average WUE (dry matter/water use) was highest for Tall Bulk which was 8.35 q/ha cm. HMP-600 had the lowest average WUE.

Average WUE (grain yield/water use) was the lowest for Tall Bulk, which leads to the fact that most of the water in Tall Bulk was used in promoting vegetative growth.

Higher WUE (dry matter/water use) in 1978 are due to sampling procedure which was more valid for 1979 than 1978.

Depth of water depletion as a function of time: Figure 4 suggests that the differences in water use from the sub-soil layers by the various genotypes could be due to their differences in rate of root development because genotypes which used more water from sub-soil start to deplete water from the deeper layers earlier. There was a difference of approximately 30 days between HMP-1700 and Tall Bulk to deplete water from layers below 90 cm.

SUMMARY

The millet genotypes studied here differed in their morphology and manner of shoot and root development which is reflected in their water use, water depletion pattern and water use efficiency. The root density and rate of root establishment in the sub-soil could make a significant contribution to the ability of millet to resist moisture stress. Such differences were evident from the patterns of moisture depletion by various types of millet.

Our data suggest that depth of water depletion was directly related to the plant height; therefore, the most desirable genotype would be an intermediate plant height type with several tillers for high yields and drought resistance.

LITERATURE CITED

1. Singh, A., D. B. Datta, and D. Singh. 1971. Laboratory germination findings on Bajra Seed (*Pennisetum typhoides*). Proc. Int. Seed Test Assoc. 36:106-107.

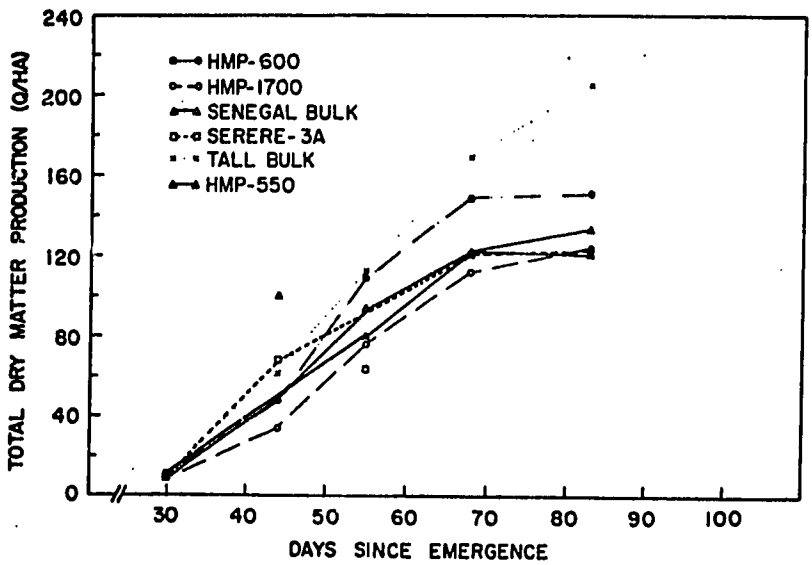

Figure 1. Total dry matter production by various genotypes as a function of time.

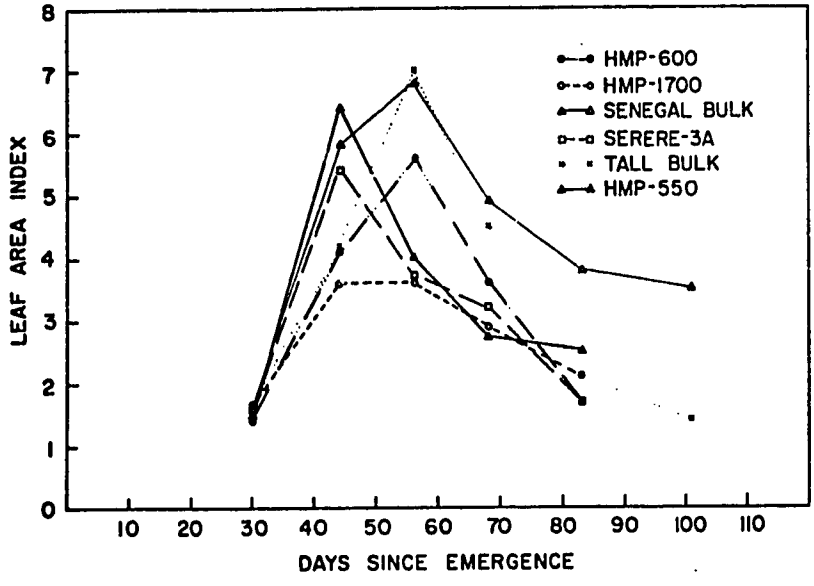

Figure 2. Leaf area index of various genotypes as a function of time.

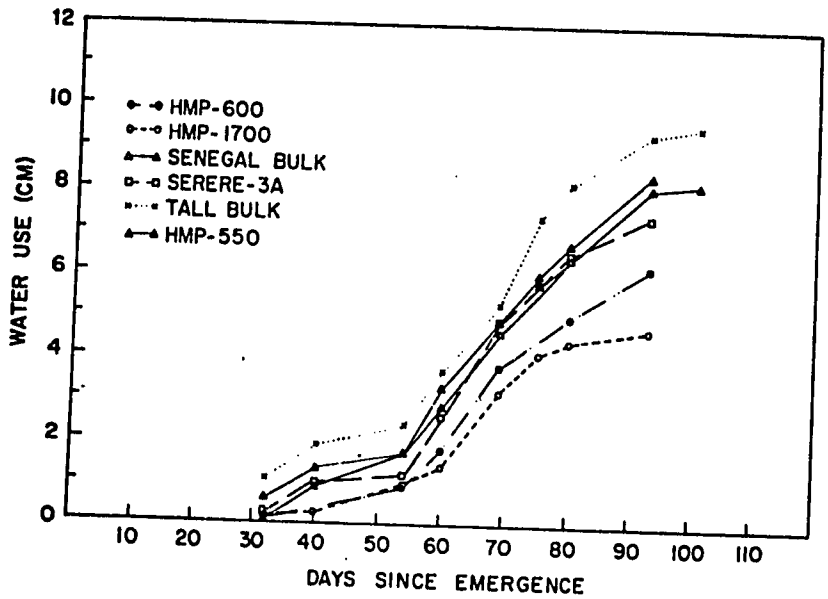

Figure 3. Cumulative water use by various genotypes from 60 to 150 cm profile during the period 17 to 93 days after emergence.

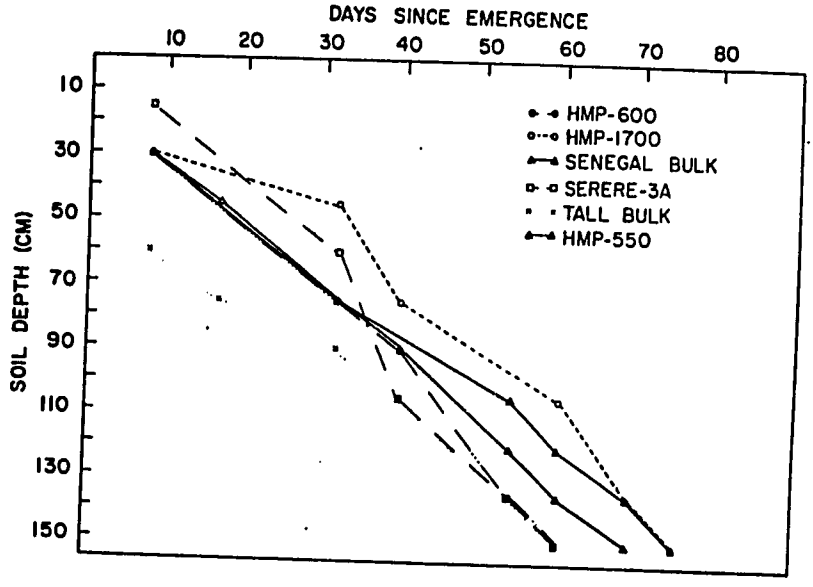

Figure 4. Depth of water depletion by various genotypes at various times during the growing season.

Table 1. Growth Stages of Millet Genotypes

Growth Stages	Genotypes					
	HMP-600	HMP-1700	Senegal Bulk	Serere -3A	Tall Bulk	HMP-550
	Days Since Emergence					
1. Emergence	0	0	0	0	0	0
2. Growing point differentiation	(29-38)	29	(29-38)	29	38	29
3. Final leaf visible	41	41	45	41	47	38
4. Bootstage	45	45	50	45	47	41
5. Panicle emergence	47	47	55	47	56	45
6. Half bloom	50	50	57	50	59	47
7. Seed set	54	54	60	54	60	48
8. Grain filling						
a. milkstage	60	56-60	69-75	60	69-80	50-56
b. soft dough	69	69	80	69-75	-	60-69
c. hard dough	75-80	75-80	87-93	80	87-93	75-80
9. Physiological maturity	87	87	96	87	96	87
Harvesting	94	94	97	94	97	94

Table 2. Grain yield (q/ha) of various genotypes in 1979.

	Genotypes					
Replication	HMP 600	HMP 1700	Senegal Bulk	Serere 3A	Tall Bulk	HMP 550
1	42.5	39.1	31.7	44.0	24.2	51.2
2	38.5	37.1	42.3	41.5	24.6	46.0
3	44.9	35.8	38.1	43.8	26.0	42.5
4	44.5	42.7	35.4	40.6	25.3	45.0
Average	42.6	38.7	36.9	42.5	25.0	46.2

Ranking of yields (Year 1979)

HMP-550	HMP-600	Serere-3A	HMP-1700	Senegal Bulk	Tall Bulk
46.2a	42.6ab	42.5ab	38.7bc	36.9c	25.0d

LSD = 4.9
(.05)

Ranking of yields (Year 1978 - first planting)

HMP-1700	Senegal Bulk	Serere-3A	RMP-1(5)C	HMP-600	Tall Bulk
43.7a	40.0a	30.4b	25.5bc	19.6cd	17.6d

LSD = 7.5
(.05)

Figures followed by the same letter are not statistically significant.

Table 3. Data on the number of tillers, number of heads, grain weight per head, and 500 kernel weight.

Genotypes	No. of tillers per m^2	No. heads per m^2	Grain weight per head(gms)	500 kernel wt.(gms)
HMP-600	28.6	20.0	22.2	5.525
HMP-1700	45.2	37.2	12.3	3.902
Senegal Bulk	47.4	20.9	20.2	4.152
Serere-3A	36.6	20.9	30.7	6.302
Tall Bulk	30.8	12.9	26.7	4.243
HMP-550	44.6	36.6	18.9	5.273

Table 4. Cumulative water use (cm) by millet genotypes.

Days Since Emergence	HMP-600	HMP-1700	Senegal Bulk	Serere 3A	Tall Bulk	HMP-550
			Water Use (cm)			
8	0.4	0.5	0.4	-	0.3	0.9
17	6.7	7.2	7.0	6.5	7.2	7.3
32	15.5	16.2	15.5	15.7	16.4	16.1
40	20.0	20.5	21.1	21.3	21.6	21.9
54	25.9	26.2	26.4	26.0	27.4	26.7
60	28.2	27.7	28.9	29.2	30.1	29.8
69	31.1	31.6	32.6	33.2	33.6	33.4
75	32.9	34.0	34.6	35.7	37.0	35.3
80	35.6	34.8	36.1	37.0	38.8	37.1
93	40.5	37.0	40.7	40.2	41.8	41.6
101			41.9		43.2	

Table 5. Total water use (cm) from the top (0-60 cm) and sub (60-150 cm) soil from the period June 27 (17 days after emergence) to September 10, 1979 (93 days after emergence).

Cultivars	Soil depth (cm) 0 - 60	60 - 150	0 - 150
	Water use (cm)		
HMP-600	27.7	6.2	33.9
HMP-1700	25.1	4.7	29.8
Senegal Bulk	25.5	8.1	33.6
Serere-3A	26.3	7.4	33.7
Tall Bulk	25.2	9.4	34.6
HMP-550	25.8	8.4	34.2

Table 6. Water use and water use efficiency of millet genotypes in the year 1978 and 1979.

Cultivars	Total Water Use (cm)			Water Use Efficiency (q/ha cm) Total Dry Matter			Grain Yield		
	1978	1979	Ave.	1978	1979	Ave.	1978	1979	Av
HMP-600	37.2	40.5	38.8	4.85	3.73	4.29	0.53	1.05	0.
HMP-1700	37.6	37.0	37.3	7.36	3.35	5.35	1.16	1.04	1.
Senegal Bulk	36.2	41.9	39.0	7.83	2.88	5.35	1.10	0.88	.9
Serere-3A	37.6	40.2	38.9	8.09	3.05	5.56	0.81	1.06	.9
Tall Bulk	41.8	43.2	42.5	11.96	4.75	8.35	0.42	0.58	.5
HMP-550	-	41.6	-	-	3.19	-	-	1.11	-
RMP-1 (5)C	36.7	-	-	8.79	-	-	.69	-	-

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 MILLETS [*Pennisetum americanum* (L.) Leeke]

Dave Wetzel and Max Jones

Proximate and amino acid analyses of pearl millet hybrids developed by Burton in Georgia are shown in Tables I and II, respectively. Protein content of the hybrids varied from 10.6 to 17.6% which is a considerably wider range of values than those previously reported (1978, annual report) for Hays millet populations. On the other hand, fat contents were generally lower than HMP or RMP populations.

We are completing amino acid analysis of the Tift hybrids as well as doing proximate and amino acid analysis on Kansas millet populations grown in six locations: Manhattan, Hays, St. John, Minneola, Garden City, and Tribune (Table III and IV).

Table I. Proximate Analyses of Pearl Millet Samples

Sample[a]	Protein (%)	Fat (%)	Ash (%)	Crude Fiber (%)	Moisture (%)
B_1[b]	14.5	4.8	1.6	1.8	9.4
B_2	14.4	4.8	1.7	2.0	9.8
B_3	17.6	4.0	2.3	1.8	8.8
B_4	14.5	4.8	1.8	2.0	10.0
B_5	15.8	4.5	1.8	1.5	9.8
B_6	14.0	4.1	1.7	1.7	9.9
B_7	14.7	3.8	1.7	1.8	9.9
Tift[c]					
1	10.6	5.5	1.7		6.0
2	11.4	5.2	1.6		6.6
3	13.4	5.1	1.8		6.4
7	12.6	4.5	1.4		5.0
8	12.1	4.9	1.6		5.5
9	12.2	5.5	1.7		4.6
11	11.3	5.3	1.7		4.7
12	11.8	4.8	1.7		5.2
15	11.8	5.9	1.8		4.5

[a]Hybrids developed by Glenn W. Burton USDA SEA, Coastal Plain Station, Tifton, GA.

[b]Grown in 1978, Manhattan, KS.

[c]Grown in 1979, Manhattan, KS.

Table II. Amino Acid Analysis

	Grams of amino acids per 100g protein corrected to 100% recovery protein						
	B-1	B-2	B-3	B-4	B-5	B-6	B-7
1 Lysine	2.68	2.90	2.75	2.87	2.74	2.49	2.84
2 Histidine	2.13	2.25	2.22	2.26	2.28	2.28	2.40
3 Ammonia	3.28	3.27	3.31	3.25	3.36	3.24	3.47
4 Arginine	4.44	4.87	4.87	4.76	5.03	4.42	5.15
5 Aspartic Acid	9.39	9.21	9.04	9.12	9.08	8.93	8.87
6 Threonine	3.90	3.82	3.75	3.78	3.73	3.75	3.71
7 Serine	5.88	5.89	5.92	5.65	5.97	5.93	5.10
8 Glutamic Acid	22.13	22.16	22.47	22.47	22.54	22.42	21.88
9 Proline	6.52	6.67	6.80	5.64	6.49	6.29	7.08
10 Half Cystine	0.75	0.54	0.57	0.67	0.47	0.61	0.58
11 Glycine	3.46	3.57	3.09	3.49	3.25	3.45	3.37
12 Alanine	8.77	9.00	9.09	8.97	9.02	9.16	8.93
13 Valine	4.04	3.97	3.95	3.93	3.91	3.90	4.02
14 Methionine	2.20	1.98	1.96	2.15	1.83	2.24	2.03
15 Isoleucine	3.17	3.14	3.10	3.12	3.14	3.13	3.15
16 Leucine	9.66	9.73	9.79	9.72	9.80	9.98	9.90
17 Tyrosine	2.91	2.54	2.72	2.57	2.74	2.89	2.76
18 Phenylalanine	4.69	4.50	4.61	4.55	4.64	4.90	4.76
Protein	14.50	14.40	17.60	14.50	15.80	14.00	14.70
Moisture	9.40	9.80	8.80	10.00	9.80	9.90	9.90

Table III

Proximate Analysis of Pearl Millet F_1 Hybrids Grown at Different Locations in Kansas

F_1 Hybrid	Pro. (%)	Fat (%)	Ash (%)	Moisture (%)
Minneola				
2279 X 7101	10.4	5.6	1.6	7.0
2118 X 7024	10.3	4.9	1.8	7.1
2224 X 7024	12.1	5.2	1.6	7.2
1166 X 1700	11.0	6.0	1.6	6.8
2090 X 7101	11.6	5.7	1.7	7.3
Ashland				
2279 X 7101	11.6	5.4	1.6	7.8
2118 X 7024	12.0	4.8	1.8	8.0
2224 X 7024	12.3	4.6	1.7	7.4
1166 X 1700	11.0	6.3	1.6	7.3
2090 X 7101	12.3	5.9	1.6	7.6
Tribune				
2279 X 7101	13.5	5.7	1.6	8.0
2118 X 7024	13.9	5.1	1.5	7.6
2224 X 7024	12.9	5.3	1.5	7.4
1166 X 1700	12.9	6.7	1.6	7.9
2090 X 7101	14.5	6.0	1.6	7.6
Hays				
2279 X 7101	15.1	5.2	1.6	8.9
2118 X 7024	12.9	6.1	1.7	10.0
2224 X 7024	14.4	5.3	1.6	9.4
1166 X 1700	16.0	6.2	1.6	9.1
2090 X 7101	13.9	5.6	1.7	9.5
Garden City				
2279 X 7101	9.5	5.9	1.5	7.8
2118 X 7024	9.4	5.4	1.6	8.4
2224 X 7024	7.3	5.5	1.6	7.3
1166 X 1700	8.8	6.7	1.6	7.8
2090 X 7101	9.3	6.1	1.7	7.5
St. John				
2279 X 7101	8.6	5.4	1.6	8.0
2118 X 7024	7.3	5.6	1.6	8.2
2224 X 7024	9.1	5.3	1.7	8.8
1166 X 1700	9.0	6.6	1.7	7.5
2090 X 7101	8.9	5.8	1.7	8.2

Table IV

Proximate Analyses of Pearl Millets Grown at Different Locations in Kansas

Sample[a]	Pro. (%)	Fat (%)	Ash (%)	Moisture (%)
Minneola				
HMP550	9.6	5.6	1.6	7.5
HMP559	10.3	5.2	1.5	7.6
HMP561	8.9	5.6	1.6	6.7
HMP1700	10.7	6.2	1.6	6.7
Ashland				
HMP550	9.6	5.4	1.6	8.8
HMP557A	9.5	5.6	1.6	8.4
HMP559	11.8	5.1	1.4	8.3
HMP561	11.3	5.2	1.6	8.1
Tribune				
HMP550	14.0	5.6	1.4	7.9
HMP557A	11.5	5.4	1.5	8.4
HMP559	13.8	4.7	1.7	9.1
HMP561	14.9	5.5	1.5	8.2
HMP1700	13.8	6.4	1.5	7.3
Hays				
HMP550	14.7	5.7	1.6	10.7
HMP559	15.9	4.5	1.7	9.8
HMP561	15.4	5.6	1.7	9.3
HMP1700	15.0	5.6	1.6	9.0
Garden City				
HMP550	9.4	5.4	1.6	7.9
HMP557A	7.9	6.0	1.6	8.6
HMP559	9.6	5.3	1.5	8.2
HMP561	8.3	5.8	1.6	7.5
St. John				
HMP559	6.9	5.0	1.5	8.9
HMP561	8.2	5.4	1.7	7.0
HMP1700	9.2	6.8	1.7	7.7

[a]Bulk populations

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

E. Varriano-Marston and R. C. Hoseney

Because pearl millet [*Pennisetum americanum* (L.) Leeke) is an important food crop in many developing countries in the semi-arid tropics, many investigators are studying its nutrient composition. Although some work has been reported on the mineral content of Indian and African cultivars (Shah and Mehta, 1959; Carr, 1961; Goswami et al., 1969a & b, 1970a & b; Deosthale et al., 1971), only one article provides information on the mineral constituents (Ca, P) of pearl millet cultivars grown in the United States (Burton et al., 1972). The following paper reports on the mineral content of 4 bulk populations and 17 lines of pearl millet grown in Kansas. In addition, the location of minerals in the grain was investigated.

MATERIALS AND METHODS

Seventeen HMP 550 S_1 lines (Tift 23 DB_1/*2PI185642) of pearl millet and four bulk populations were studied: HMP 550, a combination of 110 S_1 lines; HMP 1700 (PI263540/Tift 23 DB_1/2/Tift 239 DB_2*Serere 3A); RMP I(S) CI (parentage from Serere 3A, Serere 17, and Tift 239 DB_2); and Serere 3A, developed by Serere Exp. Stn., Uganda, Africa. The method of Purdy et al. (1968) was used to describe pedigrees of the millet samples; HMP and RMP refer to Hays Millet Population and Regional Millet Population, respectively.

Millet samples were not dehulled prior to mineral analysis. Moisture content, ash, and crude protein were determined by standard AOAC methods (1970). Samples were prepared for Ca, Mg, Zn, and Fe analyses according to the methods of Liu et al. (1974) and those minerals determined by atomic absorption spectroscopy. Na and K contents of the samples were determined by the AOAC flame photometric method (1970); total P (as P_2O_5) was determined by the molybdovanadophosphate method (AOAC, 1970). Duplicate mineral analyses were done on each sample.

Millet kernels were prepared for X-ray microanalysis by fracturing grains logitudinally with a razor blade, mounting the halves on stubs with colloidal graphite, and coating with carbon. X-ray spectra were obtained with a Tracor Northern TN-1710 X-ray energy dispersive analyzer attached to a Cambridge Stereoscan Scanning Electron microscope. Area scans were made on the germ, covering layers (including aleurone), and hard and soft endosperm. A counting time of 100 sec. was used to obtain optimum peak to background ratios.

RESULTS AND DISCUSSION

Protein, moisture, and ash contents of millet samples are presented in Table 1. Protein contents ranged from 11.1% to 14.7%; ash contents ranged from 1.4% to 1.9%. Both are within the ranges reported by Goswami et al. (1969a & b, 1970a & b) for pearl millets grown in India.

Mineral contents of the various millet samples are shown in Table 2. Contents of individual mineral elements vary somewhat among populations and S_1 lines which may be a function of agronomic conditions as well as genetic background. In general, the data indicate that (a) P, K, and Mg are the major mineral constituents in the grain; (b) pearl millet is comparable to wheat in Fe and Zn contents; (c) the Ca content of our samples was lower than that reported by other authors (Goswami et al., 1969a & b, 1970a & b); and (d) the P content in millet is more than twice that reported for wheat (Ziegler and Greer, 1971). Millet's high P content may be an important factor in determining the total nutritional value of this grain, particularly if P is present in the grain as phytin which may reduce the absorption of trace minerals from the gastrointestinal tract. Phytin phosphorus has been reported to constitute from 33 to 90% of the total phosphorus in cereal grains (Hamdy, 1971). Studies characterizing the major sources of phosphorus in pearl millet would be valuable.

The locations of minerals in pearl millet kernels were determined by X-ray energy dispersive analysis. High levels of Si and K were present in the covering layers (includes aleurone), and a major portion of the phosphorus was located in the germ (Fig. 1). High levels of iron were found in both germ and covering layers. Low mineral concentrations were observed in the hard and soft endosperms; the predominant minerals detected in those areas were S, K, and Fe. The greater concentration of minerals in the covering layers and germ than in the endosperm portions is typical of most cereal grains (MacMasters et al., 1971).

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The technical assistance of Aaron Johnson is gratefully acknowledged.

REFERENCES

Association of Official Agricultural Chemists 1970. Official Methods of Analysis (11th ed.). The Association: Washington, D.C.

Burton, G. W., A. T. Wallace, and K. O. Rachie. 1972. Chemical composition and nutritive value of pearl millet [*Pennisetum typhoides* (Burm.) Stapf and E. C. Hubbard] grain. Crop Sci. 12:187.

Carr, W. R. 1961. Observations on the nutritive value of traditionally ground cereals in Southern Rhodesia. Brit. J. Nutr. 15:339.

Deosthale, Y. G., K. Visweswara Rao, V. Nagarajan, and K. C. Pant. 1971. Varietal differences in protein and amino acids of grain bajra (*Pennisetum typhoides*). Ind. J. Nutr., and Dietet. 8:301.

Goswami, A. K., K. P. Sharma, and B. K. Gupta. 1969b. Chemical composition of bajra grains. 2. American entries. J. Nutr. and Dietet. 6:291.

Goswami, A. K., K. L. Sehgal, and K. P. Sharma. 1969a. Chemical composition of bajra grains. 1. African entries. J. Nutr. and Dietet. 6:287.

Goswami, A. K., K. L. Sehgal, and B. K. Gupta. 1970a. Chemical composition of bajra grains. 3. Indian inbreds. Ind. J. Nutr. and Dietet. 7:5.

Goswami, A. K., K. P. Sharma, and K. L. Sehgal. 1970b. Chemical composition of bajra grains. 4. Indian varieties. Ind. J. Nutr. and Dietet. 7:67.

Hamdy, M. M. 1971. Interactions between phosphates and plant proteins. In: "Symposium: Phosphates in Food Processing," p. 83. Avi Publishing Co., Westport, Conn.

Liu, D. J., G. S. Robbins, and Y. Pomeranz. 1974. Composition and Utilization of Milled Barley Products. IV. Mineral Components. Cereal Chem. 51:309.

MacMasters, M. M., J. J. C. Hinton, and Dorothy Bradbury. 1971. Microscopic structure and composition of the wheat kernel. In: "Wheat Chemistry and Technology," (Pomeranz, Y., ed.) p. 51, Amer. Assoc. Cereal Chemists, St. Paul, Minnesota.

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

Shah, H. C., and B. V. Mehta. 1959. Magnesium-phosphorus-crude fat interrelationships in the seed of pearl millet (*Pennisetum typhoideum*-Rich). Soil Sci. 87:320.

Ziegler, E., and E. W. Greer. 1971. Principles of milling. In: "Wheat Chemistry and Technology," (Pomeranz, Y., ed.) p. 115, Amer. Assoc. Cereal Chemists, St. Paul, Minn.

Table 1. Protein, moisture and ash contents of pearl millet cultivars.

Sample	Protein (%)	Moisture (%)	Ash (%)
*RMPI(S)CI[a]	11.1	14.2	1.4
*HMP1700[b]	14.7	10.4	1.6
*Serere 3A[c]	13.5	9.5	1.6
*HMP550[b]	13.6	9.6	1.8
HMP550 S_1 LINES[b]			
114	13.9	10.8	1.7
120	13.3	10.5	1.8
134	13.5	10.7	1.8
149	13.0	10.4	1.9
155	13.5	10.6	1.9
160	13.0	7.8	1.9
179	13.5	10.7	1.7
180	14.0	10.9	1.7
189	13.0	11.0	1.7
191	13.6	10.8	1.9
193	13.8	10.5	1.8
196	13.8	11.0	1.7
200	13.9	10.5	1.8
201	14.1	10.6	1.9
218	13.3	10.7	1.8
220	12.8	10.0	1.6
240	13.8	9.9	1.8

*Bulk populations

[a]1976, Manhattan, KS

[b]1977, Hays, KS

[c]1975, Hays, KS

TABLE 2. Minerals in Pearl Millet (μg/g)[a]

	Ca	Mg	Zn	Fe	Na	K	P ($X10^2$)
RMPI(S)CI	99	1167	38	73	45	3660	66.5
HMP1700	132	1330	31	61	43	3864	74.8
Serere 3A	126	1384	30	78	41	3679	79.4
HMP550	89	1389	28	79	45	4605	86.4
HMP550 S_1 LINES:							
114	81	1399	34	83	45	4524	84.3
120	112	1318	23	69	49	4993	87.8
134	74	1488	34	83	48	4471	89.0
149	122	1450	27	68	20	4436	87.5
155	79	1358	28	77	22	4876	85.9
160	109	1432	26	74	43	4808	92.3
179	96	1507	28	79	43	5106	95.1
180	65	1499	28	70	46	4628	89.7
189	81	1374	29	78	39	4643	82.8
191	92	1460	26	74	34	4954	90.5
200	79	1382	27	70	40	4605	85.0
201	84	1512	30	74	43	4657	92.2
218	76	1557	34	78	42	4203	87.3
220	116	1364	30	81	45	4037	92.3
240	98	1346	29	74	44	4224	76.1

[a]dry basis

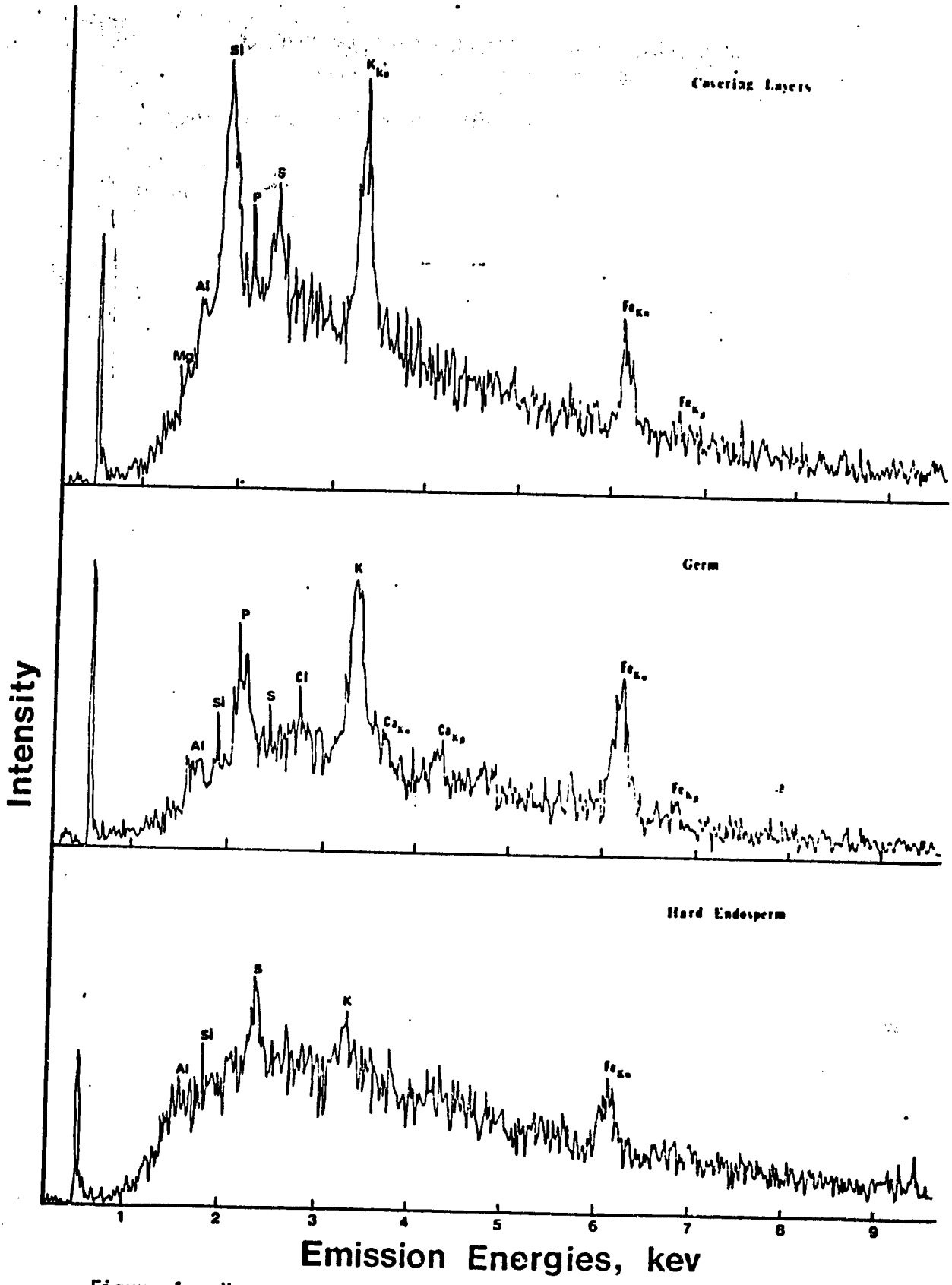


Figure 1. X-ray spectra demonstrating some of the mineral constituents in the covering layer (top), germ (middle) and hard endosperm (bottom).

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

Adelaide Beleia, E. Varriano-Marston and R. Carl Hoseney

Various species of millet are grown in Africa and India. Pearl millet [*Pennisetum americanum* (L.) Leeke], known in India as bajra and in Africa as bulrush, is drought resistant and extensively grown as a food grain.

Although the major component of pearl millet is starch, its properties have not been extensively studied, especially starch's variability among random mating populations. This paper characterizes the physicochemical properties of starches isolated from various populations of pearl millet.

MATERIALS AND METHODS

Materials

Five different random-mating bulk populations of pearl millet were used in this study: HMP550 (Tift 23 DB_1/*2PI 185642); HMP1700 (PI 263540/ Tift 23 DB_2/2*Serere 3A); RMPI(S)CI (parentage from Serere 3A, Serere 17, and Tift 239 DB_2), and Serere 3A, developed by Serere Exp. Stn., Uganda, Africa. The HMP550 and 1700 were grown at Hays Branch Exp. Stn., Hays, Kansas, in 1977; Serere 3A was grown in 1975 at Hays. The RMPI(S)CI samples were grown in Manhattan, Kansas in 1976, and 1978. The method of Purdy et al. (1968) was used to describe pedigrees of the millet samples.

Starch Isolation

Millet grain was soaked at 4 C for 24 hr. in distilled water containing 0.01% sodium azide to inhibit microbial growth. After soaking, the grain was washed several times with distilled water, wet milled in a Waring Blendor for 3 min., and screened through a 116 Nitex bolting cloth. The process of wet milling was repeated until no more starch could be separated. The starch suspension was centrifuged at 1000g for 20 min. and the upper layer (protein) of the residue was removed with a spatula and discarded. The starch (lower layer) was suspended in water, centrifuged, and the tailings were scraped off with a spatula. The last step was repeated until a white prime starch (free of tailings) was obtained, then the starch was air dried.

Characterization of Starch

Protein, fat, ash, and moisture contents of the starches were determined by AOAC methods (1975). Cold water-binding capacity was determined by the method of Medcalf and Gilles (1965); starch damage, by the AACC method (1972). Starch gelatinization temperature ranges were measured with a polarizing microscope and a Kofler hot stage (Schoch and Maywald, 1956). Initial, mid-point, and end-point values were reported.

Intrinsic viscosities of starches were determined at 35 C according to Leach (1963) with a Cannon-Fenske viscometer, capillary size 50.

Starch swelling and solubility patterns were determined by the methods of Leach et al. (1959). Pasting curves of the isolated starches were determined with an amylograph. The starch (9%) was suspended in buffer (AACC, 1972), heated from 30-95 C, held for 1 hr. at 95 C, cooled to 50 C, and held at 50 C for 1 hr.

Starch was fractionated by the method of Banks and Greenwood (1967). Amylose contents were determined by the method of McCready and Hassid (1943), and iodine affinities were determined according to Schoch (1964).

X-ray diffraction patterns of starch were determined with an X-ray diffractometer (Philips) equipped with a goniometer and Gieger-Muller counter. The sample was packed in an aluminum frame and equilibrated to 96% R.H. X-rays were $Cu_{k\alpha}$ radiation; samples were run at 35 KV, 18 ma.

RESULTS AND DISCUSSION

Proximate analyses of the isolated millet starches are shown in Table I. Except for RMP'76 and Serere 3A, protein contents of millet starches are higher than most laboratory wet-milled cereal starches and agree with values reported by Freeman and Bocan (1973). Fat contents of pearl millet starches are high and probably reflect pearl millet's high lipid content (Lai and Varriano-Marston, 1980).

Cold water-binding capacity of starches varied from 83.6% for HMP550 to 99.5% for HMP1700 (Table II). Variations in water absorption may be caused by inherent differences in the proportion of crystalline and amorphous areas in the granules. Presumably, starches containing a higher proportion of amorphous material would imbibe more water. X-ray diffraction patterns of millet starches (Fig. 1) showed the A-type X-ray pattern and indicated that the HMP550 starch was more crystalline than the HMP1700 sample which may explain the higher cold water imbibition by the latter starch.

Starch crystallinity may be affected by mechanical and/or amylolytic activity. Starch damage determinations showed that all isolated millet starches had immeasurably low damage. It can be concluded, therefore, that physicochemical differences among our millet starches are caused by inherent molecular dissimilarities.

Starch gelatinization temperature ranges provide information on starch granule structure. Initiation temperatures varied from 59 to 63 C; end-point temperatures, from 68 to 70 C (Table II). Genetic or environmental factors may be responsible for the differences among cultivars. Freeman et al. (1968) have shown that environmental temperature during grain maturation can cause differences in starch gelatinization temperatures among cultivars

Because swelling and solubility patterns provide information on the associative forces within the granule (Leach et al., 1959), those patterns were determined for millet starches. At 65 C, the two RMP starches were significantly less swollen than the other starches (Table III). Swelling power at 70 C also tended to be lower for starches from RMP populations. From 80 to 90 C, RMP starches appeared to have the greatest swelling power but those values were not significantly different from the other populations. There may have been real differences in swelling power among starch populations; we feel that the method was not as precise as has been suggested (Leach et al., 1959). Difficulties in obtaining good separations of supernatant from precipitated paste resulted in large standard deviations for swelling determinations at the higher temperatures.

Solubility patterns (Table IV) did not necessarily follow swelling power. For example HMP550 and HMP1700 had high swelling powers but low solubilities at 75 C. From 75 C to 90 C, starches isolated from RMP populations were significantly ($P < 0.05$) more soluble than the other starches, and at 95 C RMP'78 starch was the most soluble. In fact, at equal swelling, more solubles were leached from RMP starches than from the other samples (Fig. 2). It also is interesting to note that in general, starches with low swelling and solubility at temperatures below 75°C usually had high swelling and solubility at temperatures from 80 to 95 C. This phenomenon could be related to the two stage relaxation of bonding forces within the starch granules during swelling. Starch populations with low swelling and solubility during the first stage of relaxation would show higher values during the second stage.

The combined effects of swelling power and solubility on the pasting characteristics of millet starches were determined with the Brabender Amylograph (Table V). The pasting temperature for all starches was 76.5 C. Among the various starches, differences between the maximum and minimum values for Viscosity at 95 C was 100 B.U.; the same was true for Peak Viscosity. Larger differences among starches were observed after 1 hr. at 95 C and during the cooling cycle. HMP550 starch had the lowest viscosity after 1 hr. at 50 C; RMP'78 had the highest viscosity. The lower cold-paste viscosity obtained by the HMP550 starch suggests that it tends to retrograde less than starches from the other populations, which may be related, in part, to its tendency to solubilize less during heating (Table IV).

The contribution of starch molecules to the viscosity of a solution depends primarily on the particle volume that they occupy (Van Holde, 1971). Intrinsic viscosity ($\{\eta\}$) primarily measures particle volume and resistance of molecules to displacement under conditions where associative bonding effects have been minimized (Leach, 1963). Intrinsic viscosities of millet starches ranged from 1.47 to 1.71 (Table VI), with HMP1700 having the lowest and RMP'76 the highest. The range is lower than intrinsic viscosities reported for corn (Leach, 1963) or sorghum (Freeman and Bocan, 1973) and may reflect smaller molecular dimensions for millet starch molecules.

Pasting characteristics of various starches are affected by amylose and anylopectin contents as well as their arrangement in the granule. Iodine affinity often is used to estimate amylose content of starches. Iodine affinities of pearl millet starches ranged from 4.13% to 4.75% (Table VI), which, when based on an iodine binding limit of 200 mg/g, suggests that amylose contents range from 20.5 to 23.5%. However, iodine affinities are not true indicators of amylose content because they depend on chain length and degree of branching (Bates et al., 1943). Quantitative determinations of amylose by the blue value method (McCready and Hassid, 1943) showed amylose contents ranging from 20 to 22% (Table VI). Badi et al. (1976) reported a low amylose content for their millet starch (17%), but our data indicate that millet starches contain as much amylose as normal cereal starches.

LITERATURE CITED

American Association of Cereal Chemists. 1972. Methods 76-30A and 22-10. Cereal laboratory methods (7th ed.). The Association: St. Paul, Minn.

Association of Official Analytical Chemists. 1975. Official Methods of Analysis. (12th ed.), The Association: Washington, D.C.

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

Banks, W., and C. T. Greenwood. 1967. The fractionation of laboratory-isolated cereal starches using dimethyl sulphoxide. Die Stärke. 19:394.

Bates, F. L., D. French, and R. E. Rundle. 1943. Amylose and amylopectin content of starches determined by their iodine complex formation. J. Amer. Chem. Soc. 65:142.

Freeman, J. E., N. W. Kramer, and S. A. Watson. 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.

Freeman, J. E., and B. J. Bocan. 1973. Pearl millet: A potential crop for wet milling. Cereal Sci. Today. 18:69.

Lai, C. C., and E. Varriano-Marston. 1980. Lipid content and fatty acid composition of pearl millets. Cereal Chem. In press.

Leach, H. W., L. D. McCowen, and T. J. Schoch. 1959. Structure of the starch granule. 1. Swelling and solubility patterns of various starches. Cereal Chem. 36:534.

Leach, H. W. 1963. Determination of intrinsic viscosity of starches. Cereal Chem. 40:593.

McCready, R. M., and W. F. Hassid. 1943. The separation and quantitative estimation of amylose and amylopectin in potato starch. J. Amer. Chem. Soc. 65:1154.

Medcalf, D. G., and K. A. Gilles. 1965. Wheat starches. I. Composition of physiochemical properties. Cereal Chem. 42:558.

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

Schoch, T. J., and E. C. Maywald. 1956. Microscopic examination of modified starches. Anal. Chem. 28:382.

Schoch, T. J. 1964. Iodimetric determination of amylose. Potentiometric titration. Methods Carbohyd. Chem. 4:157.

Van Holde, K. E. 1971. Physical Biochemistry. Prentice-Hall, Inc., Englewood Cliffs, N.J.

Table I

Proximate Analyses of Pearl Millet Starches

Starch	Protein[1] (%)	Fat (%)	Ash (%)	Moisture (%)
HMP1700	0.77	0.09	0.12	10.8
Serere 3A	0.44	0.11	0.12	13.7
HMP550	0.66	0.13	0.13	14.1
RMP'78	0.66	0.11	0.12	14.0
RMP'76	0.55	0.19	0.10	13.0

[1]Nitrogen x 6.25

Table II

Water binding capacity and gelatinization temperature ranges of pearl millet starches.[1]

Starch	Water binding capacity[2] (%)	Gelatinization temperature (°C)		
		Initial	Mid-point	End-point
HMP1700	99.5[a]	59	65	68.5
Serere 3A	85.0[b]	61	65.5	68
HMP550	83.6[b]	60.5	65	68
RMP'78	85.0[b]	63	67.5	69
RMP'76	84.5[b]	62	67.5	70

[1]Values represent the mean of 4 determinations.

[2]Values with different superscripts differ significantly ($P < 0.01$).

Table III

Swelling Power of Starches Isolated from Pearl Millets[1]

Temperature (°C)	Random Mating Populations				
	HMP550	Serere 3A	HMP1700	RMP'76	RMP'78
60	2.1[ab]	2.3[a]	2.3[a]	2.0[b]	2.0[b]
65	4.1[a]	3.6[a]	3.7[a]	2.5[b]	2.2[b]
70	7.3[a]	6.6[ab]	7.3[a]	5.8[bc]	5.2[c]
75	9.5[a]	8.6[bc]	9.3[ab]	9.6[a]	8.3[c]
80	10.4[a]	9.5[a]	10.2[a]	10.8[a]	9.9[a]
85	11.1[a]	10.5[a]	10.9[a]	12.5[a]	11.5[a]
90	13.5[a]	12.2[a]	12.4[a]	13.3[a]	14.1[a]
95	14.3[a]	14.3[a]	14.1[a]	15.4[a]	16.4[a]

[1]Values represent the mean of 3 determinations. Within each temperature, values with different superscripts differ significantly ($P < 0.05$).

Table IV

Solubility (%) of Starches Isolated from Pearl Millet[1]

Temperature (°C)	Random Mating Populations				
	HMP550	Serere 3A	HMP1700	RMP'76	RMP'78
60	0.5^{a}	0.6^{a}	0.5^{a}	0.4^{a}	0.8^{a}
65	1.3^{a}	1.1^{ab}	1.1^{ab}	0.5^{b}	1.0^{ab}
70	1.8^{a}	2.9^{ab}	3.2^{b}	3.0^{b}	3.3^{b}
75	4.0^{a}	4.5^{a}	4.2^{a}	5.4^{b}	7.1^{b}
80	4.5^{a}	5.1^{a}	4.5^{a}	7.0^{b}	7.8^{b}
85	5.3^{a}	6.6^{a}	5.0^{a}	9.0^{b}	9.3^{b}
90	7.8^{b}	7.9^{b}	7.1^{b}	10.7^{a}	12.2^{a}
95	7.9^{d}	11.7^{bc}	8.7^{cd}	13.5^{b}	18.9^{a}

[1] Values represent the mean of 3 determinations. Within each temperature, values with different superscripts differ significantly ($P < 0.05$).

Table V

Amylograph Pasting Characteristics of Pearl Millet Starch[1]

Starch	Viscosity at 95°C	Max. Viscosity	Viscosity after 1 hr @ 95°C	Viscosity at 50°C	Viscosity after 1 hr @ 50°C
HMP1700	500	500	400	540	500
Serere 3A	440	440	440	620	580
HMP550	480	480	340	500	460
RMP'78	480	480	460	640	620
RMP'76	400	400	340	540	520

[1]Values are reported in Brabender Units (B.U.).

Table VI

Intrinsic Viscosity, Iodine Affinity, and Amylose Contents of Pearl Millet Starches

Starch	{n}[a]	Iodine affinity[b] (%)	Amylose[c] (%)
HMP1700	1.47	4.28	22.0
Serere 3A	1.54	4.13	21.0
HMP550	1.62	4.38	21.0
RMP'78	1.58	4.75	21.5
RMP'76	1.71	4.13	20.0

[a]s = ± 0.05

[b]s = ± 0.04

[c]Determined by blue value method of McCready and Hassid (1943).

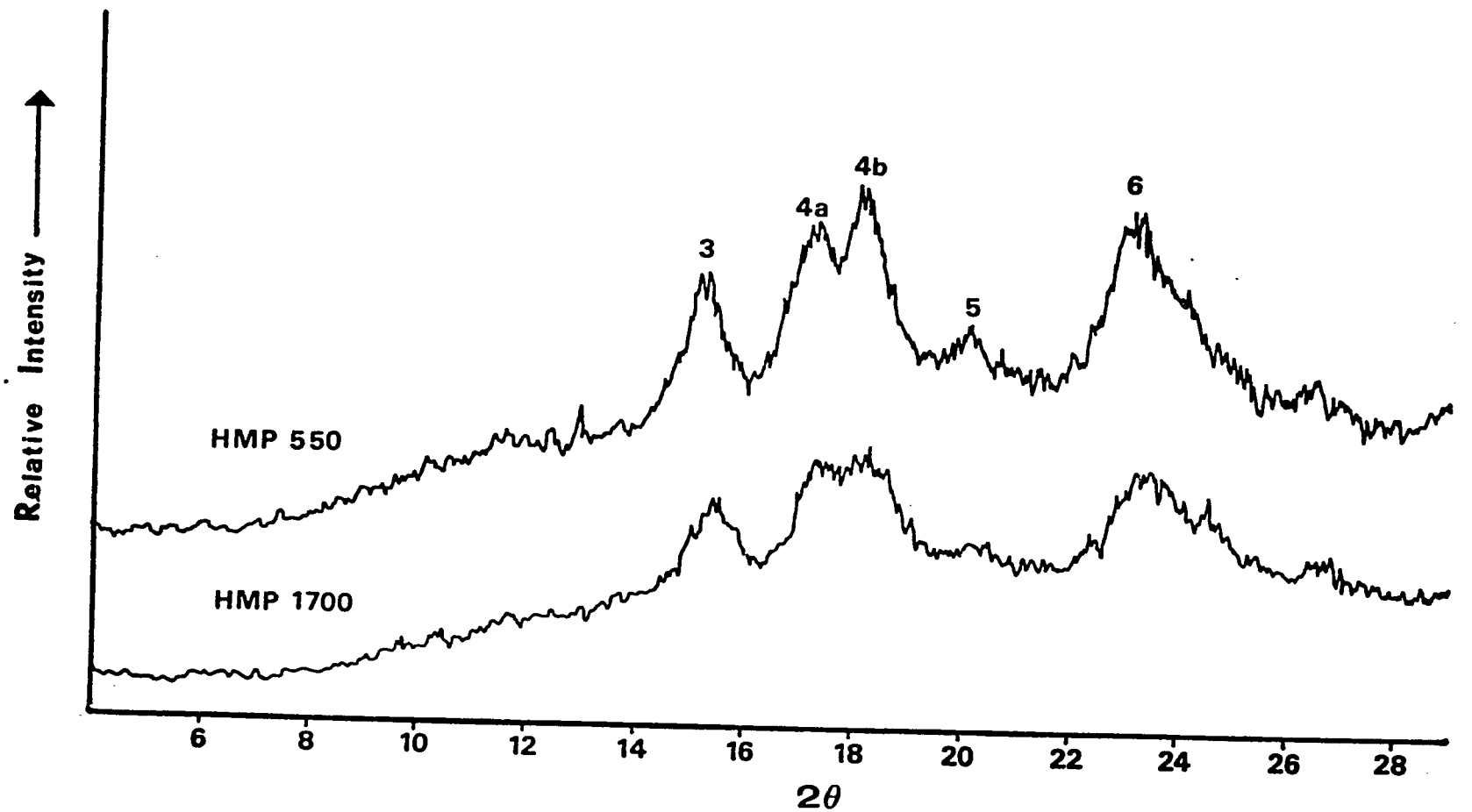


Fig. 1

X-ray diffraction patterns ($Cu_{k\alpha}$) of millet starches.

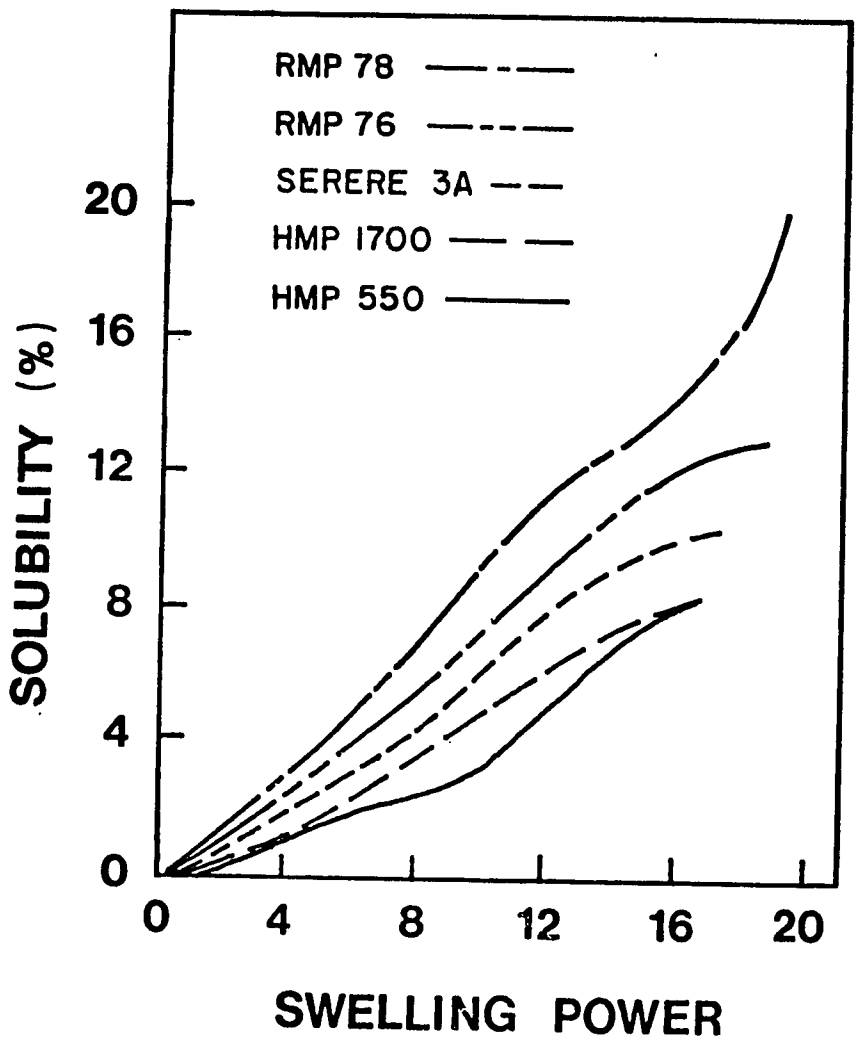


Fig. 2

Solubilities of millet starches at equal levels of swelling.

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

B. Mason and R. C. Hoseney

INTRODUCTION

The classification of cereal proteins according to their solubility properties has helped scientists to understand why certain cultivars contain more nutritious protein. The protein solubility classes are known to differ in amino acid composition and the proportion of total grain nitrogen in each of the protein solubility classes reflects upon the dietary quality of the protein in the grain (Pomeranz, 1975). The alcohol soluble prolamines tend to be especially poor in lysine and other nutritionally critical amino acids. Instead they are comparatively rich in glutamine and proline. Since the prolamines constitute a major fraction of the grain protein, the grain overall is deficient in these amino acids. The great nutritive gains achieved in breeding maize, barley, and sorghum for high lysine cultivars have resulted from depressing the synthesis of the prolamines (Mertz, 1975). Mertz (1975) expressed optimism that such alterations would be realized in the millets. Information as to whether pearl millet proteins follow similar patterns of amino acid composition would be invaluable to pearl millet breeders and others seeking to improve the protein quality of the crop. The following report summarizes the current status of our efforts to characterize the proteins of pearl millet.

MATERIALS AND MEHTODS

Amino acid composition of pearl millet milling fractions

Grain from the bulk composite HMP 550 was milled into bran, low ash flour, and high ash flour on a Brabender Quadrumat Junior Experimental Mill. In order to obtain an extraction of greater than 40 percent, it was necessary to pass the bran through the mill thereby recovering additional endosperm material. The final bran was subsequently ground prior to analysis in a Udy Cyclone Mill. The three milling fractions were tested along with a reconstituted meal for Kjeldahl nitrogen and amino acid composition. Samples were hydrolyzed in p-toluenesulfonic acid prior to determination of amino acids on a Beckman 120C analyzer. Norleucine was employed as an internal standard.

Solubility fractionation of pearl millet protein: comparison of nitrogen distribution in low ash flour and in meal

Pearl millet grain was milled as described above and the low ash flour and reconstituted meal were extracted overnight with petroleum ether and dried for 8 hours at 50°C. To a screw cap centrifuge tube containing 3 g of meal or flour (or the centrifugate from the previous extraction) was added 12 g solvent. These contents were homogenized and shaken on a horizontal reciprocating shaker. The extractions were performed at room temperature for the times indicated in Table I. Following each extraction, the tubes were centrifuged at 4,000 X G and the supernatants collected.

For a given sample replication, the supernatants for each solvent were combined and their volume determined from their weight and density. The centrifugates from the final extractions were removed from the tubes and placed on watch glasses and dried 8 hours at 50°C. After drying, they were weighed and ground in Girmi coffee grinder. For quantitation of extracted nitrogen, liquid samples were pipetted into microkjeldahl flasks and taken to dryness on a rotary evaporator before being analyzed for nitrogen.

Table I. Protein Solubility Fractionation Scheme.

Solvent	Duration (min)
Salt (0.5 M Sodium Chloride)	60
	30
	5
Alcohol (Ethanol:Water 70:30 v/v with 0.5% Sodium Acetate)	120
	60
	30
	5
SDS (0-5% Sodium Dodecyl Sulfate in a pH 10 Carbonate Buffer)	60
	30
	5

Solubility fractionation of pearl millet protein: comparison of nitrogen distribution in four lines

Four pearl millet lines were analyzed for nitrogen distribution according to the previously described solvent system. The four samples were analyzed for amino acids and had a reasonable range in lysine concentrations (Table II).

Table II. Lysine and moisture-free protein concentrations of meals from four millet lines.

Millet Line	Lysine (g/16 g N)	Protein (%)
120	2.9	15.2
149	3.1	15.1
180	2.5	15.8
193	2.7	16.1

Solubility fractionation of pearl millet protein: amino acid analysis of solubility fractions

The amino acid composition of fractions separated by the solubility classification scheme from millet meal was used to characterize pearl millet proteins belonging to the different solubility classes and to evaluate the fractionation scheme. In order to solubilize additional amounts of protein, 2-mercaptoethanol was added to the SDS solvent and 0.1 N sodium hydroxide (NaOH) was employed as a final extractant. Moreover, each solvent was used successively for 120, 60, and 30 minutes. The collected supernatants were dialyzed and freeze dried prior to hydrolysis and amino acid analysis.

RESULTS AND DISCUSSION

Amino acid composition of pearl millet milling fractions

The amino acid compositions of low ash flour, high ash flour, bran, and total meal are shown in Table III along with respective protein content and percent total mill product values. The whole meal had appreciable more lysine, arginine, and glycine and less methionine than did the flours. The differences observed between the meal and the flours were accounted for in the bran. The low ash flour was found to contain slightly more lysine and arginine than the high ash flour. The low ash flour may have contained more of the floury portions of the endosperm because the floury endosperm pulverizes more readily during milling.

Solubility fractionation of pearl millet protein: comparison of nitrogen distribution in low ash flour and meal

The results of this experiment are shown in Table IV. The nitrogen distribution in the meal and flour were not appreciably different. In both cases, the prolamine class predominated and there was a considerable insoluble residue. As would be expected, the flour was slightly richer in prolamines. The insoluble residue proteins were not concentrated in the bran.

Solubility fractionation of pearl millet protein: comparison of nitrogen distribution in samples from four distinct populations

The nitrogen distribution among the protein solubility classes for each of the four millet lines is presented in Table V. The four lines were quite similar in their protein distribution among the solubility classes. The results of this experiment did not suggest a direct relationship between lysine concentration and nitrogen distribution in these samples.

Fractionation of pearl millet protein: amino acid analysis of solubility fractions

The nitrogen distribution among the protein solubility classes is shown in Table VI.

Table III. Protein and amino acid composition of pearl millet meal and milling fractions (g per 16 g N).

Constituent	Low Ash Flour	High Ash Flour	Bran	Meal
Lysine	2.44	2.19	3.20	2.57
Histidine	2.13	2.04	2.05	2.10
Ammonia	3.89	3.42	3.09	3.23
Arginine	3.83	3.53	5.26	4.38
Aspartic	9.09	9.00	10.70	9.66
Threonine	3.65	3.64	3.80	3.72
Serine	4.97	5.08	5.13	5.12
Glutamic Acid	23.38	23.93	22.13	23.88
Proline	7.15	7.02	6.47	6.98
Half Cystine	0.46	0.68	0.56	0.54
Glycine	2.85	2.85	4.08	3.23
Alanine	8.97	9.13	8.96	9.02
Valine	4.12	4.16	3.90	3.94
Methionine	2.01	2.08	1.75	1.81
Isoleucine	3.31	3.39	2.92	3.10
Leucine	10.26	10.53	9.11	9.76
Tyrosine	2.62	2.59	2.53	2.47
Phenylalanine	4.89	4.75	4.37	4.49
Protein (14% MB)	11.50	13.00	19.60	15.90
% Total Mill Product	45%	13%	42%	100%

Table IV. Solubility fractionation of pearl millet meal and flour.

Fraction	% Nitrogen Recovered Meal	Flour
Saline Soluble	28.1	27.6
Alcohol Soluble	34.2	42.9
SDS Soluble	4.4	5.3
Residue	28.3	27.7
Total Nitrogen Recovery	95.0	103.5

Table V. Solubility fractionation of meals from four pearl millet lines.

Fraction	% Nitrogen Recovered 120	149	180	193
Saline Soluble	26.1	28.4	27.7	28.4
Alcohol Soluble	29.1	28.2	27.2	28.1
SDS Soluble	7.5	8.4	7.4	8.7
Residue	36.6	36.3	39.7	40.3
Total Nitrogen Recovery	99.3	101.3	102.0	105.5

Table VI. Solubility fractionation of pearl millet meal for amino acid analysis of solubility separated proteins.

Fraction	% Nitrogen Recovered
Saline Soluble	27.3
Alcohol Soluble	38.8
SDS: 2-ME in pH 10 Soluble	16.9
NaOH Soluble	9.8
Insoluble Residue	8.2
Total Nitrogen Recovered	101.0

The addition of 2-mercaptoethanol to the SDS-carbonate buffer (pH 10) enhanced the nitrogen extracted by that solvent. Moreover, the NaOH solubilized about half of the remaining residues, and thus over 90% of the nitrogen was solubilized.

The amino acid analyses of the five solubility fractions are shown in Table VII. The amino acid compositions of the pearl millet solubility classes are comparable to that of corn and sorghum (Wall and Paulis, 1977). The saline solubles are rich in lysine, arginine, histidine, and aspartic acid. The prolamines are rich in leucine, alanine, phenylalanine, and glutamine. The solvent containing SDS, 2-mercaptoethanol, and buffered at pH 10 with cabonate extracted proteins that were rich in basic amino acids, threonine and cysteine. The NaOH solubles and the insolubles showed comparable amino acid compositions.

Present and Future work

At the present our efforts are directed towards explaining and overcoming the difficulty with which all of the pearl millet grain nitrogen is solubilized. The residue nitrogen does appear to be protein: the amino acid composition of the residue was comparable to that of the meal except for increased amounts of proline. The insoluble protein occurs in the endosperm as evidenced by the incomplete extraction of flour nitrogen but precise localization of the insoluble protein is needed. The possibility that this extensive protein insolubility is accountable to differential compartmentalization within endosperm cells is being investigated. Selective solubilization of matrix and protein body protein and the isolation of the protein bodies themselves is being undertaken. Mechanical separation of hard and soft endosperm protein might further localize the insoluble protein.

Table VII. Amino acid concentrations of protein from solubility fractions (g per 16 g nitrogen).

Amino Acid	Saline Soluble	Alcohol Soluble	SDS: 2-ME pH 10 Soluble	NaOH Soluble	Insoluble
Lysine	3.71	0.00	4.58	2.56	2.49
Histidine	4.43	1.78	4.68	2.91	3.63
Ammonia	1.92	4.35	0.82	2.14	2.29
Arginine	4.16	2.02	7.59	3.91	3.71
Aspartic Acid	9.75	7.12	10.70	8.61	9.38
Threonine	4.22	2.97	4.25	4.35	4.38
Serine	4.67	5.07	6.07	5.31	5.65
Glutmaic Acid	21.18	28.25	15.70	22.04	19.80
Proline	9.22	6.80	6.05	6.96	6.80
Glycine	4.27	0.55	6.95	3.55	4.82
Alanine	8.59	9.93	9.86	8.96	9.18
Half Cystine	0.69	0.75	1.15	0.50	0.00
Valine	3.81	4.22	4.27	4.50	4.75
Methionine	0.98	1.06	1.02	1.98	2.10
Isoleucine	2.54	3.67	2.47	3.14	3.24
Leucine	8.11	13.37	6.12	10.03	10.01
Tyrosine	4.11	2.88	3.62	3.74	3.52
Phenylalanine	3.63	5.22	4.10	4.79	4.72
% Recovery	92.40	101.80	84.90	95.70	80.70

Electrophoretic techniques for the analysis of the polypeptides present in the different solubility fractions are being developed. These methods will allow characterization of the solubility classes and will assist in the refinement of a fractionation scheme which reflects grain protein nutritive quality and allows for maximal solubilization of grain nitrogen.

REFERENCES

Mertz, E. T. Breeding for improved nutritional value in cereals. p. 1-12. In Friedman (ed.). Protein nutritional quality in foods and feeds: Part 2. Quality factors -- plant breeding, composition, processing, and nutrients. Marcel Dekker, New York (1975).

Pomeranz, Y. Proteins and amino acids of barley, oats, and buchwheat. p. 13-78. In Friedman (ed.). op. cit. (1975)

Wall, J. S. and Paulis, J. W. Corn and sorghum grain proteins. In Ad. Cer. Sci. and Tech. Vol. II, Y. Pomeranz (ed.). American Association of Cereal Chemists, St. Paul, Minnesota (1977).

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

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

One important factor in determining grain quality is its milling characteristics. Recently, a laboratory decorticating mill for small grains was developed by Shepherd (1979). The objective of this study was to determine the responses of different random mating populations of pearl millet [*Pennisetum americanum* (L.) Leeke] and cultivars of grain sorghum [*S. bicolor* (L.) Moench] to decortication on Shepherd's Udy Cyclone modified mill. We wanted to determine if decortication behavior could be used to differentiate samples and thus, provide information on milling quality.

MATERIALS AND METHODS

Materials

Data on pearl millet and sorghum samples that were studied are shown in Table 1. The pedigree of the millet cultivars grown in Kansas was as follows: HMP 1700 (PI 263540/Tift 23 DB_1/2/Tift 239 DB_2/2*Serere 3A), HMP 550 (Tift 23 DB_1/*2PI 185642), RMP I(S)CI (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. These two samples were selected from the marketplace in Khartoum, Sudan, and represent "good" (green) and "poor" (yellow) quality grains as judged by the villagers based on flavor characteristics and price differential in the marketplace (Badi, 1979).

Two of the sorghum cultivars (SRAI W4, SRAI W6) were developed at the Seed Research Association, Scott City, Kansas, and the Dwarf White originated in Sudan but was grown in Kansas.

Grain Cleaning

After light weight debris had been removed with an aspirator, the grain was passed over a 5½/64" X 3/4" slotted sieve to remove undersized seeds. 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.

The Udy Cyclone Mill was fitted with 4 blades so that the distance from blade tip to blade tip was 4.25", a 46 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. These conditions proved to be too severe for the Sudanese millets. Those samples were also decorticated with an 80 mesh grit and at 1500 rpm. The mill conditions for the decortication of the sorghum samples were the same as for the Kansas grown millets.

Preliminary decortications were performed on 10 g samples of millet and sorghum in order to determine the optimum times for obtaining 5, 10, 15, and 20% bran removal. The bran fractions were weighed and collected every 20 sec. 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).

RESULTS AND DISCUSSION

Millets

The amount of bran removed from pearl millets during decortication varied considerably across populations. At a constant level of bran removal, the Serere 3A and RMP I(S)CI required more time than the other samples to obtain the same degree of decortication. Conversely, the Sudanese millets were much easier to decorticate than the Kansas millets, except for HMP 550 population.

As was mentioned earlier, the mill conditions had to be changed (less abrasive surface and lower rpm) for the Sudanese millets because the grains were more easily decorticated than the Kansas populations. Differences between Sudanese millets could be more easily observed when they were decorticated at 1500 rpm; the green millet required more time than the yellow millet to obtain the same level of bran removal.

Sorghum

The Udy Cyclone Mill was also useful in differentiating sorghum cultivars. The Dwarf White required much less time than the SRAI cultivars to obtain the same level of bran removal. When the decortication of sorghum and millet were compared, it was apparent that sorghum was more readily decorticated than millet. Differences may be related to structural dissimilarities.

Structural Studies

Photographs of stained decorticated grains showed that the pericarp layers were progressively removed during decortication. The decortication was quite uniform, but in most kernels the germ was not completely removed by the decortication process.

Scanning electron micrographs of half-kernels of pearl millet and grain sorghum that were decorticated to 12.5% and 5.9% bran removal, respectively, indicated that the bran was removed in large flakes during the decortication of sorghum while pearl millet bran was removed in smaller flakes which were structurally weaker and broke down to readily pass the 1 mm screen. Differences in decortication may be related to different pericarp structures as well as variations in size and shape of kernels. A comparison of the two grains indicates that the mesocarp cells of pearl millet, unlike grain sorghum, are devoid of starch granules. Similar structural observations were made by Sullins and Rooney (1977).

When millet was decorticated in the Udy Mill, the structural point of detachment of the bran was at the junction between the endosperm and aleurone layer. Conversely, the weakest structural point during sorghum decortication was in the mesocarp. Therefore, it can be concluded that the process of decortication of the two grains follows a different pattern due to inherent structural dissimilarities.

The decortication studies also suggested that pearl millet samples from Sudan were easier to decorticate than Kansas-grown millets. At present, we have not determined the reason for those differences. However, we are investigating methods to measure the hardness of whole and decorticated samples.

LITERATURE CITED

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

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

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

Sullins, R. D. and L. W. Rooney. 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.

Table 1. Proximate composition of pearl millet and sorghum samples.

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
RMP I(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.

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

Sandra Dassenko and Beth Fryer

Milling processes for pearl millet are necessary to produce an acceptable product for use in food preparations (Novellie, 1977; Desikachar, 1977; Oke, 1977). The whole grain is objectionable for consumption due to the coarse mouthfeel and a longer cooking time needed than for a refined product. Rao et al. (1953) investigated processing techniques to improve whole grain palatability and cooking quality. Milling removes the bran and leaves a polished or pearled grain. The polished grain is more suitable for a variety of preparations than products made from meal. In addition, Goussault and Adrian (1977) reported that industrial milling gives nutritional advantages over a traditional wood-mortar milling process. After milling and sifting, a more digestible product can be produced but protein quality is lower than the whole grain product (Goussault and Adrian, 1977).

Like other cereals, millet protein is deficient in the amino acid lysine. Lysine is especially critical for growth in children. In the diets of people in subtropical areas, millet protein is supplemented with legumes or pulses which complement by providing lysine. The millet, in turn, will provide the sulfur-containing amino acids which are in low levels in pulses. The complementary effect produces a diet with good quality protein (Oke, 1977).

Protein value also can be evaluated in relation to the digestibility of the millet. Dassenko and Fryer (unpublished data, 1980) showed that cooking millet in the form of Chapaties made the protein less available with a significantly lowered PER. The less digestible the grain, the less protein that is available for use, although the protein is of good quality. Milling and sifting of millet improves protein digestibility but nitrogen becomes quantitatively deficient. The decrease in nitrogen is due to the higher percentage of protein including the amino acid lysine which is lost in the outer layers of the grain during processing (Goussault and Adrian, 1977).

The objectives of the following study were (1) to determine the effect of milling, fermentation and cooking on certain vitamins and minerals in millet, and (2) to determine the bioavailability in the rate of protein from millet meal, millet flour and their fermented and cooked counterparts.

MATERIALS AND METHODS

Diet Preparations

Pearl millet meal and millet flour (67% extraction) were obtained from the Department of Grain Science and Industry. The grain was milled on a Buhler experimental mill. Proximate analyses of the samples are

shown in Table I. The meal and flour were used to prepare diets for use in the animal study. A casein diet was the control. A raw, a cooked, and a fermented and cooked product were prepared from both meal and flour.

The cooked product was prepared by mixing 400 g of millet flour with 600 ml of distilled water to form a slurry. The slurry was stirred into 1000 ml of boiling water and cooked for 10 min, stirring constantly. The cooked product was cooled and placed in containers for freeze drying.

The fermented product was prepared by mixing 400 g of millet flour with 600 ml of distilled water and allowing it to sit in glass jars at room temperature for 24 hr. It was stirred into 1000 ml boiling water and cooked for 10 min, stirring constantly. After cooling, the product was put into containers for freeze drying.

Following freeze drying the millet was labeled and stored in a freezer at -20 C. When ready to use, the chunks of millet were blended to a powder in a Hobart mixer. A sample of each product was analyzed for protein, moisture, ash, and fat according to AOAC methods (1972).

The diets were formulated with raw, cooked, and fermented and cooked freeze-dried products. The millet was incorporated as the only source of protein in all diets (except casein control) at the 10% level. The feed composition is shown in Table II.

Vitamin and Mineral Analyses

Vitamins. Thiamine, Riboflavin and niacin were determined by AACC methods (1968) with some modifications in the thiamine and riboflavin methods. In the thiamine-thiochrome method 0.1 N HCl was used instead of sulfuric acid in the extraction step. In the fluorometric method for riboflavin, 1 ml of glacial acetic acid was added to the standard solution prior to the addition of potassium permanganate. Without the acetic acid, the millet solution showed a precipitate after the oxidation step.

Minerals. Millet samples were prepared for mineral analysis by a modification of the Berry and Johnson (1966) ashing procedure. The dry samples were wet with 1.8 N H_2SO_4 in absolute alcohol and the alcohol was burned off; the product was cooled and then ashed in a muffle furnace at 550 C for 5 hr, starting with a cold muffle. At the end of that period, the ash was dissolved in 10 ml HCl (1.2 N) on a steam bath and concentrated to dryness. The product was then placed in the muffle at 550 C for 2 hr; this last step was repeated two or three times until a white ash was obtained. The white ash was dissolved and made to a volume of 100 ml with 5% HCl. Lanthanum chloride (1% La) was used in the final solution as a protective agent. Atomic absorption was used to determine Ca, Mg, and Fe and flame emission to determine Na and K (Perkin-Elmer Spectrophotomer Model 460).

Biological Evaluations

Weanling rats were used to determine protein bioavailability. Rats were assigned to seven diet groups with eight animals per group. Water and food were provided ad libitum. Weekly weight gain and feed intake were recorded. Protein efficiency ratios (PER) were calculated as:

$$PER = \frac{\text{gm weight gain}}{\text{gm protein intake}}$$

Feces were collected and dried during the last three weeks of the study. They were dried and ground into a powder and analyzed for nitrogen by the macrokjeldahl procedure and for energy value with a bomb calorimeter. The calculations were as follows:

$$\text{Coefficient of Digestibility of Protein} = \frac{N_{food} - N_{Feces}}{N_{food}} \times 100$$

$$\text{Coefficient of Digestibility of Food Energy} = \frac{KCal_{food} - KCal_{feces}}{KCal_{food}} \times 100.$$

Statistical Analysis

The data were subjected to analysis of variance. Least significant differences were determined.

RESULTS AND DISCUSSION

Nutrient Content

Vitamin analyses of the grain samples used in the diets indicated that the milling process did not significantly ($P < 0.05$) lower the thiamine, riboflavin or niacin contents of the grain (Table III). However, the natural fermentation process increased the concentration of those vitamins in the samples. An increase in the B-vitamin content of naturally fermented grains has also been reported for sorghum (Kazanas, 1979). Cooking did not, in general, result in the destruction of B vitamins.

The milling process significantly ($P < 0.05$) decreased the levels of Mg, Ca, and Na in the millet flour but had little effect on the concentrations of K or Fe in the samples (Table IV). High levels of K and Fe in millet flour were expected since Varriano-Marston and Hoseney (1980) showed that the predominant minerals in endosperm portions of pearl millet are K and Fe.

The levels of Mg, Ca, K, and Fe in millet meal and flour were increased by fermentation and cooking. The increase may be due to contamination of fermentation and/or cooking utensils or water with those minerals. It is well-known that food processing and preparation procedures can contribute significantly to the mineral content of diets.

For example, Carr (1961) reported an Fe content of 460 μg/g of grain for pearl millet ground on stones containing high levels of Fe.

Amino acid analyses of millet meal, millet flour and the fermented and cooked products are shown in Table V. In general, there were no significant changes in amino acids as a result of milling, fermentation or cooking.

Biological Evaluations

Feed intake. The feed intake for rats on casein diets was significantly ($P < 0.05$) greater than for rats on the millet-based diets (Table VI). Milling pearl millet did not increase the feed intake by the rats, nor did fermentation and/or cooking.

Weight gain. Values for weight gain, adjusted for feed intake, indicated that animals fed casein diets gained significantly ($P < 0.05$) more weight than animals on millet diets (Table VI). The milling process did not significantly ($P < 0.05$) increase the weight gained by the animals fed millet. Furthermore, cooking did not affect the adjusted weight gain of animals fed millet meal. However, when millet flour was cooked, it significantly ($P < 0.05$) increased weight gain compared to the cooked milled meal.

A combination of fermentation and cooking of meal or flour significantly ($P < 0.05$) lowered the adjusted weight gain compared to the raw or cooked counterparts (Table VI). These results suggest that fermentation, rather than cooking, was responsible for the lowered weight gains.

Protein efficiency ratios (PER). Like most diets based on cereal grains, pearl millet diets yielded lower PER's than casein diets (Table VII). However, a significant ($P < 0.05$) increase in PER resulted when the grain was milled. Some component(s) of the outer layers of the grain must be decreasing PER.

Cooking millet meal or flour did not significantly ($P < 0.05$) alter the PER compared to the raw counterparts (Table VII). However, fermentation before cooking significantly ($P < 0.05$) lowered the PER, suggesting that fermentation exerts a negative effect on protein bioavilability.

Protein and calorie digestibility. As expected, the digestibility of casein protein was significantly ($P < 0.05$) greater than millet protein (Table VIII). The milling process did not increase the digestibility of millet protein, neither did cooking or fermentation and cooking.

Although milling did not significantly ($P < 0.05$) affect calorie digestibility, calories became more digestible when millet flour (but not meal) was cooked (Table VIII). Fermentation had no effect on calorie digestibility.

LITERATURE CITED

Berry, W. L. and C. M. Johnson. 1966. Determination of calcium and magnesium in plant material and culture solutions, using atomic absorption spectroscopy. Applied Spectroscopy 20:209.

Carr, W. R. 1961. Observations on the nutritive value of traditionally ground cereals in Southern Rhodesia. Brit. J. Nutr. 15:339.

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.

Goussault, B. and J. Adrian. 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 Homan Food." (Dendy, D.A.V., ed.) p. 13, Tropical Products Institute, London.

Kazanas, N. 1979. Natural Fermentation of Sorghum to Improve its Nutritive Value. Ph.D. Thesis. University of Missouri, Columbia, MO.

Novellie, L. 1977. Beverages from sorghum and millets. In "Proceedings of a Symposium on Sorghum and Millets for Human Food." (Dendy, D.A.V., ed.) p. 73, Tropical Products Institute, London.

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." (Dendy, D.A.V., ed.) p. 121, Tropical Products Institute, London.

Sullins, R. D. and L. W. Rooney. 1977. Pericarp and endosperm structure of pearl millet. IACC Symposium "Sorghum and millets for human food." ed. D.A.V. Dendy.

Varriano-Marston, E. and R. C. Hoseney. 1980. Note on Mineral Content and Location in Pearl Millet. Cereal Chem. In press.

Table I. Proximate Composition of Pearl Millet Meal and Flour.

	Meal	Flour (67% Extraction)
Moisture (%)	12.6	11.2
Protein (%)	13.7	12.7
Ash (%)	1.9	1.7
Fat (%)	5.8	5.2

Table II. Feed Composition(Percent)of Diets

Component	Diets Containing Millet Meal			Diets Containing Millet Flour			Casein
	raw	cooked	fermented & cooked	raw	cooked	fermented and cooked	
Protein Source	72.99	68.03	68.03	78.74	70.42	71.43	11.11
Oil	4.20	4.67	5.14	3.43	3.70	4.64	8.0
Salt Mix	3.76	3.64	3.64	3.50	3.59	3.43	5.0
Vitamin Mix	2.20	2.20	2.20	2.20	2.20	2.20	2.2
Moisture	3.83	10.50	9.96	2.08	10.38	9.86	12.0
Cornstarch	3.02	10.96	11.03	8.54	8.20	6.94	58.69
Alphacel	0	0	0	1.50	1.50	1.50	3.0

Table III. Effect of Flour Extraction Level and Food Preparation Method on Vitamin Content in Pearl Millet Samples.[1]

Sample	Thiamine (μg/g)[2]		Riboflavin (μg/g)	Niacin (μg/g)
	Method A	Method B		
Millet Meal				
raw	4.00^{a}	5.05^{a}	2.24^{a}	36.9^{bc}
fermented	4.10^{a}	6.58^{b}	2.79^{b}	45.8^{a}
cooked	4.84^{b}	6.20^{c}	2.50^{bc}	43.1^{ab}
fermented & cooked	3.89^{a}	6.66^{d}	2.56^{bc}	46.6^{a}
Millet Flour - 67% Extraction				
raw	3.88^{a}	5.27^{a}	2.10^{a}	31.1^{c}
fermented	4.76^{c}	7.10^{e}	2.37^{c}	39.2^{ab}
cooked	6.79^{d}	7.81^{f}	2.65^{bc}	42.6^{ab}
fermented & cooked	4.06^{a}	7.90^{f}	2.68^{bc}	42.6^{ab}

[1]Within each vitamin, values with different superscripts differ significantly ($P < 0.05$). All values reported on dry basis.

[2]In method B, the extract was passed through a purification column prior to the determination.

Table IV. Effect of Flour Extraction Level and Food Preparation Method on Mineral Content (μg/g) in Pearl Millet Samples.[1]

Sample	Mg	Ca	Na	K	Fe
Millet Meal					
raw	1988^{b}	84^{c}	29^{c}	3230^{d}	74^{a}
fermented	2205^{a}	122^{a}	25^{cd}	4047^{a}	96^{b}
cooked	2146^{ab}	127^{a}	32^{c}	3629^{c}	217^{c}
fermented & cooked	2230^{a}	131^{a}	43^{a}	3762^{bc}	344^{d}
Millet Flour - 67% Extraction					
raw	1753^{c}	70^{d}	21^{de}	3094^{d}	77^{a}
fermented	2302^{a}	123^{a}	19^{e}	3918^{ab}	83^{a}
cooked	2347^{a}	103^{b}	39^{b}	3655^{c}	95^{b}
fermented & cooked	2326^{a}	102^{b}	40^{ab}	3954^{ab}	153^{e}

[1]Within each mineral, values with different superscripts differ significantly ($P < 0.05$). Values are on dry basis.

Table V. Grams of Amino Acids per 100 g protein corrected to 100% Recovery Protein Basis

	Raw		Cooked		Fermented		Fermented & Cooked	
	Meal	Flour	Meal	Flour	Meal	Flour	Meal	Flour
Lysine	2.96	3.29	2.95	3.48	2.59	2.61	3.06	3.40
Histidine	2.18	2.18	2.22	2.37	2.03	2.08	2.21	2.66
Ammonia	3.48	3.27	3.43	3.23	3.30	3.52	3.60	3.79
Arginine	4.71	5.51	4.99	6.06	4.87	4.84	4.46	4.64
Aspartic Acid	9.57	9.82	9.43	9.73	10.42	9.52	9.41	9.14
Threonine	3.73	3.74	3.80	3.72	3.88	3.83	3.71	3.69
Serine	5.55	5.49	5.77	5.27	5.09	5.70	5.31	5.36
Glutamic Acid	22.57	21.92	22.24	21.19	21.88	21.46	21.41	20.56
Proline	7.11	7.02	7.15	7.27	6.62	6.63	7.75	7.91
Half Cystine	0.58	0.59	0.52	0.62	0.62	0.48	0.53	0.53
Glycine	3.15	3.66	3.14	3.60	3.55	3.35	3.49	3.77
Alanine	8.79	8.63	8.67	8.40	9.00	9.23	8.89	8.50
Valine	3.90	3.95	4.00	3.94	3.95	4.14	4.12	4.18
Methionine	1.82	1.94	1.87	1.96	2.00	1.95	1.91	1.99
Isoleucine	3.06	3.04	3.06	2.97	3.19	3.26	3.18	3.19
Leucine	9.50	9.11	9.54	8.91	9.58	9.84	9.61	9.35
Tyrosine	2.75	2.59	2.67	2.76	2.73	2.82	2.65	2.70
Phenylalanine	4.59	4.25	4.54	4.52	4.71	4.75	4.70	4.63
Protein	13.70	12.70	14.70	14.20	13.80	14.90	14.70	14.00
Moisture	11.20	12.60	2.20	2.30	1.90	2.30	3.00	3.00

Table VI. Effect of Flour Extraction Level and Food Preparation Method on Feed Intake and Weight Gain of Rats Fed Millet-Based Diets.[1]

Diet	Number of animals	Total Feed Intake (g)	Total Weight Gain (g)	
			Unadjusted	Adjusted
Millet Meal				
raw	8	245.50^{bc}	42.12^{cd}	49.85^{c}
cooked	7	228.57^{bc}	42.00^{d}	49.21^{c}
fermented and cooked	8	211.25^{c}	29.88^{e}	40.65^{d}
Millet Flour - 67% Extraction				
raw	8	263.75^{b}	53.75^{bc}	53.73^{bc}
cooked	8	266.38^{b}	58.25^{b}	57.69^{b}
fermented and cooked	8	243.75^{bc}	45.12^{cd}	49.21^{c}
Casein	8	381.88^{a}	110.88^{a}	86.56^{a}

[1]Within each column, values with different superscripts differ significantly ($P < 0.05$).

Table VII. Effect of Flour Extraction Level and Food Preparation Method on Protein Efficiency Ratio (PER) of Pearl Millet-Based Diets.[1]

Diet	Number of Animals	Mean PER	Adjusted PER[2]
Millet Meal			
raw	8	1.882[c]	1.696
cooked	7	1.743[c]	1.571
fermented & cooked	8	1.364[d]	1.229
Millet Flour - 67% Extraction			
raw	8	2.051[b]	1.848
cooked	8	2.104[b]	1.896
fermented & cooked	8	1.766[c]	1.592
Casein	8	2.774[a]	2.500

[1]Values with different superscripts differ significantly ($P < 0.05$).

[2]Mean PER adjusted to a casein PER of 2.5.

Table VIII. Effect of Flavor Extraction Level and Food Preparation Method on Protein and Calorie Digestibility.[1]

Diet	Number of Animals	Protein Digestibility[2] (%)	Calorie Digestibility[3] (%)
Millet Meal			
raw	8	89.40^{bc}	93.62^{cd}
cooked	7	89.30^{bc}	93.49^{c}
fermented and cooked	8	88.94^{c}	93.95^{bd}
Millet Flour - 67% Extraction			
raw	8	89.79^{b}	93.44^{c}
cooked	8	89.72^{b}	94.06^{b}
fermented and cooked	8	89.66^{bc}	94.05^{b}
Casein	8	94.52^{a}	96.11^{a}

[1]Within each column, values with different superscripts differ significantly ($P < 0.05$).

[2] $\frac{N_{food} - N_{feces}}{N_{food}} \times 100$

[3] $\frac{KCal_{feed} - KCal_{feces}}{KCal_{feed}} \times 100$

INFLUENCE OF CERTAIN GRAIN DIETS ON CHOLESTEROL LEVELS IN GUINEA PIGS

Carol Klopfenstein

Epidemiological data have shown that in certain population groups in Africa and Asia where serum cholesterol levels are low and the incidence of coronary heart disease is rare, lightly processed cereals comprise a large portion of the diet (Trowell, 1972, 1975; Connor et al., 1978; Phillips et al., 1978). Some information has been reported on the effects of inclusion of wheat and oats in the diet on blood plasma cholesterol levels in animals (McNaughton, 1978; de Groot et al., 1963; Fisher and Griminger, 1967). However, two cereals, sorghum and pearl millet, are the basic foodstuffs of people in many parts of Africa and Asia, but little data have been published on the effects of those grains on serum and liver cholesterol levels in laboratory animals or humans. Therefore, the main objective of this study was to determine the effects of grain sorghum and pearl millet on serum and liver cholesterol levels in laboratory animals. Wheat and oats were also investigated in order to have a means of comparison with existing publications. Guinea pigs were chosen as the test animal because they, like humans, require ascorbic acid in the diet, while other experimental animals (with the exception of monkeys and apes) do not require dietary ascorbic acid and have demonstrated the ability to synthesize it in large quantities. Since ascorbic acid plays an important role in the conversion of cholesterol to bile acids, one of the body's major pathways for cholesterol removal, we considered it essential to have this often uncontrolled variable at a constant, known level.

MATERIALS AND METHODS

Five groups of male albino English Shorthair guinea pigs (Anacare, Manhasset, NY) weighing 169-273 grams were kept in individual, wire-bottomed cages and given feed and water *ad libitum*. Composition of the diets is given in Table 1. In the experimental grain diets hard red winter wheat, commercial rolled oats, pearl millet (HMP 550) and a commercial grain sorghum (low tannin) were isocalorically and isonitrogenously substituted for skim milk powder, sucrose and cellulose. The diets contained approximately 27% protein and had an energy value of about 356 kcal/100g. Whole wheat, millet and grain sorghum were ground in a small roller mill (corrugated rolls set at 0.016 in.). Feeds were pelleted in a California pellet mill and stored in a cool place until fed. After 43 days on the diets, blood samples were taken from the animals by heart puncture, the animals were killed and the livers quickly removed, weighed, frozen and stored at -13°C. Serum was prepared by allowing the blood to clot for 1 hour at 37°C, then centrifuging at 5000 rpm for 20 minutes. Cholesterol content of serum and liver was determined using the stable iron reagent of Rosenthal et al. (1957). Serum protein was first precipitated with absolute ethanol. Liver cholesterol was extracted with chloroform-methanol (Klopfenstein and Clegg, 1980) and an aliquot of the chloroform extract was evaporated to dryness, redissolved in absolute ethanol and used for analysis.

Table 1 - Composition of Diets

Component	Control	Wheat, rolled oats, millet, sorghum
	%	%
Casein[a]	20	20
Skim milk powder[b]	20	0
Sucrose	29	0
Cellulose[b] (Alphacel)	19	10
Soybean oil[c]	9.9	9.9
Cholesterol (cp grade)	0.1	0.1
NaCl	0.5	0.5
$CaCO_3$	1.0	1.0
$MgSO_4$	0.5	0.5
Ground grain	0	58

Both diets contained an ascorbic acid deficient vitamin diet fortification mix (1 Kg/100 lb diet).

All animals received 8 g lettuce/day.

All animals received oral feedings of 10 mg ascorbic acid/day in 20% sucrose.

[a]Vitamin-free casein, U.S. Biochemical Corp., Cleveland, OH.

[b]ICN Nutritional Biochemicals, Cleveland, OH.

[c]Humko Products, Memphis, TN.

Table 2. Influence of Grain Diets on Various Parameters in Guinea Pigs

Diet	Weight Gained* (grams)	Alkaline phosphatase units**	Serum Cholesterol (mg %)	Liver Cholesterol ($\frac{mg}{100g}$)	Liver Weight (g) / 100 g animal wt.
Control	111 ± 51^{a} (4)+	4.35 ± 1.21^{ab} (3)	102 ± 50^{a} (3)	499 ± 199^{a} (3)	3.7 ± 1.3^{a} (4)
HRW Wheat	111 ± 41^{a} (4)	5.30 ± 2.10^{ab} (4)	80 ± 20^{a} (4)	654 ± 166^{a} (4)	4.7 ± 0.9^{a} (4)
Rolled Oats	64 ± 34^{a} (5)	5.32 ± 1.67^{ab} (5)	83 ± 39^{a} (5)	674 ± 144^{a} (5)	4.1 ± 0.7^{a} (5)
Pearl Millet	68 ± 40^{a} (4)	4.32 ± 1.82^{b} (4)	88 ± 26^{a} (4)	674 ± 17^{a} (3)	5.0 ± 1.3^{a} (4)
Grain Sorghum	113 ± 43^{a} (4)	7.06 ± 0.95^{a} (4)	69 ± 4^{a} (4)	251 ± 40^{b} (4)	4.4 ± 0.3^{a} (4)

*After 43 days on diet

+Number of animals/group

**Sigma units

Values in Table are means ± SEM. Means having the same superscripts are not significantly different @ $P < 0.05$ (Duncan's multiple range test).

Serum alkaline phosphatase was determined using the 2-amino-2-methyl-1-propanol (AMP) method described in Sigma Technical Bulletin No. 104 (1978).

RESULTS AND DISCUSSION

Animals receiving the control, wheat and grain sorghum diets, appeared to grow somewhat faster than those on the oats and millet diets, but the standard deviations indicated no significant differences at $P < 0.05$ (Table 2). Ratios of liver weight to animal weight were also the same for all diets (Table 2). Weight gains for our guinea pigs were considerably lower than those reported by Veen-Baigent et al. (1975) for animals fed the Reid-Briggs semisynthetic diet which is comparable in protein content and energy value (30% protein, 3.38 kcal/g) to our diets (27% protein, 3.56 kcal/g). The Reid-Briggs diet, however, differed in that it contained 6% of a salt mixture. It is possible that animals used in the present experiment were marginally deficient in an undetermined mineral element. Furthermore, our animals were not provided a dietary adaptation period, which may be partly responsible for their low weight gains.

Alkaline phosphatase levels tend to roughly parallel the rate of active bone formation (Henry, 1967), with children having higher values than teenagers or adults. Agergaard (1976) has found a constant and significant correlation (0.95) between the growth rate of pigs and plasma enzyme content, indicating that alkaline phosphatase may be closely associated with the metabolic process of somatic growth. Alkaline phosphatase levels in our animals were significantly lower ($P < .05$) in the slower-growing millet-fed group than in the faster-growing grain sorghum-fed group (Table 2). The correlation between guinea pig serum alkaline phosphatase levels and growth rate calculated using the data from the last 10 days of the experiment was 0.54; Agergaard (1976) found a higher correlation between these two factors. Further investigations should be conducted in this area.

Serum cholesterol levels in animals fed the grain sorghum diet appeared to be lower than with the other diets, but standard deviations were large so differences were not significant at $P < 0.05$ (Table 2).

Liver cholesterol concentration was significantly lower ($P \leq 0.01$) in animals fed the grain sorghum diet than in any other experimental group. The liver cholesterol levels for the wheat-, oats-, and millet-fed guinea pigs were the same as that of the control group (Table 2).

A dietary cholesterol level of 0.1% apparently did not affect blood cholesterol concentration, since results reported here agree with those of Ginter (1977) who found a range of 88-118 mg% for guinea pigs on a cholesterol-free diet. Liver cholesterol levels did appear to be elevated by 0.1% dietary cholesterol, with the exception of the grain sorghum-fed animals which had 251 mg cholesterol/100 grams of liver. Ginter (1976) reported liver cholesterol levels ranging from 325-456 mg/100 g in normal guinea pigs. Traber and Ostwald (1978) have shown that while guinea pigs

fed 0.1% cholesterol do not become hypercholesterolemic, their body cholesterol pools exhibit extensive expansion. Evidently, the grain sorghum diet inhibited the liver cholesterol accumulation.

It is apparent that much remains to be learned about the effects of dietary components on blood and liver cholesterol concentrations. Data collected in this preliminary study indicate that the cholesterol-lowering effects of grain sorghum should be further investigated.

REFERENCES

Agergaard, N. 1976. Plasma alkaline phosphatase activity and growth in pigs. K. Vet.-Landbohoejsk 19:A40-A49; Chem. Abstr. 1979, 90:52214a.

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.

deGroot, A. P., R. Luyken, and N. A. Pikaar. 1963. Cholesterol-lowering effect of rolled oats. Lancet 2:303.

Fisher, H., and P. Griminger. 1967. Cholesterol-lowering effects of certain grains and of oat fractions in the chick. Proc. Soc. Exp. Biol. Med. 126:108-111.

Ginter, E. 1977. Vitamin C and cholesterol. Int. J. for Vit. Nutr. Res. 16; Reevaluation of vitamin C, Hanck, A., and Ritzel, G., Hans Huber, Stuttgart. pp. 53-56.

Henry, R. J. 1967. Clinical Chemistry: Principles and Technics. Harper and Rowe, N.Y. p. 492.

Klopfenstein, C. F., and R. E. Clegg. 1980. Effects of ascorbic acid, vitamin E and fatty acids on lipid composition in cockerels. Poultry Sci. In press.

McNaughton, J. L. 1978. Effect of dietary fiber on egg yolk, liver and plasma cholesterol concentrations of the laying hen. J. Nutr. 108: 1842-1848.

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.

Sigma Technical Bulletin. 1978. No. 104. Sigma Chemical Co., St. Louis, MO.

Traber, M. G., and R. Ostwald. 1978. Cholesterol absorption and steriod excretion in cholesterol-fed guinea pigs. J. Lipid Res. 19:488-456.

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.

Veen-Baigent, M. J., A. R. Ten Cate, E. Bright-See, and A. V. Rao. 1975. Effects of ascorbic acid on health parameters in guinea pigs. Ann. N.Y. Acad. Sci. 28:339-354.

PEARL MILLET: IT'S CHEMISTRY AND UTILIZATION

R. C. Hoseney and E. Varriano-Marston

I. INTRODUCTION

A number of species of millets are grown in various parts of the world. From an economic standpoint the following are the most important:

Pearl millet [*Pennisetum americanum* L. Leeke], also called bulrush millet in Africa and bajra in India and often identified in literature by the older name of *Pennisetum typhoides*.

Proso, common or broom corn millet (*Panicum miliaceum*), widely grown in the Soviet Union, Manchuria, and China.

Finger millet (*Eleusine coracana*), also called ragi, widely grown in India and Africa.

In this paper we shall deal only with the chemistry and structure of pearl millet. Pearl millet 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. It is the first crop one sees growing as one comes out of the desert and provides the only means of survival for many people throughout its distribution. As water becomes more available, grain sorghum generally replaces pearl millet. Practically all the pearl millet grown is consumed directly as human food, with only minor amounts being fed to animals.

On a worldwide basis there are about equal areas planted to millets (all types) as grain sorghums. For the years 1967 through 1971, annual cultivation of pearl millet averaged 31 million hectares and production averaged 18 million metric tons. This accounted for 4.9% of the world's cultivated lands planted to cereals and 1.8% of total cereal production (Pomeranz, 1975). In a crop such as pearl millet, which is often grown as a crop of last resort, a low yield is not necessarily bad. A poor yield is infinitely better than no yield, for no yield means starvation. Thus, a consistently low-yielding line is much preferred to a potentially high-yielding line that may fail completely in a poor year.

Pearl millet is generally planted in the spring after the first substantial rain of the rainy season. The crop is notoriously poor at emerging through a hard crust of soil. Thus, it is not planted in dry soil to await rain, which will provide moisture but will also give a hard crust to the soil and lead to poor stands. Planting after the rain will avoid the problem. Once the millet has emerged it generally is very tolerant of mother nature's whims and almost always will produce some seed.

It has only been in the last 20 years that plant breeders have made serious attempts at developing improved varieties of pearl millet (Brunken et al., 1977). The plant height varies widely and the variability in head

type is quite large (Fig. 1). The world collection of pearl millet is small compared to the land races available. An attempt to expand and maintain the world collection of pearl millet is underway 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; genetic contamination at growouts has been considerable (van der Maesen, 1978).

Plant breeders have provided the impetus for studies on the chemistry, nutrition, and food uses of pearl millet. Their success in producing seeds with improved yields heightens concerns about the nutritional and functional quality of new pearl millet cultivars. The following paper provides a summary of pearl millet chemistry and utilization and delineates areas where more research is needed.

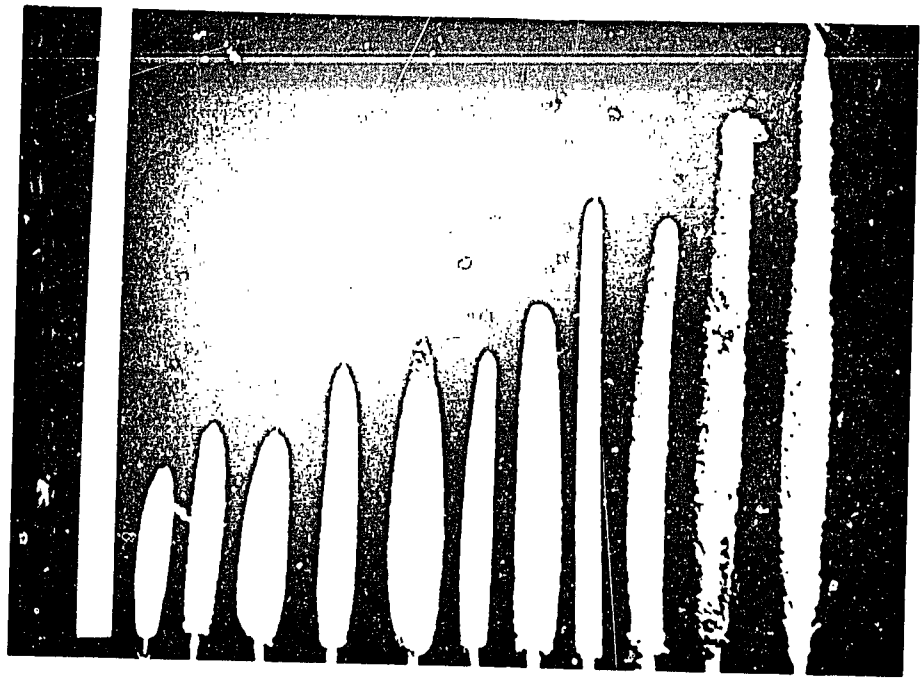


Figure 1. A selection of head types found in pearl millet. Courtesy of Dr. Gary Paulsen, K.S.U.

II. SIZE AND STRUCTURE OF THE GRAIN

Kernels of pearl millet are generally tear shaped and about 1/3rd the size of sorghum kernels; an average 100 kernel weight is about 0.89 g compared to about 2.8 g for sorghum (Freemen and Bocan, 1973). Different cultivars of millet vary widely in seed sizes (Fig. 2).

Gross structural features of fractured pearl millet kernels (Fig. 3) indicate that (a) the germ is large in proportion to the rest of the

kernel and (b) in any given sample the ratio of hard to soft endosperm varies considerably. A closer view of the pericarp (Fig. 4) shows that it contains three layers: the epicarp, the mesocarp, and the endocarp. Unlike in sorghum, no starch granules have been found in millet mesocarp (Badi et al., 1976a; Sullins and Rooney, 1977). In addition, Sullins and Rooney (1977) found that the testa layer was absent in all 5 pearl millet samples examined.

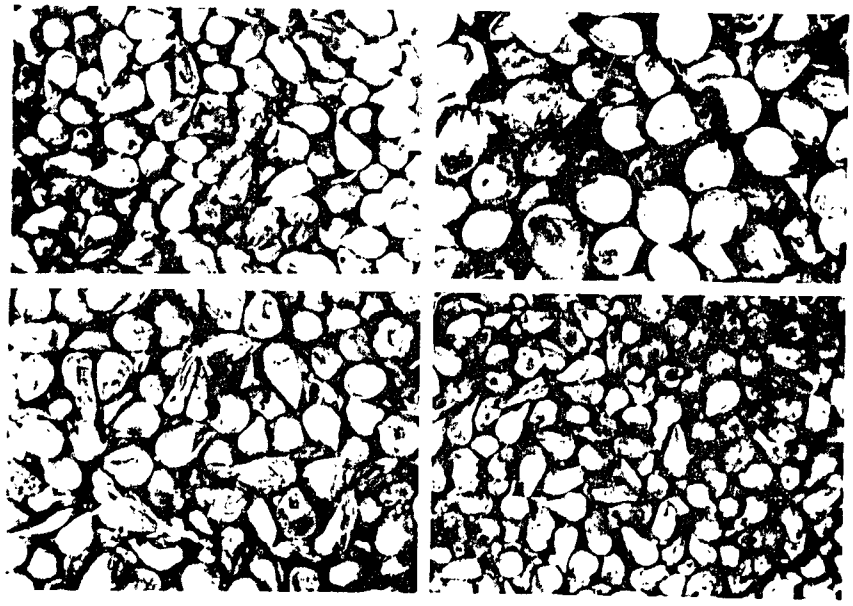


Figure 2. An example of large (lower left), small (lower right), and medium (upper left) pearl millet seed sizes compared with grain sorghum (upper right).

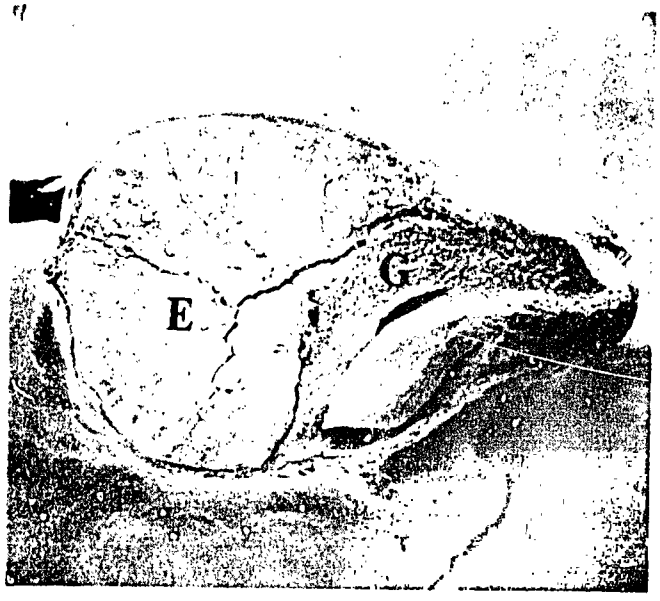


Figure 3. A fractured kernel of pearl millet showing the relatively large germ (G) to endosperm (E) ratio. Magnification 25x.

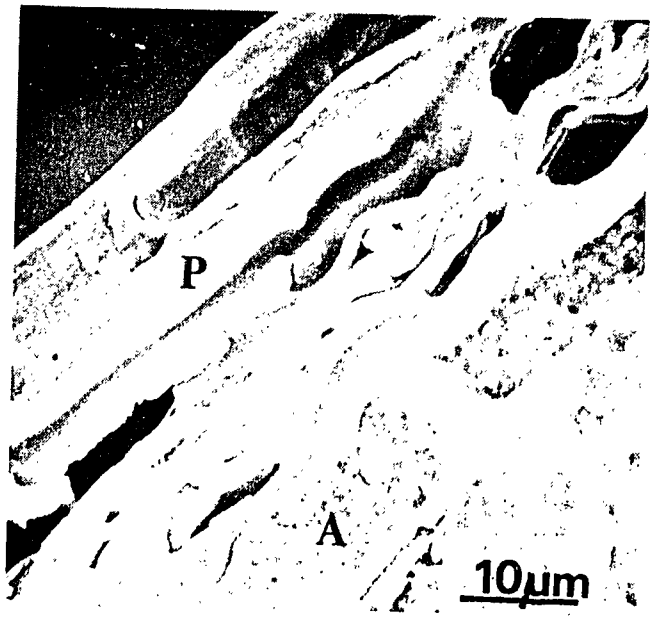


Figure 4. A SEM micrograph of the outer edge of pearl millet showing the pericarp (P) and aleurone (A) layer.

A single layer of aleurone cells surrounds the periphery of the kernel and is firmly attached to the pericarp. Those cells, along with the pericarp and germ, contain most of the lipid that is present in the grain (Lai and Varriano-Marston, 1979).

The hard endosperm (Fig. 5) contains polygonal starch granules embedded in a protein matrix which in turn contains protein bodies ranging in size from 0.3 to 4 µm (Badi et al., 1976a; Sullins and Rooney, 1977; Adams et al., 1976). Transmission electron micrographs (Fig. 6) indicate that these protein bodies have a well-defined internal structure as evidenced by the pattern of electron scattering.

The soft or floury endosperm of pearl millet contains loosely packed spherical starch granules (Fig. 7) and no protein bodies. Sullins and Rooney (1977) have suggested that the matrix protein concentration in the floury endosperm cells is higher than that of the same protein in the hard endosperm cells.

Figure 5. A SEM micrograph of the hard endosperm of pearl millet showing the starch (S), indentation in the starch (I), and protein bodies (P).

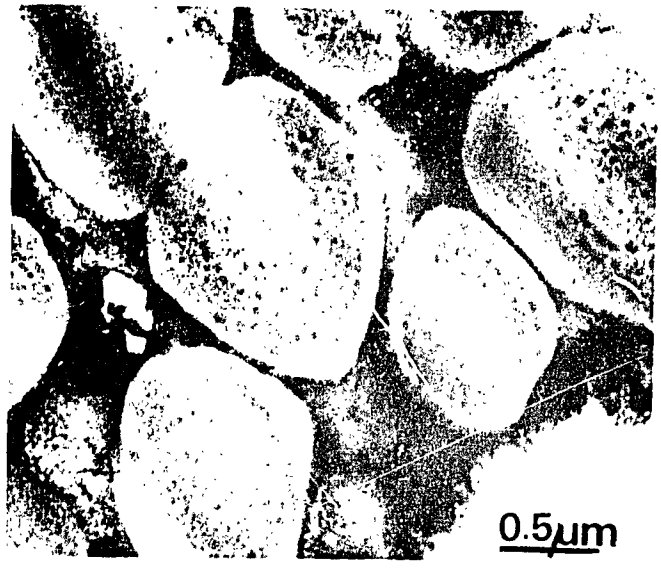


Figure 6. A TEM micrograph of the protein bodies from pearl millet.

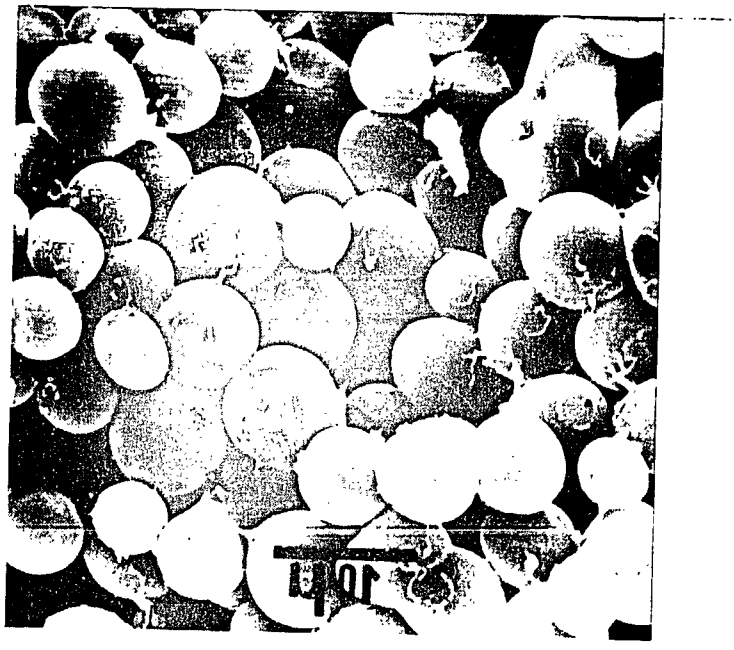


Figure 7. A SEM micrograph of the soft endosperm of pearl millet showing the spherical starch granules.

III. CHEMICAL COMPOSITION

A. Protein

It is always difficult, if not impossible, to make valid generalizations about the protein contents of various cereals. Factors that can affect the protein content of an individual sample are too numerous. For example, the environment, availability of nutrients (added or indigenous), the genetics of the sample, and the yield of the sample compared to its yield potential are all factors that affect a sample's protein content. Thus, to compare the protein content of individual samples of different grains is meaningless, and even when large numbers of samples are evaluated it is dangerous to draw firm conclusions. With those disclaimers, we will now say that pearl millet has high protein content when compared with samples of other small grains grown under similar conditions. Whether the higher protein content is inherent in pearl millet or the result of one or more of the above factors is open to question.

1. Effect of Nitrogen Application. Sawhney and Naik (1969) found that N applied at the rate of 88 kg/ha increased the protein of pearl millet (from 12.6 to 13.4%). Similar results (Deosthate et al., 1971) showed that nitrogen fertilization up to 120 kg N/ha increased both yield and protein content. At higher levels of nitrogen, the yield decreased and the protein content remained essentially constant.

2. Amino Acid Composition. Representative amino acid composition data for pearl millet are given in Table 1.

Table 1. Range of amino acids in pearl millet meals (g AA/16g N).

Amino acid	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
½ 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

The data illustrates the wide variability found in pearl millet for most amino acids. For example, lysine ranges from 1.8 to 3.9 g/16 g N. The variability may be a reflection of the wide genetic base or the lack of man's effectiveness in breeding the cereal. Generally, pearl millet is comparable to the other cereal grains; it is deficient in lysine, tryptophan, threonine, and the sulfur containing amino acids. However, the data show that at least certain lines of millet are high in lysine and tryptophan when compared to other cereals.

The amino acid composition varies with different anatomical parts of the grain. Flour milled from pearl millet was found to be lower in lysine, arginine, and glycine, and higher in methionine than was the whole meal (Badi et al., 1976a). Conversely, the bran was high in lysine, arginine, glycine, and aspartic acid and low in glutamic acid and the sulfur-containing amino acids.

3. Protein Classes. Cereal proteins are generally classified according to the solubilities in a series of solvents. The different classes of proteins have different amino acid compositions and thus a knowledge of the amount of protein in each solubility class gives a rough estimation of the sample's amino acid composition. The alcohol-

soluble prolamines are of special interest because they are generally poor in lysine and other nutritionally critical amino acids (Pomeranz, 1975). Prolamines are relatively rich in glutamine and proline. Because the prolamines are a major fraction of the grain protein, most cereals are deficient in lysine, tryptophan, etc. The development of high-lysine maize, barley, and sorghum has resulted from depressed synthesis of prolamines (Mertz, 1975). It is not known whether the high-lysine millets also have low prolamine.

Relatively little has been reported on the distribution of various protein classes in pearl millet or on the amino acid composition of different protein classes. Narayamurti and Aiyar (1930) extracted proteins from pearl millet meals with successive solvents of water, 6% salt, 70% cold ethanol, 70% hot ethanol, and 0.04% NaOH. Percentages of the total protein extracted with each solvent were 13%, 8.7%, 33.3%, 7%, and 9.1%, respectively. Thus, 71% of the protein in the meal was recovered in the extracts. Abhyander et al. (1939) reported similar results with similar solvents.

Sawhney and Naik (1969) studied the distribution of nitrogen in the protein fractions of several pearl millet varieties as fractionated with a modified Mendel-Osborne procedure (Naik, 1968). In all the samples analyzed, the prolamines and glutelins predominated, accounting for about 60% of the protein present. The albumin fraction averaged 15% and the globulins 9%. The proportions of the different fractions varied from cultivar to cultivar. The prolamine and glutelin fractions ranged from 21 to 38% and from 24 to 37%, respectively, of the total protein present. In the different samples, nitrogen recovery ranged from 72 to 92%.

Abhyander et al. (1939) isolated a prolamine and two globulin fractions from pearl millet and analyzed each fraction for 4 amino acids. One of the globulins coagulated at 43 to 45°C and the other at 82 to 85°C. The analysis for arginine, histidine, cysteine, and lysine showed considerable differences in the amino acid composition of the two globulins. The lysine content of the prolamine fraction (2.5%) was essentially equal to the lysine content of the total protein. Narayamurti and Aiyar (1930) extracted pearl millet with 70% ethanol and analyzed this prolamine fraction for essential amino acids. Surprisingly they found rather high levels of tryptophan (2.8g/16 g N) and moderate amounts of lysine (1.1g/16 g N).

Sawhney and Naik (1969) reported amino acid analyses (Table 2) for 4 protein solubility classes from one pearl millet sample.

As expected, compared to the other two fractions, the albumins and globulins contained higher concentrations of basic amino acids such as lysine, arginine, and histidine as well as the sulfur-containing amino acids. Prolamines were found to be rich in glutamic acid, proline, and leucine as well as in tryptophan. Pearl millet prolamine apparently differs markedly from that of other cereals in being unusually high in tryptophan; although, like that of other cereals, pearl millet prolamine is rich in glutamic acid and proline and deficient in lysine.

The prolamines of proso millet were reportedly soluble in t-butyl alcohol (Jones et al., 1970). Treatment of pearl millet with t-butyl alcohol solubilized protein but did not solubilize the protein bodies presumed to be prolamines (Badi et al., 1976a). The authors concluded that pearl millet may contain two alcohol-soluble proteins.

Table 2. Amino acid composition of different protein fractions of HB-1 pearl millet (Sawhney & Naik, 1969) (g AA/16g N).

Amino Acid	Albumin	Globulin	Prolamine	Glutelin
Aspartic Acid	12.46	11.42	7.48	6.36
Threonine	2.12	2.64	3.46	2.92
Serine	4.81	5.62	6.12	5.35
Glutamic Acid	16.36	18.71	22.24	21.68
Proline	8.82	7.46	10.23	9.42
Glycine	7.35	4.12	1.23	2.74
Alanine	8.11	6.02	9.41	10.42
Valine	5.64	7.34	3.24	4.12
Cysteine	2.92	2.62	1.42	1.24
Methionine	1.94	2.12	1.02	1.34
Isoleucine	4.12	2.48	3.32	3.83
Leucine	6.11	5.62	12.06	10.18
Tryosine	3.28	4.31	4.62	4.44
Phenylalanine	3.82	4.14	3.82	4.94
Lysine	3.92	3.74	1.66	2.14
Histidine	2.18	2.22	2.14	1.64
Arginine	4.36	4.82	3.04	4.92
Tryptophan	1.52	0.54	2.84	0.69

B. Carbohydrates

1. Starch. As in all cereals, starch composes the major carbohydrate of pearl millet, ranging from 56 to 65% of the grain (Freeman and Bocan, 1973; Sheorain and Wagle, 1973). Starch granules range in size from 4 to 12 μm, and are polygonal and spherical in shape (Fig. 8).

Unlike in other cereal starches, the large hila is clearly visible (Fig. 9) in fractured polygonal granules (Badi et al., 1976b).

Some physicochemical characteristics of pearl millet starch are shown in Table 3. Iodine affinities of 4.43 to 5.05% suggest that millet starch contains an amylose content equal to that of most other cereals. Beleia et al. (1979) found amylose contents of 20 to 22% for 5 pearl millet cultivars. Badi et al. (1976b) reported 17% amylose in starch from one pearl millet population.

Figure 8. A SEM micrograph of starch isolated from pearl millet.

Figure 9. A SEM micrograph of the hard endosperm of pearl millet showing damaged starch (D) and the hila (H).

Initiation and end-point gelatinization temperatures vary among cultivars but fall within the ranges reported for sorghum and corn starches. Starch pasting properties also vary among cultivars (Table 3), particularly with respect to the viscosity after the 1-hr holding period at 95°C. At 95°C, Freeman and Bocan (1973) found a decrease in viscosity of the paste while Badi et al. (1976b) observed the opposite effect.

Table 3. 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	---
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	600,660	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. (1976) using 50 g starch; 1 sample studied
2. Freeman and Bocan (1973) using 35 g starch; 2 samples studied
3. Beleia et al. (1979) using 50 g starch; 5 samples studied

Solubility and swelling power tests provide information on the behavior of pearl millet starch during heating. Figure 10 provides an example of the swelling and solubility patterns obtained for millets. Values for starch swelling power at 85°C range from 10.97 to 13.51; solubility varies from 3.2 to 7.89% (Freeman and Bocan, 1973; Beleia et al., 1979).

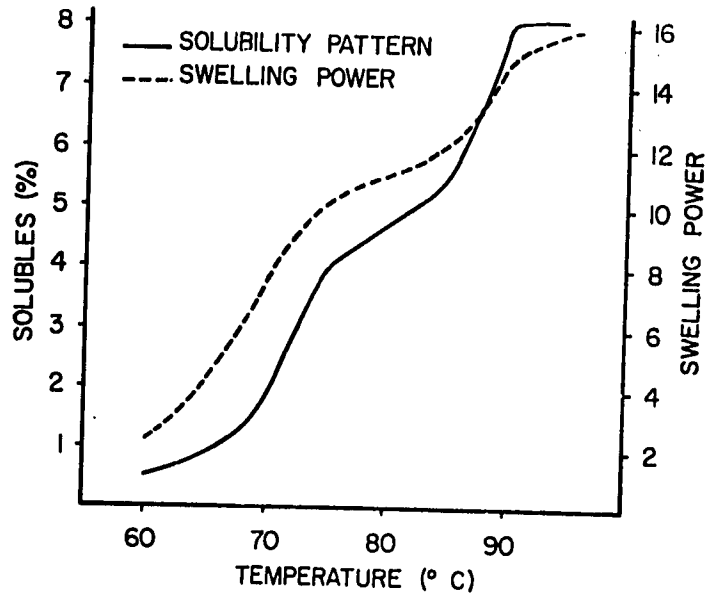


Figure 10. Solubility and swelling patterns of pearl millet starch.

Pearl millet flour has been reported to give low amylograph peak viscosities (Badi et al., 1976b; Beleia et al., 1979). Because millet starch gives a peak viscosity similar to that of sorghum and cornstarch, this implies that pearl millet flour has a high amylase activity. Studies on sound millet indicate that amylase activity is 8-15 times greater than that reported for sound wheat (Sheorain and Wagle, 1973; Varriano-Marston et al., 1979). The high activity observed in millet flour is due to a high alpha-amylase activity (Varriano-Marston et al., 1979).

Pearl millet starch has been shown to be more resistant than sorghum starch to attack by pancreatic alpha-amylase or by amyloglucosidase (Sullins and Rooney, 1977). However, the mode of attack of native amylases on pearl millet starch has not been thoroughly investigated. Studies on fermented millet meal indicate that the enzymes preferentially attack the spherical granules (Fig. 11) and that starch hydrolysis is more vigorous at the center of the granule than at the periphery (Varriano-Marston et al.,

1979). Others have also suggested that degradation of starch by amylases is more complete in the granule center than the outer portions (Sullins and Rooney, 1977).

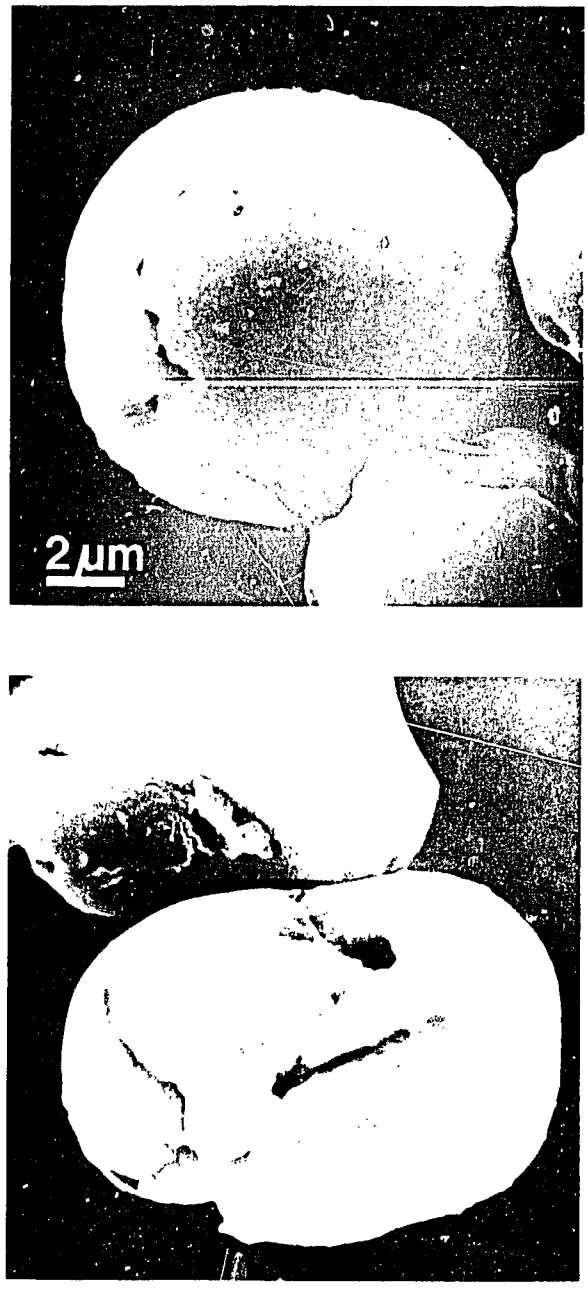


Figure 11. A SEM micrograph of an enzyme attack of a spherical starch granule.

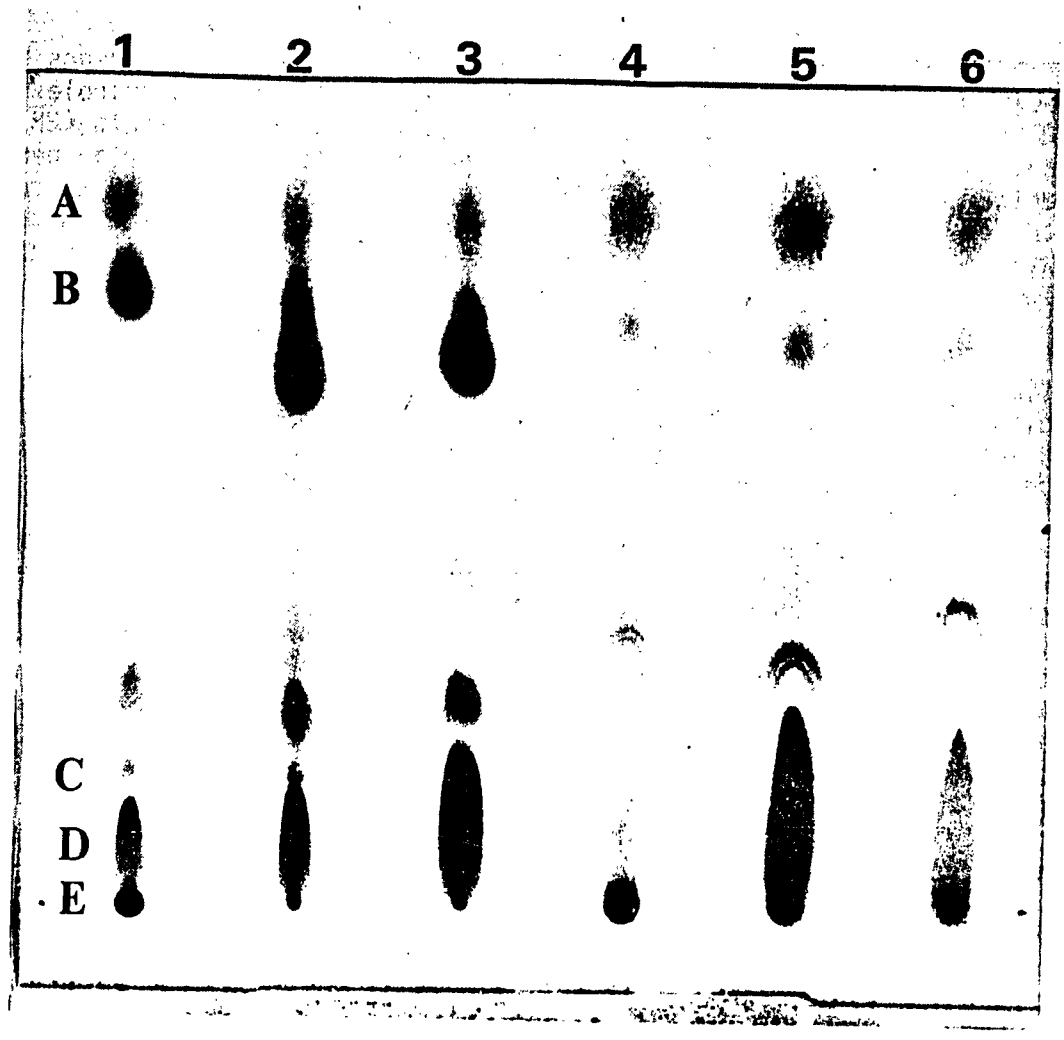


Figure 12a. Thin-layer chromatograms of nonpolar free and bound lipids from wheat, sorghum, and millet. Pattern 1, free wheat lipids; pattern 2, free sorghum lipids; pattern 3, free millet lipids; pattern 4, bound wheat lipids; pattern 5, bound sorghum lipids; and pattern 6, bound millet lipids. The spots are tentatively identified as A, hydrocarbons and steryl esters; B, triglycerides; C, diglycerides; D, free fatty acids; and E, unresolved polar lipids.

2. Pentosans. Bailey et al. (1979) separated pentosans from pearl millet on the basis of their solubility. Pentosans soluble in 80% ethanol had relatively high glucose and galactose contents (28.4% and 18.5%, respectively). Galactose was the principal sugar in pentosans extracted with water at 50°C. Pentosans solubilized in water at room temperature or in 0.5 N alkali consisted predominantly of arabinose and xylose. In general, the water-soluble pentosans from millet contained less glucose than comparable fractions from grain sorghum.

The differences in sugar composition of the various pentosan fractions affects the configuration of the molecules. Sedimentation coefficients determined by Bailey at al. (1979) suggested that the pentosans soluble in water at R.T. or in alkali had branched structures while pentosans solubilized in water at 50°C has a linear configuration.

3. Other Carbohydrates. Although fiber may play a significant role in human nutrition, no information is available on the chemical structure or characteristics of fiber in pearl millet. Crude fiber values of whole pearl millet grain have been reported to range from 1.96% to 31.88%(Carr, 1961; Reichert and Youngs, 1977; Desikachar, 1977). Reichert and Youngs (1976) dehulled pearl millet on a barley pearler, an abrasive mill, an attrition mill, or with a wooden pestle and reported crude fiber values of 0.58, 0.72, 0.96, and 1.12%, respectively.

Data on the types and levels of free sugars present in pearl millet are limited. Lineback and Pompipom (1978) studied one pearl millet population and reported a total free sugar content of 10 mg glucose/g flour.

C. Lipids

1. Composition and Characteristics. The free lipid content of pearl millet cultivars varies from 3.03% to 7.40% (Sharma and Goswami, 1969; Goswami et al., 1969a & b; 1970a & b; Rooney, 1978; Lai and Varriano-Marston, 1979). American cultivars generally have a higher free lipid content than those from Africa or India.

Acidity and saponification values of free lipids from pearl millet varied from 2.02 to 11.95 mg/100 g and 190 to 333 mg/g, respectively (Sharma and Goswami, 1969; Agawal and Sinka, 1964).

The composition of the free lipid fraction from pearl millet has also been studied using thin-layer chromatography (Pruthi and Bhatia, 1970; Badi et al., 1976a; Lai and Varriano-Marston, 1979). Triglycerides were found to be the major components of the free nonpolar lipids (Fig. 12a).

Monogalactosyl diglyceride was the major component of the free polar lipids (Fig. 12b).

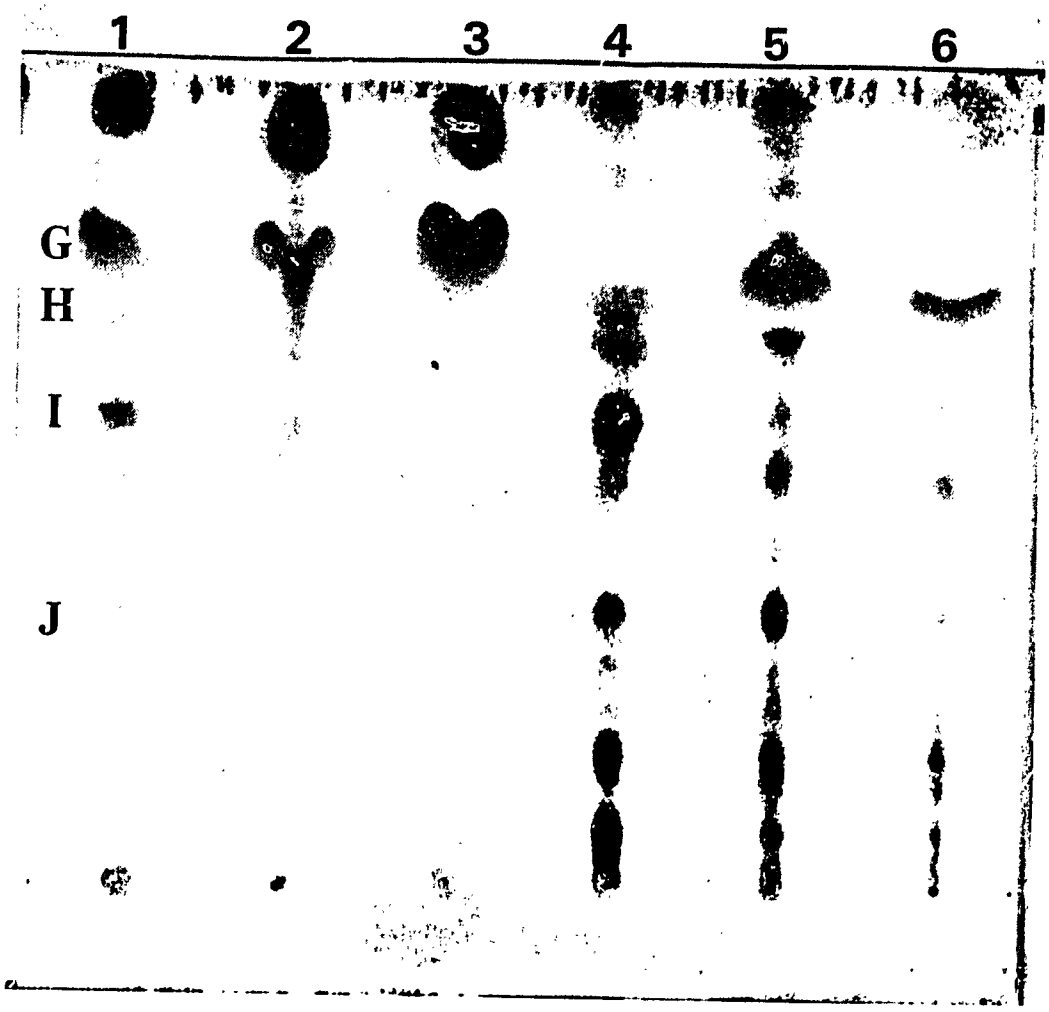


Figure 12b. Thin-layer chromatograms of polar free and bound lipids from wheat, sorghum, and millet. Pattern 1, free wheat lipids; pattern 2, free sorghum lipids; pattern 3, free millet lipids; pattern 4, bound wheat lipids; pattern 5, bound sorghum lipids; and pattern 6, bound millet lipids. The spots are tentatively identified as F, unresolved nonpolar lipids; G, monogalactosyl diglyceride; H, phosphatidyl ethanolamine; I, digalactosyl diglyceride; and J, phosphatidyl choline.

The fatty acids present in the free lipids were studied by Agawal and Sinka (1964) using a urea adduct method. They found that oleic acid was the major fatty acid (53.84%), followed by linoleic (34.88%), palmitic (10.8%), stearic (0.28%), and myristic (0.20%). A bromination method indicated that there was no linolenic acid present in the free lipid fraction.

On the other hand, Jellum and Powell (1971), using gas chromatography, studied 65 lines of pearl millet and found that linoleic acid was the major fatty acid present (40.3 to 51.7%) in the free lipid fraction. Oleic acid ranged from 20.2 to 30.6%; palmitic acid ranged from 17.7 to 25.0%. In addition, these authors showed that pearl millet lines contained on the average 3.69% linolenic acid, 3.9% stearic acid, 0.64% arachidic acid, and 0.55% palmitoleic acid. The data of Jellum and Powell (1971) show that differences in fatty acid values reported in the literature for pearl millet not only are due to genetic differences and seed maturity but also are affected by lipid extraction procedures.

Little work has been published on the bound lipids in pearl millet. Pruthi and Bhatia (1970) studied two Indian varieties and found that the lipids extracted with water-saturated n-butanol composed 0.5% of the millet grain. On the other hand, Lai and Varriano-Marston (1979) reported bound lipid contents of 0.58%-0.90% for 18 samples of pearl millet grown in Kansas.

The major lipid components of the polar, bound lipid fraction are phosphatidyl choline, sterol glycosides, and di- and monogalactosyl glycerides. Acylglycerols were the major component of the nonpolar, bound lipids (Pruthi and Bhatia, 1970; Badi et al., 1976a; Lai and Varriano-Marston, 1979).

2. Changes During Storage. Pearl millet quality quickly deteriorates once it has been ground into a meal (Reddy, 1978). Although studies on the storage of millet flour have been conducted, the types of millet under study were not clearly identified (Carovale and Quaglia, 1973; Feron and Bouquet, 1948; Nechaev et al., 1973).

Alterations in the lipid components may be responsible for the deterioration in millet flour quality during storage. Carnovale and Quaglia (1973) found a 3% decrease in the amount of ether extractable lipids after 3 mo. storage of millet flour at 30°C, 95% R.H. However, the authors did not account for the "lost" lipids. In addition, their results contradict the data of Nechaev et al. (1973) who showed essentially no change in total ether extractable lipids in millet during storage.

Carnovale and Quaglia (1973) also noted changes in fatty acid composition in their millet flours during storage. Palmitic acid levels decreased 2.2 to 4.5% while levels of stearic, oleic, and linolenic acids declined to a lesser degree during the storage period. Conversely,

linoleic acid levels in the free lipid fraction increased during storage. Infrared studies on the extracted lipids showed increases in the absorption of the -COOH group, indicating an increase in free acidity level. In general, their data suggest that hydrolytic as well as oxidative changes in lipid components occur during storage. These changes were more rapid and pronounced in lower grade flours.

Work by Thiam et al. (1976) suggests that although lipolytic activity occurs in millet flour during storage at 30°C, 90-95% R.H., the major cause of quality deterioration is microbial fermentation. Propagation of microorganisms during storage resulted in the consumption of sugars and the liberation of alcohols. Essentially no lipoxygenase activity was found.

D. Vitamins and Minerals

1. Minerals. Ash content in pearl millet lines varies from 1.46% to 3.88% (Goswami et al., 1969 a & b, 1970 a & b; Deosthale et al., 1971; Burton et al., 1972; Varriano-Marston and Hoseney, 1979). These values are high compared to those for wheat, corn, or sorghum (Casey and Lorenz, 1977).

Some of the mineral constituents of pearl millet have been identified; a summary of those data is presented in Table 4. The values for Na, Ca, Mg, and Cu fall within the range reported for wheat. However, some varieties of millet contain very low levels of Ca. The Mn and Mo contents of millet are considerably lower than those found in wheat while in many cases the P, K, and Fe contents of the grain are considerably higher than values reported for wheat. High Fe values may be due, in part, to the equipment used to mill the grains prior to analysis. For example, Carr (1961) reported an Fe content of 46 mg/100 g of grain for pearl millet ground on a stone containing high Fe levels.

X-ray energy dispersive analysis has been used to study the location of minerals in pearl millet grains (Varriano-Marston and Hoseney, 1979). High levels of Si and K were found in the covering layers while P was concentrated mainly in the germ. About equal amounts of Fe were found in the germ and covering layers. The endosperm portions exhibited low mineral concentrations; the predominant elements detected were S, K, and Fe.

2. Vitamins. Little work has been reported on the vitamin content of pearl millet. Carr (1961) reported thiamine and riboflavin contents of 0.22 mg/100 g and 0.26 mg/100 g, respectively, for one sample of millet. Current work in the authors' laboratory indicates that there is little variability in riboflavin content among cultivars; 18 cultivars showed riboflavin contents ranging from 0.21 to 0.38 mg/100 g (unpublished data). These values are similar to those published for wheat.

No journal articles have been published on the levels of niacin, vitamin A, or vitamin E in pearl millet. However, Hariharan et al. (1965)

reported a vitamin A content of 153 I.U./100 g for their "poor pearl millet diet."

Table 4. Minerals in pearl millet (*P. americanum*)[a]

Element	mg/100 g(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., 1969 a,b; Shah and Mehta, 1959; Burton et al., 1972; Varriano-Marston and Hoseney, 1979.

[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.

E. Pigments

Pearl millet varies widely in color from an off-white to dark brown. The most common colors are yellow and slate grey. In general the slate grey is preferred.

Color plays a role in consumer acceptance of millet grains. Therefore, characterization of the pigments in pearl millet is an important step in the study of flour quality.

In some parts of Africa, millet grains are soaked overnight in water containing sour milk or tamarind pods (Vogel and Graham, 1979). This step not only alters the flavor of the resultant products but also whitens the grain. Reichert and Youngs (1979) investigated the phenomenon of millet bleaching and found that the discoloration was pH dependent. Soaking in a solution of 0.2N HCl or citric acid was as effective as sour milk or tamarind pods in bleaching the grain pigments. Further studies by Reichert (1979) suggested that C-glycosylflavonoids (glucosylvitexin, glucosylorientin, and vitexin) were responsible for the natural grey color of pearl millet grains, and that these pigments were concentrated in the peripheral regions of the grain.

IV. NUTRITIONAL QUALITY

In some developing nations, a high percentage of the calorie intake of individuals comes from cereal grains. This great dependence on cereal grains in the diet has fostered investigations into their nutritional quality.

Information on the nutritional quality of pearl millet for human food has been extrapolated from studies conducted with weanling albino rats. The use of rats as a test animal is open to question. The rat's much higher protein requirement, as a result of its faster growth rate, is one factor that must be considered when extrapolating rat data to humans. Another factor is the relative inactivity of rats in test cages. The shortcomings of using rats as test animals are dealt with quite well by Vaghefi et al. (1974). Generally, protein efficiency ratios (PER) and weight gains are used as guides to nutritional quality. It must be remembered that PER is only a measure of the quality (amino acid balance) of the protein. It does not measure the usefulness of a sample or type of grain as a food. For PER value to have meaning, other factors such as vitamins or minerals in the diet must not be limiting and the protein content of the diet must be 10% or less. Unfortunately, in some cases, poor methodology may only provide erroneous results, particularly when PER studies are conducted using dietary protein levels above 10%.

The PER's for pearl millet alone or supplemented with amino acids or other sources of plant protein are summarized in Table 5. The PER for unsupplemented pearl millet is higher than that reported for wheat or sorghum (Pushpamma et al., 1972; Rao et al., 1964; Oke, 1977). The addition of lysine to a pearl millet diet results in a dramatic increase in the PER. This is commensurate with the fact that, in many millet cultivars, lysine is the limiting amino acid. The amino acid profiles in millet may be complemented by other plant proteins. Including legumes in the diet significantly improves the PER (Table 5).

The effect of vitamin and mineral supplements on the growth rate of rats fed pearl millet is shown by Hariharan et al. (1965). The data of Daniel et al. (1965) show that with diets inadequate in minerals and vitamins the supplementary value of lysine was not realized.

Milling processes and products influence pearl millet PER and digestibility (Goussault and Adrian, 1977). The traditional wooden mortar milling of pearl millet gives a product which has a PER equal to that of the original grain. The SOTRAMIL process decreases the PER from 1.83 to 1.75 going from the whole grain to the flour. Dehusking and decortication by the SEPIAL process progressively lowered the PER.

Most of the PER studies on pearl millet have been done on the raw grain. Recently Dassenko (1979) has shown that cooking millet in the form of chapaties lowers the PER. She found the reduction in PER to be much greater when chapaties were made from the whole meal rather than from 67% extraction flour.

Because energy is a basic need of man, one can measure the nutrient requirements based on calories (Hansen, 1973). Oke (1977) has applied this technique to pearl millet and 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, pearl millet is an excellent food.

Table 5. 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

V. MILLING

A number of traditional and mechanical processes are used to mill pearl millet. Those processes not only alter the nutritional quality of the products (as was mentioned above) but also often alter the meal's end-use performance.

A. Traditional Processes

The traditional wooden mortar and pestle method of milling pearl millet (Fig. 13) is still used in the rural areas of many developing countries (Carr, 1961; Reichert and Young, 1977; Goussault and Adrian, 1977; Adrian et al., 1976). The grain plus a small amount of water (10 to 20%) is placed in the mortar and the grain is dehulled by a pounding action. After drying, the bran and fine material are removed by winnowing with a closely woven basket (Fig. 14). Home grinding mills such as the round mill stones shown in Figure 15 may then be used to grind the grain into a fine flour (Vogel and Graham, 1979). Other grinding methods such as flat stones and additional pounding with mortar and pestle are also used. The analysis for a flour produced by these traditional processes was 10.3% protein, 3.55% cellulose plus lignin, and 2.7% lysine (Goussault and Adrian, 1977). An excellent description of traditional processing of cereal grain in Southern Rhodesia is given by Carr (1961).

Figure 13. A lady using a mortar and pestle to dehull pearl millet.

Figure 14. Winnowing pearl millet. Courtesy of Richard Vanderlip, KSU.

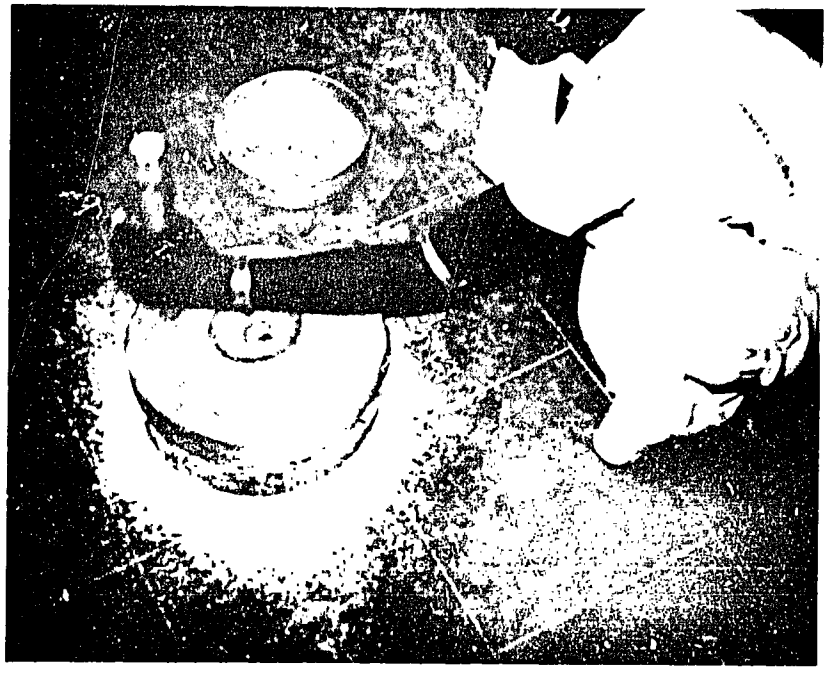


Figure 15. Grinding grain with a hand operated stone mill.

B. Mechanical Milling Processes

The traditional milling processes are laborious. Most villages have grinders, usually diesel powered, that are hammer or burr type mills (Vogel and Graham, 1979). Thus, for a fee or percentage of grain a villager can get his grain ground to a whole meal. The fineness of the grind will depend more on the grinder available than on the consumer desires. However, this method is very time saving and much less work than hand pounding.

Several industrial milling processes have been proposed for producing pearl millet flour (Goussalt and Adrian, 1977). The SOTRAMIL process was developed in Zinder, Niger. In this process, washed grain is graded and then dehusked on a horizontal millstone (Bavaria dehusking machine). An attrition apparatus is then used to grind the grain, and the flour is separated by sifting. The extraction rate is 65-75%, and the particle size averages 40 μm. The process reduces the cellulose and lignin content from about 4.50% in the whole grain to 1.00% in the flour, and the protein content drops about 2%. However, the level of lysine in the flour is almost the same as that in the whole grain.

The French SEPIAL process is another method that has been used to dehusk pearl millet (Foussault and Adrian, 1977). Dehusking is achieved by placing dampened grains into an apparatus where the rotation of a vertical arm equipped with paddles results in the removal of the pericarp by friction of the grains against each other. After the husks have been mechanically separated from the grains, the husked grain (approximately 92.5% of the total grain) can be further decorticated to remove a protein fraction (aleurone and parts of germ and scuttelum) representing 8.5% of the grain. Decorticated grain can then be ground to yield a meal that represents 80% of the total grain. The decorticated grain contains about the same protein content as the total grain but less cellulose and lignin and less lysine.

Other types of equipment have been used to mill pearl millet. Perten (1977) studied the applicability of the Buhler laboratory roller mill MLU 202 for processing pearl millet and sorghum, and found that wheat milling technology was not so suitable as were other methods for these grains. He concluded that the millet must be decorticated prior to flour production because millet bran and germ are easily pulverized. The results are high ash and fat values in the flour fractions. In addition, the wheat milling equipment produced coarser flour than did grinding the decorticated grain in an attrition or hammer mill.

The Palyi-Hansen milling system (deMan et al., 1973) consists basically of two parallel plates provided with band saw blades set in a radial fashion around a circular strip on the plates. One of the plates is fixed to the housing of the huller and the other one to a rotating drum. Decortication of millet typically gives about 76% debranned grain, with ash, fiber, protein, and fat all decreased in relation to the original grain (Rasper, 1977).

In comparison of attrition and abrasive mills Reichert and Youngs (1976) concluded that the abrasive mill was generally more suitable for dehulling sorghum and millet. Their conclusion was based on loss of color per loss of material weight as well as kernel-cracking analysis. The chemical composition of products produced on the above mills was compared with that of grains dehulled traditionally by mortar and pestle (Reichert and Youngs, 1977). In general, mechanically dehulled grains lost more oil, ash, and protein than did traditionally dehulled grain at the same extraction. Crude fiber was removed more efficiently with an abrasive mill than with an attrition or the traditional method.

VI. FOOD USES

Pearl millet used as food can take many forms and names. However, if we look at the foods carefully we find a relatively few general types (Vogel and Graham, 1979).

A. Unleavened Bread

The chapati or roti of India is similar to the well-known wheat chapati. However, millet flour does not possess the dough-forming properties of wheat flour. Thus, considerable skill is required to produce a thin, flexible chapati that will remain soft for one day. The dough is formed and baked on a hot griddle. An ideal product will puff to give a semi-light texture. In some areas hot water is used to partially gelatinize the starch and thus make the chapati easier to work with; however, the final product is not so light or desirable. The ideal product is light, flexible, uniformly round, and firm but not tough to the bite and will retain these properties for one day. Generally, an ideal chapati is not made from millet.

B. Leavened Bread

These products are not leavened with yeast or chemicals but generally with steam. The Sudanese kisra is an example of this product. The Sudanese generally use sorghum flour, but millet can be and is used. The flour-water mixture is often allowed to set overnight to produce a nice sour taste from the lactic acid bacteria. A starter is often used. The mixture should be a very thin batter. It is quickly spread to a thin layer on a hot (150°C) iron plate. Within a few seconds it can be stripped from the plate to give a thin moist sheet. The kisra is generally light, in both color and texture, moist (30 to 50% moisture), quite flexible, and pleasantly acidic in taste. The starch is gelatinized and there is no gritty taste.

C. Rice Substitute Products

Dehulled, whole, or cracked grains are steamed and consumed similarly to rice. Although not a rice substitute, couscous of Senegal is a steamed agglomerated product. Liquid is gradually added to millet flour to form small beads or agglomerates. The agglomerates either are steamed or are dried first and then steamed.

H. Composite Flours for Breadmaking

The use of pearl millet flour to partly replace wheat flour has met with reasonable success. Generally, there is a rather large drop in loaf volume as the percentage of millet is increased; however, all reports indicate that bread containing millet flour has excellent flavor (Dendy et al., 1970; Basse, 1978; Badi et al., 1976b; Casier et al., 1977).

I. Snack Foods

Traditional snack foods are limited; however, roasted grain or popped grain would both certainly qualify. Use of pearl millet as a substitute for all or part of wheat flour 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).

REFERENCES

Abhyander, V. A., W. V. Kotastane, and N. Naryana. 1939. Proc. Indian Acad. Sci. section B, 9:126.

Adams, C. A., L. Novellie, and N. V. D. Liebenberg. 1976. Cereal Chem. 53:1.

Adrian, J., B. Goussault, F. Arnal-Peyrot, M. F. Samson, and S.E.P.I.A.L. 1976. Agron. Tropicale 30:43.

Agawal, P. N., and N. S. Sinka. 1964. Indian J. Agron. 63:288.

Badi, S. M., R. C. Hoseney, and A. J. Casady. 1976a. Cereal Chem. 53:478.

Badi, S. M., R. C. Hoseney, and P. L. Finney. 1976b. Cereal Chem. 53:718.

Badi, S. M. and R. C. Hoseney. 1976. Cereal Chem. 53:733.

Badi, S. M., H. Perten, A. I. Mustafa, and P. Albert. 1978. Abstract A5-2. Cereal Foods World 23:485.

Bailey, A. V., G. Sumrell, and G. W. Burton. 1979. Cereal Foods World 24:23.

Banigo, E. O. I. and H. G. Muller. 1972. J. Sci. Fd. Agric. 23:101.

Basse, Marie-Therese. 1978. Ceres. May-June. p. 38.

Beleia, A., E. Varriano-Marston, and R. C. Hoseney. 1979. Cereal Chem. (submitted).

Brunken, Jere, J. M. J. DeWitt, and J. R. Harlan. 1977. Econ. Bot. 31:163.

Burton, G. W., A. T. Wallace, and K. O. Rachie. 1972. Crop Sci. 12:187.

Carovale, E. and G. B. Quaglia. 1973. Ann. Technol. Agric. 22:371.

Carr, W. R. 1961. Brit. J. Nutr. 15:339.

Casey, P. and K. Lorenz. 1977. Baker's Digest 51(1):45.

Casier, J. P. J., G. de Paepe, H. Willems, G. Goffings, and H. Noppen. 1977. In "Proceedings of a Symposium on Sorghum and Millets for Human Food" (D.A.V. Dendy, ed.), p. 127. Tropical Products Inst., London.

Daniel, V. A., R. Leela, T. S. Subramanyarajurs, S. Venkat Rao, K. Hariharas, M. Rajalakshimi, H. A. B. Parpia. 1965. J. Nutr. Dietet. 2:134.

Dassenko, S. 1979. Ph.D. Thesis, Kansas State University, Manhattan, KS.

de Man, J. M., E. O. I. Banigo, V. Rasper, and H. Gade. 1973. Can. Inst. Food Sci. Technol. 6:188.

Dendy, D. A. V., P. A. Clarke, and A. W. James. 1970. Tropical Sci. 12: 131.

Deosthale, Y. G., K. V. Rao, V. Nagarajan, and K. C. Pant. 1971. Ind. J. Nutr. Dietet. 8:301.

Desikachar, H. S. R. 1977. In "Proceedings of a Symposium on Sorghum and Millets for Human Food" (D. A. V. Dendy, ed.) p. 41. Tropical Products Institute, London.

Dhamija, S. S. and D. P. Singh. 1978. J. Food Sci. Tech. 15:197.

Feron, F. and F. Bouquet. 1948. Anales de la Nutrition et de L'alimentation. 2:537.

Freeman, J. E. and B. J. Bocan. 1973. Cereal Sci. Today 18:69.

Goswami, A. K., K. L. Sharma, and K. P. Sharma. 1969a. J. Nutr. and Dietet. 6:287.

Goswami, A. K., K. P. Sharma, and B. K. Gupta. 1969b. J. Nutr. and Dietet. 6:291.

Goswami, A. K., K. L. Sehgal, and B. K. Gupta. 1970a. Ind. J. Nutr. and Dietet. 7:5.

Goswami, A. K., K. P. Sehgal, and K. L. Sehgal. 1970b. Ind. J. Nutr. and Dietet. 7:67.

Goussault, B. and J. Adrian. 1977. In "Proceedings of a Symposium on Sorghum and Millets for Human Food" (D. A. V. Dendy, ed.). p. 13. Tropical Products Institute, London.

Hansen, R. G. 1973. Nutr. Rev. 31:1.

Hariharan, K., T. S. Subramanyarajurs, B. S. M. Desai, S. Venkat Rao, D. Rajalakshmi, M. Swaminathan, and H. A. B. Parpia. 1965. J. Nutr. Dietet. 2:196.

Jellum, M. D. and J. B. Powell. 1971. Agron. J. 63:29.

Jones, R. W., A. C. Beckwith, U. Khoo, and G. E. Inglett. 1970. J. Agr. Food Chem. 18:37.

Lai, C. C. and E. Varriano-Marston. 1979. Cereal Chem. (submitted).

Lineback, D. R. and S. Ponpipom. 1978. Die Stärke. 29:52.

Mertz, E. T. 1975. In: "Protein Nutritional Quality in Foods and Feeds." (M. Friedman, ed.), p. 1. Marcel Dekker, New York.

Naik, M. S. 1968. Indian J. Genet. 28:142.

Narayamurti, D. and C. V. R. Aiyar. 1930. J. Indian Chem. Soc. 7:945.

Nechaev, A. P., N. N. Busareva, Ya. I. Denisenko, and D. J. Kuznetsov. 1973. Applied Bioch. & Micro. 9:617.

Novellie, L. 1977. In "Proceedings of a Symposium on Sorghum and Millets for Human Food" (D. A. V. Dendy, ed.), p. 73. Tropical Products Institute, London.

Oke, O. L. 1977. In: "Proceedings of a Symposium on Sorghum and Millets for Human Food" (D. A. V. Dendy, ed.), p. 121. Tropical Products Institute, London.

Perten, H. 1977. In "Proceedings of a Symposium on Sorghum and Millets for Human Food." (D. A. V. Dendy, ed.), p. 53. Tropical Products Institute, London.

Pomeranz, Y. 1975. In: "Protein Nutritional Quality of Food and Feeds" (M. Friedman, ed.), p. 13. Marcel Dekker, New York.

Pruthi, T. D. and I. S. Bhatia. 1970. J. Sci. Fd. Agric. 21:419.

Pushpamma, S., D. B. Parrish, and C. W. Deyoe. 1972. Nutr. Reports Intern. 5:93.

Rao, S. Venkat, M. Swaminathan, and H. A. B. Parpia. 1964. J. Nutr. Dietet. 1:128.

Rasper, V. F. 1977. In: "Proceedings of a Symposium on Sorghum and Millets for Human Food" (D. A. V. Dendy, ed.) p. 59. Tropical Products Institute, London.

Reddy, Geervani. 1978. Home Science College, Hyderabad, India. Personal communication.

Reichert, R. D. and C. G. Youngs. 1976. Cereal Chem. 53:829.

Reichert, R. D. and C. G. Youngs. 1977. Cereal Chem. 54:174.

Reichert, R. D. and C. G. Youngs. 1979. Abstract, Cereal Foods World 24:23.

Reichert, R. D. 1979. Cereal Chem. (submitted).

Rooney, L. W. 1978. Cereal Chem. 55:584.

Sawhney, S. K. and M. S. Naik. 1969. J. Genetics and Plant Breeding 29:395.

Shah, H. C. and B. V. Mehta. 1959. Soil Sci. 87:320.

Sharma, K. P. and A. K. Goswami. 1969. J. Nutr. and Dietet. 6:316.

Sheorain, V. S. and D. S. Wagle. 1973. J. Fd. Sci. Tech. 10:184.

Singh, D. P. and P. Tauro. 1977. J. Food Sci. Tech. 14:255.

Sullins, L. W. and R. D. Rooney. 1977. In "Proceedings of a Symposium on Sorghum and Millets for Human Food" (D. A. V. Dendy, ed.), p. 91. Tropical Products Institute, London.

Thiam, A. A., R. Drapron, and D. Richard-Molard. 1976. Ann. Technol. Agric. 25:253.

Vaghefi, S. B., D. D. Makdani, and O. Mickelsen. 1974. Amer. J. Clinical Nutr. 27:1231.

van der Maesen, L. J. G. 1978. Genetic resources at ICRISAT. International Crop Research Institute for the Semi-Arid Tropics, Hyderabad, India.

Varriano-Marston, E. and R. C. Hoseney. 1979. Cereal Chem. (submitted).

Varriano-Marston, E., Grace Huang, and D. Gottneid. 1979. Cereal Chem. (submitted).

Vogel, S. and M. Graham. 1979. "Sorghum and Millet: Food Production and Use", International Development Res. Center, Ottawa, Canada.

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

INTRODUCTION

Pearl millet [*Pennisetum americanum* (L.) Leeke] is a staple food of people in Africa and Asia. Within the past 10 years considerable empahsis has been placed on its nutritional components (Casey and Lorenz, 1977; Dendy, 1977). However, data reported on the lipid composition of different cultivars are limited (Jellum and Powell, 1971; Pruthi and Bhatia, 1970). Furthermore, the fatty acid composition of free (ether extractable) and bound lipids (not extractable with ether but extractable with water-saturated butanol) has not been reported. This paper compares the lipid content in different random-mating populations and S_1 lines of pearl millet, and describes qualitative differences in fatty acids between free and bound lipids.

MATERIALS AND METHODS

Materials

Pearl millets were grown near Hays, Kansas. Seventeen HMP550 S_1 lines (Tift 23DB$_1$/*2PI185642) that were harvested in 1977 were studied. In addition four bulk populations were studied: HMP550, a combination of 110S$_1$ lines; HMP1700 (PI263540/Tift 23 DB$_1$/2/Tift 239DB$_2$/2*Serere 3A); RMPI(S)CI (parentage from Serere 3A, Serere 17 and Tift 239DB$_2$); and Serere 3A, developed by Serere Exp. Stn., Uganda, Africa. The latter cultivar was harvested in 1975.

Methods

Location of lipids. Whole kernels from each millet population were soaked in distilled water overnight at 4°C. Kernels were then hand sectioned and stained with Oil Red O (Lillie and Ashburn 1943) or Nile Blue (Cain 1947). Light photomicrographs were taken on a Reichert (Austria) light microscope; a Wild Heerbrugg stereoscopic microscope was used to record images of stained half-kernels.

Lipid extraction. Millet was ground on a Wiley mill with a 40 mesh screen. Free lipids were extracted with petroleum ether (bp 38 to 55°C) in a Goldfish apparatus for 14 hrs. Bound lipids were then extracted from the residue two times with water-saturated n-butanol in a Stein mill. In the first extraction, 50 ml of solvent was added and the residue and solvent were mixed for 4, 2, and 2 min, with 1-min intervals between extractions. The second extraction was done three times, 2 min each at 1-min intervals. The rest of the drying and re-extraction procedure was as described by Daftary and Pomeranz (1965) on wheat samples. All lipid extractions were done in duplicate.

Thin-layer chromatography. The free and bound lipid fractions from bulk populations and 4 S_1 lines were characterized by thin-layer chromatography on 0.25 mm silica gel G (Brinkmann, Instruments) with chloroform: methanol: water (65:25:4, v/v/v) to separate polar components and chloroform to separate nonpolar components. Lipid samples were applied at 200 µg/spot. After separation, the spots were visualized by spraying the plates with a chromic H_2SO_4 reagent; a ninhydrin reagent for detection of free amino groups (Lepage 1964); α-naphthol containing reagent specific for sugar containing compounds (Feldman et al 1965); or with a molybdenum blue spray specific for phosphorous containing compounds (Dittmer and Lester 1964). Lipids were tentatively identified by cochromatography with known lipid compounds (Sigma Chemical Co.), by comparison of relative Rf values, and by reactions of the specific sprays.

Gas chromatography. Esterification of fatty acids from bulk populations was carried out by placing a 5 ml aliquot of lipid extract in teflon-stoppered culture tubes and evaporating to dryness under a stream of N_2. Two ml of 0.5N methanolic NaOH were added and the vial was sealed. The contents were heated in a boiling water bath for about 2 min followed by the addition of 5 ml BF_3-methanol (14% w/v; Supelco) and heating again for another 2 min. The contents of the tube were then transfered to a 50 ml separatory funnel with 20 ml of water. Fatty acid methyl esters were extracted with hexane and analyzed on the gas chromatograph. Duplicate analyses were run on each sample.

Fatty acid methyl esters were identified on a Hewlett Packard 5750 Gas Chromatograph with a flame ionization detector. The column was 6 ft. X 1/8 in. packed with 10% Sp-2330 on 100/120 Chromosorb W AW (Supelco Inc.). Temperature at injection port was 250°C; column temperature was 195°C and N_2 carrier gas flow was .40 ml/min. Relative peak areas were determined by multiplying the peak height by the width of the peak at half height. Weight percentage compositions were calculated by applying correction factors obtained from chromatograms of known mixtures (Supelco, Inc.). Peaks were tentatively identified by comparing the relative retention times with those from the reference standard mixtures run on the same column under the same conditions.

Statistical analysis. Standard deviation of means or least significant difference tests were determined on all data (Steel and Torrie 1960).

RESULTS AND DISCUSSION

Lipid Location

Histochemical studies on half-kernels showed that most lipids were concentrated in the germ and pericarp of the grain (Fig. 1a). Further observations on thin sections indicated that although the endosperm absorbed small quantities of lipid stain, most of the lipids were concentrated in the pericarp and aleurone layers (Fig. 1b).

Free and Bound Lipids

Lipid contents varied among populations but averaged 6.75% free and 0.76% bound lipids (Table I). Serere 3A contained significantly ($P < 0.05$) less free and bound lipids than other populations. In addition, the ratio of free to bound lipids was the highest for Serere 3A.

Variability in free and bound lipids also existed among S_1 lines; values ranged from 5.55% to 7.03% for free lipids and 0.57% to 0.88% for bound lipids (Table I). The average for S_1 lines was 6.20% free and 0.70% bound lipids. Pruthi and Bhatia (1970) reported free and bound lipid contents of 5.0% and 0.5%, respectively, for two pearl millet cultivars. The S_1 lines were similar to bulk samples in ratios of both free and bound lipids.

Thin-layer Chromatography

Lipid components of free and bound fractions were separated by thin-layer chromatography (Figs. 2 and 3). Although 4 bulk populations and 4 S_1 lines were studied, only the results of three samples are shown because they all had similar TLC patterns. Nonpolar lipid components (Fig. 2), both free and bound, were tentatively identified as: Hydrocarbons and steryl esters, triacylglycerols, free fatty acids, sitosterol, and partial acyglycerols. Sitosterol spots were differentiated from free fatty acids by the appearance of a pink-mauve color after spraying with chromic H_2SO_4 reagent. The nonpolar components of the free lipid fraction were similar to those identified by Pruthi and Bhatia (1970). Triacylglycerols were the major free nonpolar lipids.

Like Badi et al. (1976) we found that the bound nonpolar lipids contained the same components as the free nonpolar lipids. However, bound nonpolar lipids showed two spots corresponding the the Rf of the triacylglycerol standard (Fig. 2). This subfractionation may be due to the presence of triacylglycerols with fatty acids of different chain lengths(Malins and Mangold 1960).

Polar lipids were chromatographed (Fig. 3), and the fractionated components were tentatively identified by their reactions to specific sprays and by comparison of Rf values with that of the standards (Table II). They were lysophosphatidyl choline (b); phosphatidyl choline (e), digalactosyl diglycerides (f), phosphatidyl ethanolamine (g), cerebrosides (h), and free fatty acids (i). The sitosterol standard (S) had the same Rf as spot i on the chromatogram in Fig. 3. However, that unknown did not turn pink-mauve during the initial charring period after spraying with chromic H_2SO_4 so they were tentatively identified as free fatty acids. Badi et al., (1976) identified monogalactosyl diglyceride (MGDG) in the bound polar lipids of pearl millet. However, we were unable to detect MGDG on our chromatograms; free fatty acids were probably misidentified as MGDG by Badi et al. (1976).

The free lipids of our pearl millet samples contained no polar components (Fig. 3) which agrees with the results.

Gas Chromatography

Fatty acid compositions of free and bound lipids of pearl millet populations are presented in Tables III and IV. Pearl millets were high in unsaturated acids, averaging 70.3% of the total fatty acids of the free lipids and 51.7% of the fatty acids of the bound lipids. Significant differences ($P < 0.05$) in some fatty acid contents were observed across populations.

Linoleic (C18:2), oleic (C18:1) and palmitic (C16:0) acids were the principal acids in free lipids (Fig. 4), which agrees with the results previously reported (Jellum and Powell 1971; Rooney 1978) for the fatty acid composition of millet free lipids. However, Agarwal and Sinha (1964), using the urea adduct method, found that oleic acid (53.84%) was the major acid in their millet samples. Jellum and Powell (1971), using a combination of methanol and petroleum ether as an extractant, reported similar levels of palmitic acid ($\bar{x}$ = 21%), linolenic acid ($\bar{x}$ = 3.7%), and oleic acid ($\bar{x}$ =26%) as we found in our Kansas millets. However, they reported an average of 45% linoleic acid compared to 38% in our samples (Table III). Rooney (1978) also reported a linoleic acid content of 46% for pearl millet, but he gave no details of the lipid extractant or chromatographic conditions. It has been clearly shown that differences in lipid extraction procedures as well as genetic variability contribute to differences in reported fatty acid contents of pearl millets (Jellum and Powell 1971).

Jellum and Powell (1971) reported that other unidentified fatty acids represented less than 0.5% of the total fatty acids in pearl millet. We tentatively identified trace levels of C14:0 and C22:0 in free lipids of our Kansas Samples (Table III).

Qualitatively, fatty acids that were present in free lipids, except C22:0, were also found in bound lipids (Fig. 5). Like the free lipids, linoleic, oleic and palmitic acids were the major fatty acids in the bound lipids. However, C18:1 and C18:2 were present in lower weight percentages in bound than in free lipids (Table IV). In addition, six other fatty acids were tentatively identified in bound lipids (C10:0, C12:0, C12:0, C15:0, C17:0, and C24:0), and of the total bound fatty acids, 1.34% to 2.16% had an odd number of carbon atoms. The total percentage of long chain fatty acids (C20:0 and above) was also greater for bound than free lipids.

LITERATURE CITED

Agarwol, P. N., and Sinha, N. S. 1964. Chemical Composition of the oil from the seeds of *Pennisetum typhoideum* (Bajra). Indian J. Agron. 63:288.

Badi, S. M., Hoseney, R. C., and Casady, A. J. 1976. Pearl millet I. Characterization by SEM, amino acid analysis, lipid composition, and prolamine solubility. Cereal Chem. 53:478.

Cain, A. J. 1947. The use of nile blue in the examination of lipids. Quart. J. Microscop. Sci., 88:383-392.

Casey, P., and Lorenz, K. 1977. Millet--functional and nutritional properties. Bakers Dig. 51(1):45.

Daftary, R. D., and Pomeranz, Y. 1965. Changes in lipid composition in maturing wheat. J Food Sci. 30:577.

Dendy, D. A. V. 1977. "Proceedings of a Symposium on Sorghum and millet for human food." Tropical Products Institute, London.

Dittmer, J. C., and Lester, R. L. 1964. A simple specific spray for the detection of phospholipids on thin-layer chromatograms. J.Lipid Res. 5:126.

Feldman, G. L., Feldman, L. L., and Rouser, G. 1965. Occurrence of glycolipids in the lens of the human eye. J. Amer. Oil Chem. Soc. 42:742.

Jellum, M. D, and Powell, J. B. 1971. Fatty acid compsition of oil from pearl millet seed. Agron. J. 63:29

Lepage, M. 1964. The separation and identification of plant phospholipids and glycolipids by two-dimensional thin-layer chromatography. J. Chromatog. 13:99.

Lillie, R. D., and As-burn, L. L. 1943. Supersaturated solutions of fat stains. Archs. Path. 36:432.

Malins, D. C. and Mangold, H. K. 1960. Analysis of complex lipid mixtures by thin-layer chromatography and complementary vethods. J. Am. Oil Chem. Soc. 37:576.

Pruthi, T. D., and Bhatia, I. S. 1970. Lipids in cereals. I. *Pennisetum typhoideum*. J. Sci. Food Agric. 21:419.

Rooney, L. W. 1978. Sorghum and pearl millet lipids. Cereal Chem. 55:584.

Steel, R. G. D., and Torrie, J. H. 1960. "Principles and Procedures of Statistics." McGraw-Hill Book Co., Inc., New York.

TABLE I. Free and Bound Lipids of Pearl Millet Samples.

Sample	Free Lipid (%)	Bound Lipid (%)	Ratio Free/bound
Bulk Populations*			
Serere 3A	6.20[a]	0.59[a]	10.5
RMPI(S)CI	6.80[b]	0.90[bd]	7.6
HMP1700	6.92[bc]	0.74[c]	9.4
HMP550	7.08[c]	0.82[d]	8.6
average	6.75	0.76	
$HMP550S_1$, LINES**			
114	6.33	0.88	7.2
120	6.21	0.70	8.9
134	6.45	0.65	9.9
149	6.40	0.77	8.3
155	6.46	0.73	8.9
160	6.14	0.58	10.6
179	6.50	0.75	8.7
180	6.32	0.74	8.5
189	5.87	0.76	7.7
191	6.19	0.78	7.9
193	6.07	0.64	9.5
196	5.66	0.57	9.9
200	5.78	0.70	8.3
201	5.95	0.73	8.1
218	5.55	0.68	8.2
220	7.03	0.64	11.0
240	6.56	0.67	9.8
average	6.20	0.70	

*Within each fatty acid, values with different superscripts differ significantly ($P < 0.05$).

**Least significant differences ($P < 0.05$) for S_1 free and bound lipids are 0.24 and 0.09, respectively.

Table II

Polar Lipid Components of Pearl Millets Shown in Figure 3.*

Spot	Rf	Tentative Identification	Spray Reagents			
			Chromic H_2SO_4	Ninhydrin	Molybdenum	α-Naphthol
j	.93	Unresolved nonpolar lipids	+	--	--	--
i	.83	Free fatty acids	+	--	--	--
h	.62	Cerebrosides	+	--	--	+
g	.48	Phosphatidyl ethanolamine	+	+	+	--
f	.41	Digalactosyl diglyceride	+	--	--	+
e	.24	Phosphatidyl choline	+	--	+	--
d	.16	Unknown	+	+	+	--
c	.12	Unknown	+	+	--	--
b	.07	Lysophosphatidyl choline	+	--	+	--
a	.03	Unknown	+	+	+	+

* Positive reaction (+); negative reaction (--)

TABLE III. Fatty Acid Composition (%) of Free Lipids from Pearl Millet Populations.

Fatty Acid	Populations[1]			
	Serere 3A	RMPI(S)CI	HMP1700	HMP550
C14:0	0.13	trace	0.21	trace
C16:0	20.01[a]	20.71[a]	21.62[a]	21.56[a]
C16:1	1.10[a]	1.10[a]	0.93[a]	0.96[a]
C18:0	8.83[a]	10.10[b]	6.09[c]	6.76[c]
C18:1	27.23[a]	28.04[a]	28.21[a]	28.20[a]
C18:2	37.83[ab]	36.72[b]	38.02[ab]	39.78[a]
C18:3	4.14[a]	2.17[b]	4.19[a]	2.36[b]
C20:0	0.75[a]	1.19[b]	0.75[a]	1.04[b]
C22:0	trace	trace	trace	trace

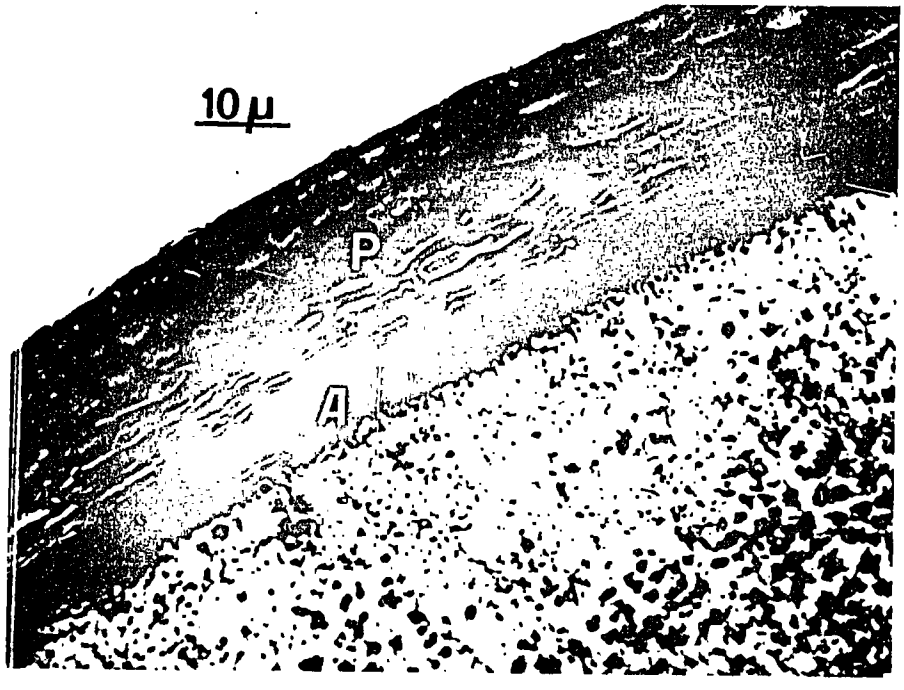
[1]Within each fatty acid, values with different superscripts differ significantly ($P < 0.05$).

TABLE IV. Fatty Acid Composition (%) of Bound Lipids from Pearl Millet Populations.

Fatty Acid	Populations[1]			
	Serere 3A	RMPI(S)CI	HMP1700	HMP550
C10:0	3.41[a]	0.73[b]	4.0[a]	1.18[b]
Unknown	0.56[a]	1.32[b]	0.91[b]	0.85[b]
C12:0	1.90[a]	0.71[b]	3.16[c]	1.05[b]
C13:0	0.33[a]	0.51[a]	0.52[a]	0.62[a]
C14:0	0.53[a]	0.79[a]	0.54[a]	0.42[a]
C15:0	0.98[a]	0.32[bc]	1.31[a]	0.73[ac]
C16:0	22.12[ab]	23.21[a]	20.80[b]	21.11[ab]
C16:1	0.91[a]	1.36[b]	0.78[a]	0.96[a]
C17:0	0.33[a]	0.51[a]	0.33[a]	0.23[a]
C18:0	6.47[a]	7.91[b]	4.79[c]	5.12[c]
C18:1	19.36[a]	18.76[a]	16.62[b]	19.49[a]
C18:2	26.62[a]	29.02[b]	32.29[c]	29.37[b]
C18:3	3.25[a]	2.98[a]	1.89[b]	3.16[a]
C20:0	5.12[a]	5.09[a]	7.10[b]	7.81[b]
C24:0	7.96[a]	7.68[a]	5.00[b]	7.87[a]

[1]Within each fatty acid, values with different superscripts differ significantly ($P < 0.05$).

A



B

Figure 1. Cross-section of pearl millet kernel (HMP550) stained with Nile blue: (a) showing coloration of the germ (G) and pericarp (P) and (b) high lipid concentration in the aleurone layer (A).

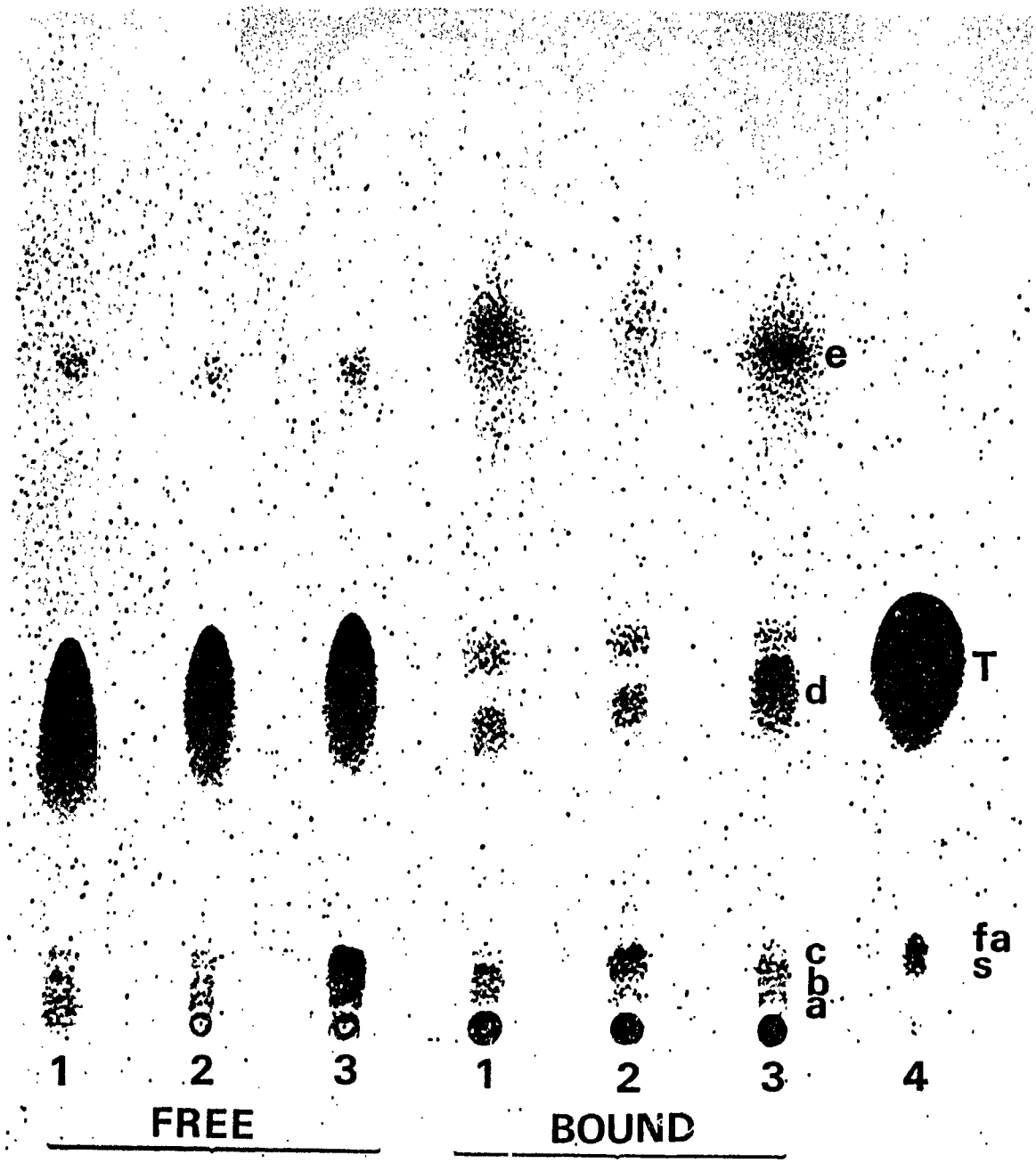


Figure 2. Thin-layer chromatograms of nonpolar components of free and bound lipids from HMP550 (1), RMPI(S)CI (2), and Serere 3A (3). Nonpolar reference standards (4) are free fatty acids (fa), sitosterol (S), and triacylglycerols (T). Nonpolar lipids are tentatively identified as (a) partial glycerides (a), sitosterol (b), free fatty acids (c), triacylglycerols (d), and hydrocarbons and steryl esters (e).

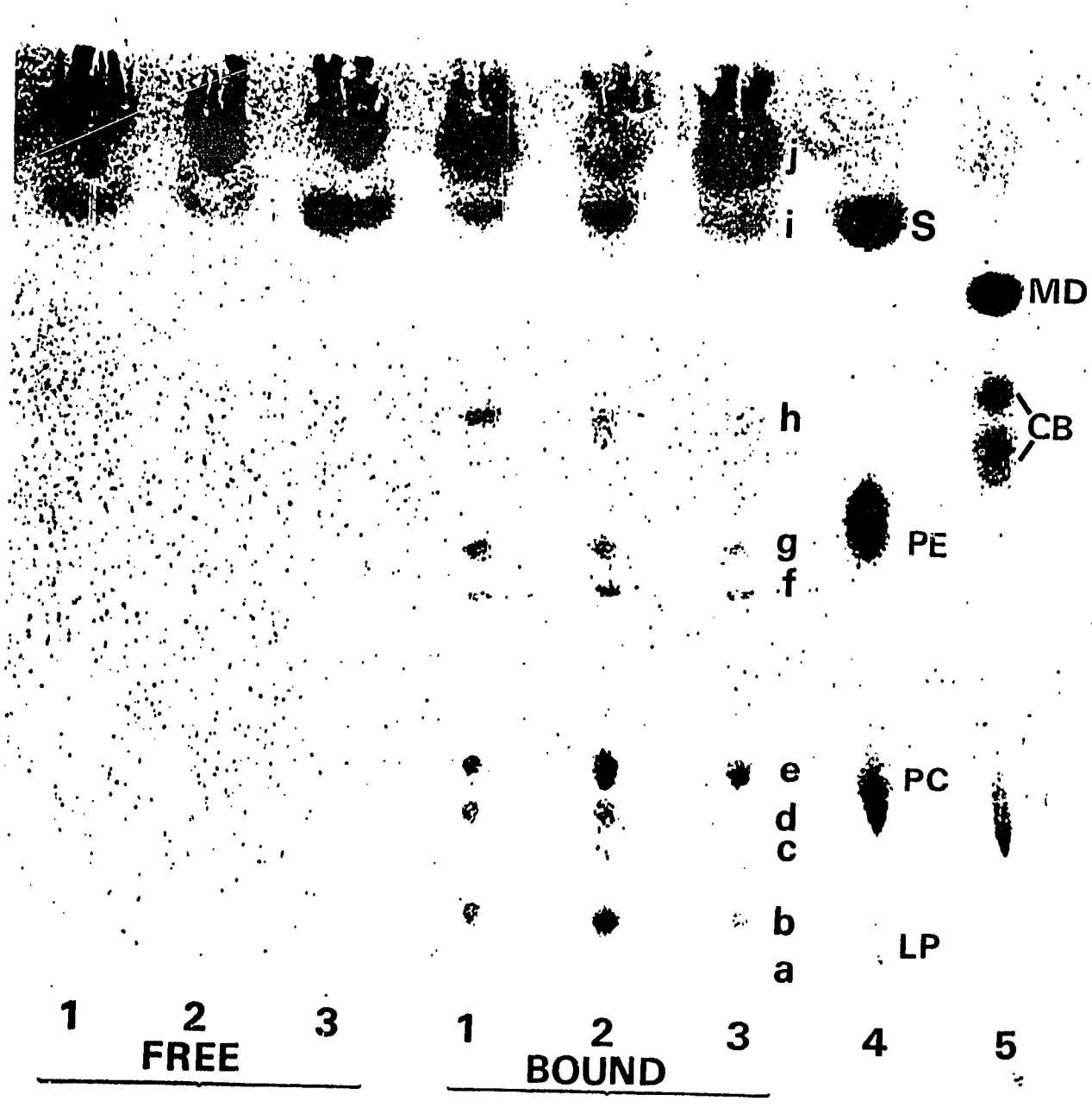


Figure 3. Thin-layer chromatogram of polar components of free and bound lipids from HMP550 (1), RMPI(S)CI (2), and Serere 3A (3). Polar reference standards (4 & 5) are lysophosphatidyl choline (LP), phosphatidyl choline (PC), phosphatidyl ethanolamine (PE), sitosterol (S), cerebrosides (CB) and monogalactosyl diglyceride (MD).

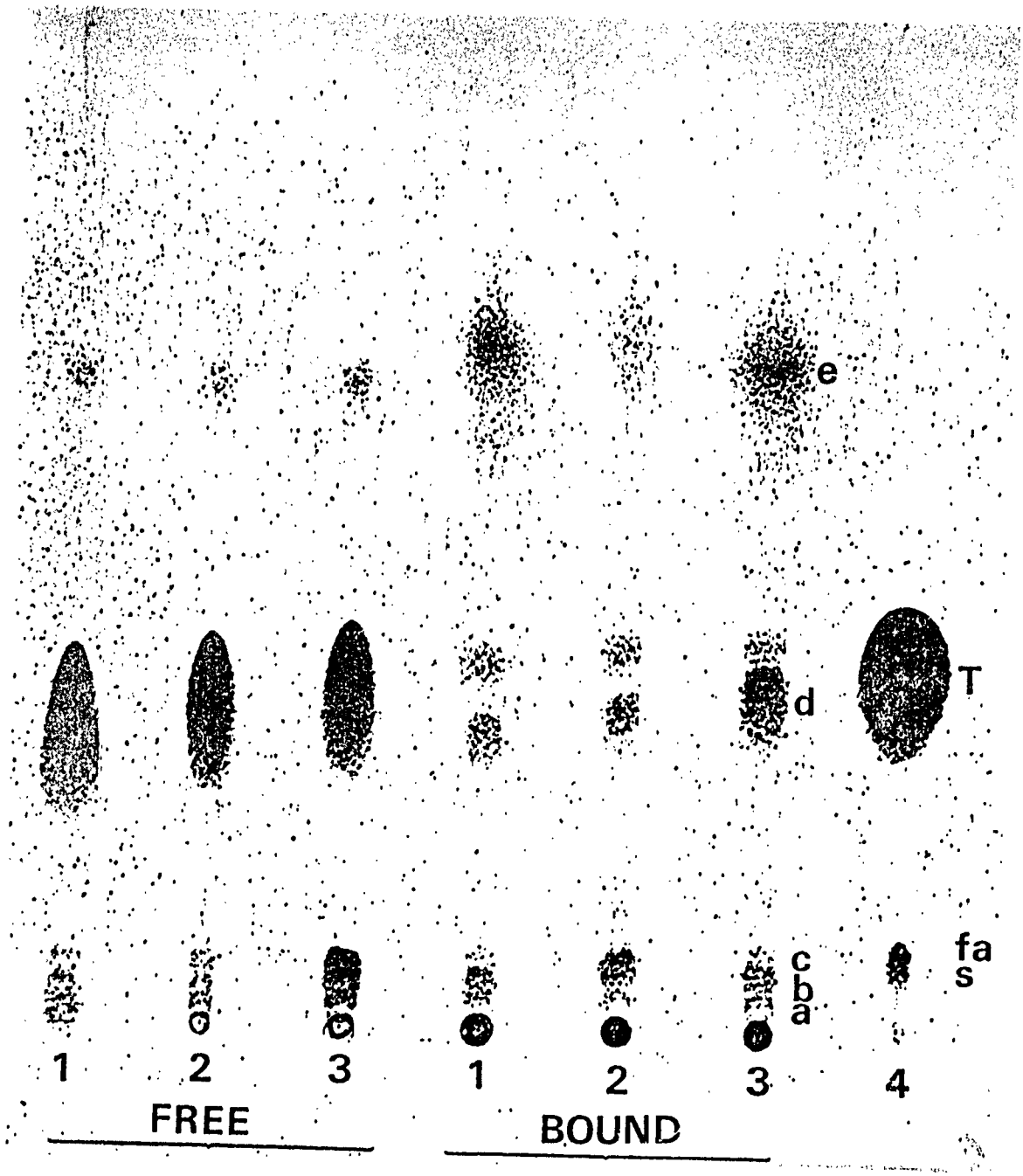


Figure 3. Thin-layer chromatogram of polar components of free and bound lipids from HMP550 (1), RMPI(S)CI (2), and Serere 3A (3). Polar reference standards (4 & 5) are lysophosphatidyl choline (LP), phosphatidyl choline (PC), phosphatidyl ethanolamine (PE), sitosterol (S), cerebrosides (CB) and monogalactosyl diglyceride (MD).

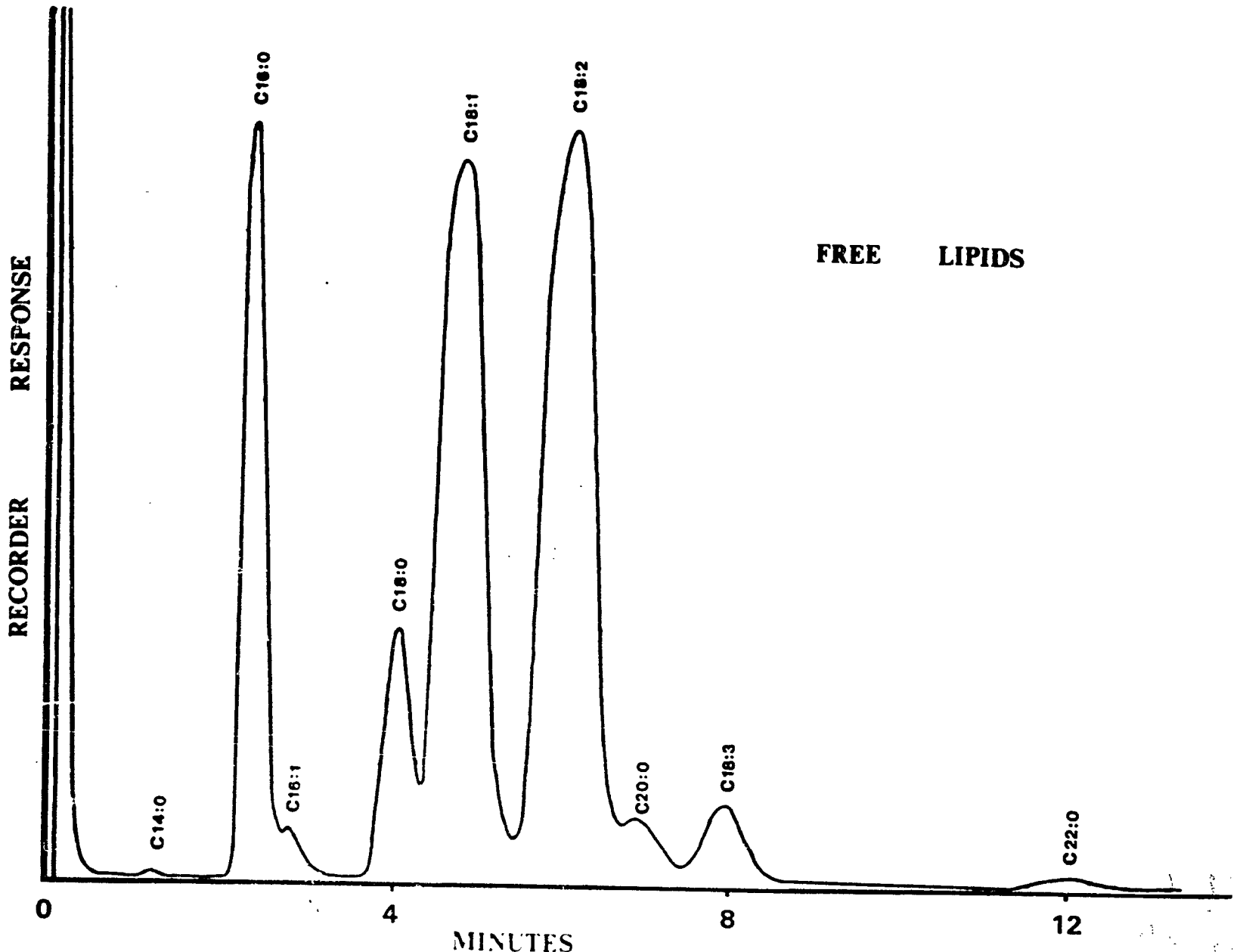


Figure 4. Gas chromatogram of fatty acid methyl esters of the free lipid fraction from pearl millet meal (HMP550).

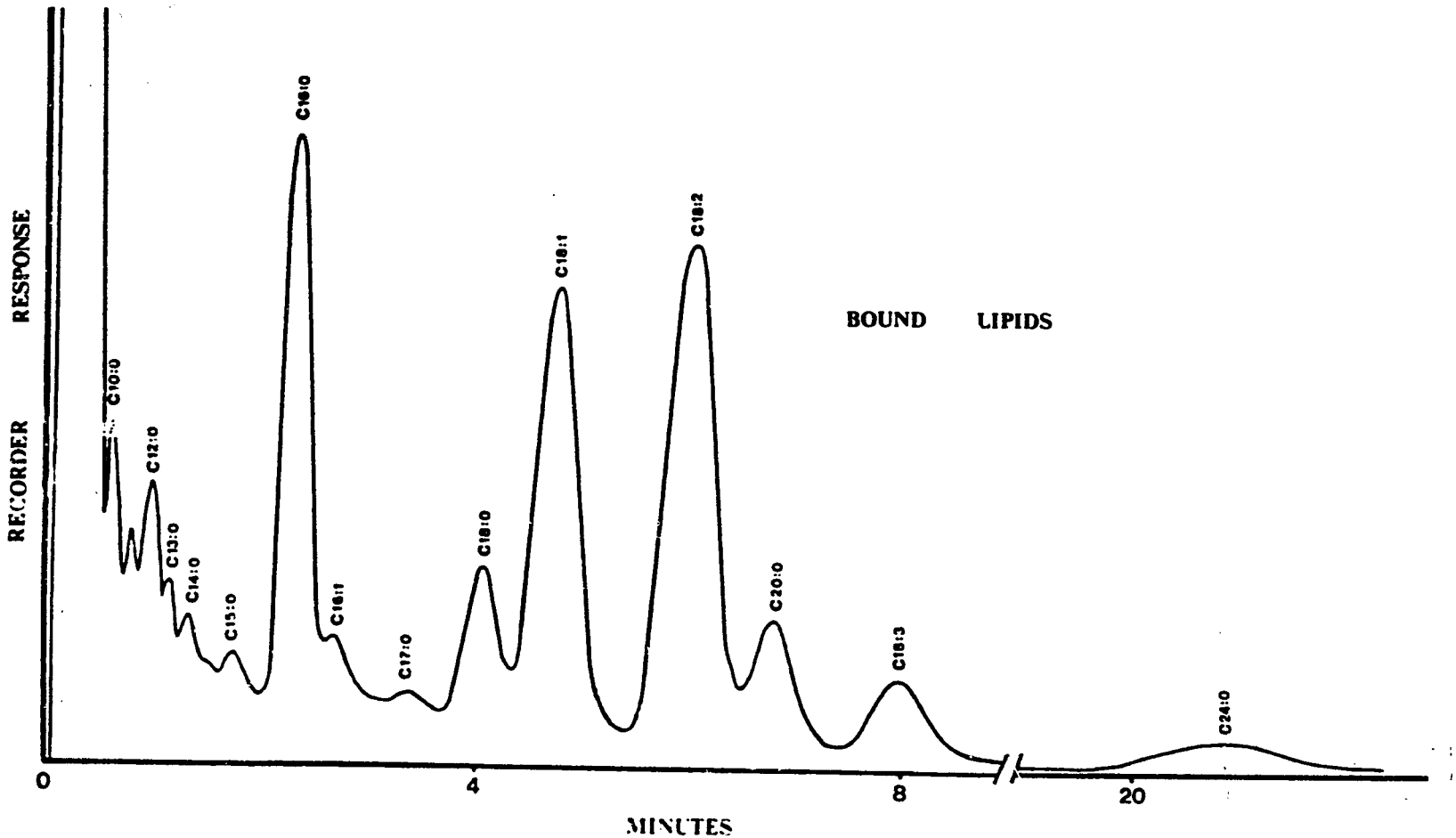


Figure 5. Gas chromatogram of fatty acid methyl esters of the bound lipid fraction from pearl millet meal (HMP550).

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

C. C. Lai and E. Varriano-Marston

A number of traditional and mechanized processes are used to mill pearl millet (Wyss, 1977; Rasper, 1977; Goussault and Adrian, 1977) with extraction rates from about 75% for the SOTRAMIL process (Goussault and Adrian, 1977) to about 85% for wooden-mortar milling. None of the milling processes completely separate the germ from the rest of the kernel, so the lipids in the germ can be adsorbed by the components of the milled products and lower the flour's keeping quality. Based on chemical analyses, Carnovale and Quaglia (1973) suggested that rapid deterioration in quality of pearl millet flour (16.3% moisture) during storage for three months at 30 C stems mainly from hydrolytic rather than oxidative decomposition of lipids. Thiam et al. (1976) stored millet flours for 17 days at 30 C, 50 and 75% relative humidities, and found that microbial growth did not occur, nor did off-flavors or odors. In addition, lipid oxidation was not detected by those authors. Details of the sensory evaluation of stored flours were not reported by Carnovale and Quaglia (1973) or Thiam et al. (1976) so the relationship between chemical and organoleptic changes could not be assessed. Described here are organoleptic evaluations of stored pearl millet meal that correspond to both hydrolytic and oxidative changes in millet lipid components during the first week of storage.

MATERIALS AND METHODS

Materials

We used an HMP550 (Tift 23DB$_1$/*PI185642) random mating bulk pearl millet population from the Branch Experiment Station, Hays, Kansas. The whole grain was ground in an experimental roller mill to pass a 50GG screen. The meal was stored in replicates in cotton bags under the following storage condition: 19 C, 58% R.H.; 27 C, 64% R.H. and 42 C, 75% R.H. After designated storage periods, samples were taken from the bags by a hollow tube probe.

Methods

Moisture content and mold count. Standard AACC methods (1962) were used for the moisture determinations and mold counts.

Sniff test. The sniff test was conducted with seven selected panelists (3 females, 4 males) with previous sensory evaluation experience. They were first acquainted with the aroma characteristics of the fresh and aged millet meal samples, as a frame of reference for future comparisons.

Samples taken at the same time (0, 12, 36, 60, 84, and 108 hr) from the three storage conditions were presented to the panel members in odor-free glass jars. Six coded samples were presented in a random order at each sitting. Panelists were asked to sniff the samples one at a time

and compare them with the reference samples. Results and comments were recorded on a score sheet consisting of the words "Fresh" and "Aged" separated by a horizontal line. The panelists were asked to mark an "X" at the appropriate distance on the line that best described their feelings about the sample. Each sniff test value was derived by measuring the distance in centimeters from the fresh reference point to the point marked by the panelist.

Thin-layer and gas chromatography. Free and bound lipids were extracted, fatty acids were esterified, and methyl esters were determined by gas chromatography. Free lipids from samples stored 0, 60 and 108 hr were also characterized by thin-layer chromatography. Methods for lipid analysis were previously described (Lai and Varriano-Marston 1980).

Fat acidity and peroxide value. Fat acidity was determined by the AOAC rapid method (1960). For peroxide value determinations, 5 g samples were mixed with 50 ml chloroform in a Stein mill for 3 min. The peroxide value of the filtrate was determined by the method of Takagi et al. (1978). Replicate samples for fat acidity and peroxide value determinations were taken at the same time periods as described above for the odor evaluations.

Histology. Millet kernels were soaked in distilled water, and lipase location was determined by the Tween (Bancroft, 1975) and β-naphthyllaurate (Sastry et al., 1977) methods.

Statistical analyses. An analysis of variance was run on the data (Snedecor and Cochran, 1967), and Duncan's (1955) multiple range test was applied to determine significant differences among means.

RESULTS AND DISCUSSION

Mycology

Microflora affects the quality of cereal grains during storage. Fungal growth is often related to increases in fat acidity (Baker et al., 1959), and fungal lipases are responsible for the increases in free fatty acids (Goodman and Christensen, 1952; Dirks et al., 1955), so fungal growth must be determined in all storage studies involving grains.

In microbiological studies of our stored millet meals, the samples contained normal levels of field fungi typically found in cereal grains grown in Kansas. *Alternaria*, *Fusarium*, and *Cladosporium* were the major fungi but the genera *Mucor*, *Phoma*, *Aspergillus*, and *Penicillium* also were identified in small numbers in some samples.

For all storage conditions, mold counts declined the first 6 weeks of storage (Table 1), so fungal growth probably had little effect on quality deterioration in millet meal during the early weeks of storage.

After 9 weeks, only samples stored at 42 C, 75% R.H. showed increased mold counts, with *Penicillium* the predominant species (Table 1). Storage fungi, like *Penicillium*, grow at equilibrium relative humidities of 70 to 90%. Conversely, field fungi require high moisture conditions for growth, and die off rapidly in grains held with moisture contents in equilibrium with relative humidites of 70 to 75% (Lutey and Christensen, 1963).

Sniff Test

Reports from India (Reddy, 1978) suggested that millet could be kept for only a few days after grinding, so we had our panelists do odor evaluations to see if quality deterioration could be detected by panelists during the first 5 days of storage.

During the taste panel orientation, freshly ground millet (FRESH) and millet meal that had been stored at 42 C more than three months (AGED) were studied by the panelists. They described the aroma of the FRESH sample as fresh, green, and sweet, resembling creamed corn; the AGED sample as sour or acidic, musty, and dry and dusty.

Marked disappearance of sweet aromas paralleled the increased appearance of dusty and oxidized characters in the stored samples. In addition, the panel noticed that high temperatures and humidities shortened the time necessary before AGED characters were detected. The olfactory data confirmed significant ($P < 0.01$) changes in the odor response of panelists for samples stored 12 hr. at 42 C, 75% R.H. On the other hand, 60 and 108 hr., respectively, were required before significant odor changes were noted for millet meals stored at 27 C, 64% R.H. and 19 C, 58% R.H.

Thin-layer and Gas Chromatography

Sensory evaluation data indicated that millet meal quality changed early in storage. We wanted to determine if alterations in lipid components were related to those changes.

Thin-layer chromatography of free nonpolar lipids extracted from millet meal stored for up to 108 hr showed progressive increases in free fatty acid and partial glyceride components during storage, indicating hydrolytic breakdown of triacylglycerols.

Changes in pearl millet's fatty acid composition of both free and bound lipids during storage at 42 C, 75% R.H., were determined and are presented in Tables 2 and 3, respectively. Although fatty acid composition did not change qualitatively during storage, quantities of fatty acids changed in both free and bound lipid fractions, more in bound than in free lipids. For example, of the C18 acids, there was a slight increase in oleic and linolenic acids of the free lipid fraction after 108 hr storage (Table 2) while all bound C18 acids decreased during storage (Table 3). Reductions in unsaturated acids of the bound lipids are indicative of oxidative changes.

Fat Acidity

Hydrolytic changes in lipids during storage were also followed by determining fat acidity values. Fat acidity and moisture content of millet meal stored at 42 C, 75% R.H., increased rapidly during the first 108 hours of storage compared to samples stored at 27 C, 63% R.H. or 19 C, 58% R.H. (Fig. 1). The period for detecting odor changes in samples from all storage conditions corresponded to a fat acidity of 30 mg KPH/100g of meal. The high moisture content of samples stored at 42 C may have accelerated development of both fat acidity and objectionable odors.

Peroxide Value

Peroxide values, which indicate oxidative changes in lipids, steadily increased early in storage, reached a maximum, and then gradually declined under all three storage conditions (Fig. 2). However, rates that peroxide values changed differed for each storage treatment. Samples stored at 42 C, 75% R.H., terminated the induction period earlier than those stored at either 27 C, 64% R.H. or 19 C, 58% R.H. For each storage condition, the end of the induction period coincided with the time when panelists first detected an odor change.

Histology

The data show that both hydrolytic and oxidative changes in millet lipid components parallel odor changes panelists observed, so one way to reduce lipid changes during storage would be to remove the major lipid-containing parts of the kernels: the pericarp, aleurone, and germ (Lai and Varriano-Marston, 1980). Decortication studies by De Francisco et al. (1980) indicate that pearl millet pericarp is easily removed but that germ portions remain attached to the kernels. Our histochemical studies on pearl millet kernels indicated that lipase activity was located mainly in the germ, pericarp, and aleurone and subaleurone layers (Fig. 3), so decortication procedures would probably reduce lipid changes during storage, but the germ remaining in decorticated kernels would assure continued oxidative and lipolytic activity.

ACKNOWLEDGMENT

We thank J. F. Caul for assistance in conducting sensory evaluation tests and R. Burroughs for microbiological assistance.

LITERATURE CITED

AACC. 1962. Cereal Laboratory Methods, 7th ed. Amer. Assoc. of Cereal Chemists. St. Paul, Minnesota.

AOAC. 1960. Official Methods of Analysis, 9th ed. Assoc. of Official Agric. Chem. Washington, D.C.

Baker, D., M. H. Neustadt, L. Zeleny. 1959. Relationships between fat acidity values and types of damage in grain. Cereal Chem. 36:308.

Bancroft, J. D. 1975. Histochemical Technique. 2nd ed. Butterworth & Co. Ltd., London.

Carnovale, E. and G. B. Quaglia. 1973. Influence of temperature and humidity controlled storage on the chemical composition of milling products from millet. Ann. Technol. Agric. 22:371.

De Francisco, A., A. Shepherd, R. C. Hoseney, and E. Varriano-Marston. 1980. Kansas State University and USDA Western Regional Research Center. Unpublished results.

Dirks, B. M., P. D. Boyer, and W. F. Geddes. 1955. Some properties of fungal lipases and their significance in stored grain. Cereal Chem. 32:356.

Duncan, D. B. 1955. New Multiple range and Multiple F tests. Biometrics 11:1.

Goodman, J. J. and C. M. Christensen. 1952. Grain storage studies. XI. Lipolytic activity of fungi isolated from stored corn. Cereal Chem. 29:299.

Goussault, B. and J. Adrian. 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. Tropical Products Institute, London.

Lai, C. C. and E. Varriano-Marston. 1980. Lipid composition of pearl millet [*Pennisetum americanum* (L.) Leeke]. Cereal Chem. In press.

Lutey, R. W. and C. M. Christensen. 1963. Influence of moisture content, temperature, and length of storage upon survival of fungi in barley kernels. Phytopath. 53:713.

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 (D.A.V. Dendy, ed.), p. 59. Tropical Products Inst., London.

Reddy, Geeravani. 1978. Home Science College, Hyderabad, India. Personal Communication.

Sastry, B. S., M. Ramakrishna, and M. R. Raghavendra Rao. 1977. Histochemical localization of lipase in the rice grain. J. Food Sci. Tech. (Mysore) 14:273.

Snedecor, G. A. and W. G. Cochran. 1967. Statistical Methods, 6th ed. The Iowa State University Press, Ames, IA.

Takagi, T., Y. Mitsuno, and M. Masumura. 1978. Determination of peroxide value by the colorimetric iodine method with protection of iodide as cadmium complex. Lipids 13:147.

Thiam, A. A., R. Drapron, and D. Richard-Molard. 1976. Causes D'Alteration Des Farines De Mil Et De Sorgh. Ann. Technol. Agric. 25(3):253.

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. Tropical Products Institute, London.

Table I. Mold Counts[1] in Stored Pearl Millet Meal.

Time (Weeks)	Storage condition		
	19 C 58% R.H.	27 C 64% R.H.	42 C 75% R.H.
Fresh	14,800	14,800	14,800
3	10,800	11,250	400
6	10,200	6,100	200
9	10,750	4,100	1,250
12	5,150	3,000	31,800

[1]Number of mold colonies per gram of sample.

Table 2. Changes in Fatty Acid Composition (%) of Free Lipids of Pearl Millet During Storage at 42 C, 75% R.H.[1]

Fatty acid	Storage time, hr.		
	Fresh	60	108
C14:0	trace	0.09	0.08
C16:0	21.56[a]	20.83[a]	19.19[b]
C16:1	0.96[a]	1.19[a]	1.19[a]
C18:0	7.32[a]	7.38[a]	7.82[a]
C18:1	28.20[a]	28.10[a]	29.85[b]
C18:2	38.78[a]	38.21[a]	37.53[a]
C18:3	2.36[a]	3.45[ab]	3.75[b]
C20:0	1.04[a]	0.78[b]	0.61[b]
C22:0	trace	trace	trace

[1]Within each fatty acid, values with different superscripts differ significantly ($P < 0.05$).

Table 3. Changes in Fatty Acid Composition (%) of Bound Lipids of Pearl Millet During Storage at 42 C, 75% R.H.[1]

Fatty acid	Storage Time, Hours		
	Fresh	60	108
C10:0	1.18[a]	7.44[b]	6.41[b]
Unknown	0.85[a]	0.34[a]	0.68[a]
C12:0	1.05[a]	4.28[b]	7.08[b]
C13:0	0.62[a]	0.65[a]	2.20[b]
C14:0	0.42[a]	0.18[a]	0.30[a]
C15:0	0.73[a]	2.60[b]	2.72[b]
C16:0	21.11[a]	21.65[a]	21.19[a]
C16:1	0.96[a]	0.59[b]	0.51[b]
C17:0	0.23[a]	0.52[b]	0.90[c]
C18:0	5.12[a]	3.27[b]	3.23[b]
C18:1	19.49[a]	17.65[a]	15.22[b]
C18:2	29.37[a]	28.08[a]	26.52[b]
C18:3	3.16[a]	2.13[a]	1.32[b]
C20:0	7.81[a]	1.19[b]	0.89[b]
C24:0	7.87[a]	9.38[b]	10.67[b]

[1]Within each fatty acid, values with different superscripts differ significantly ($P < 0.05$).

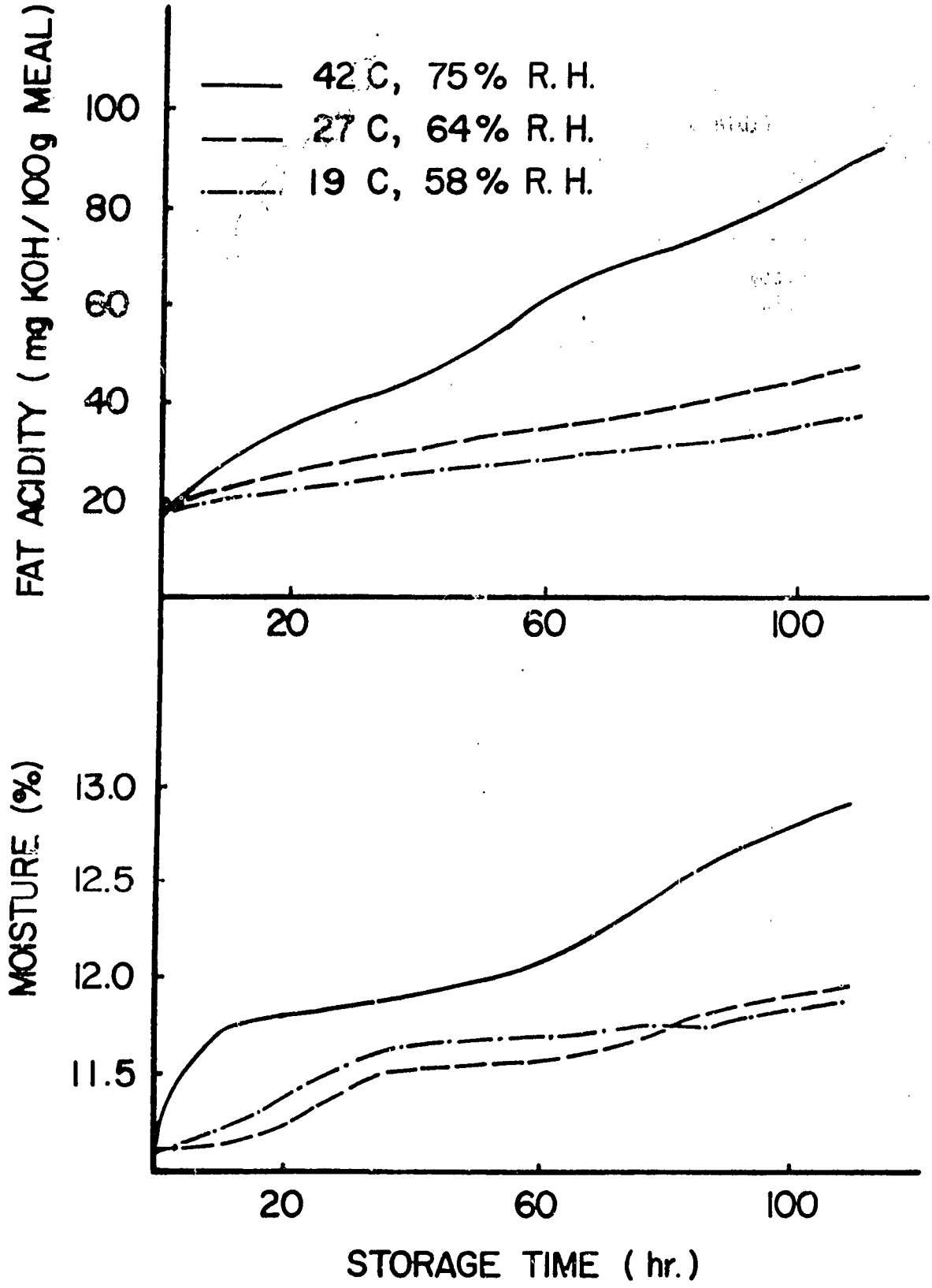


Figure 1. Changes in fat acidities and moisture contents of millet meal during storage.

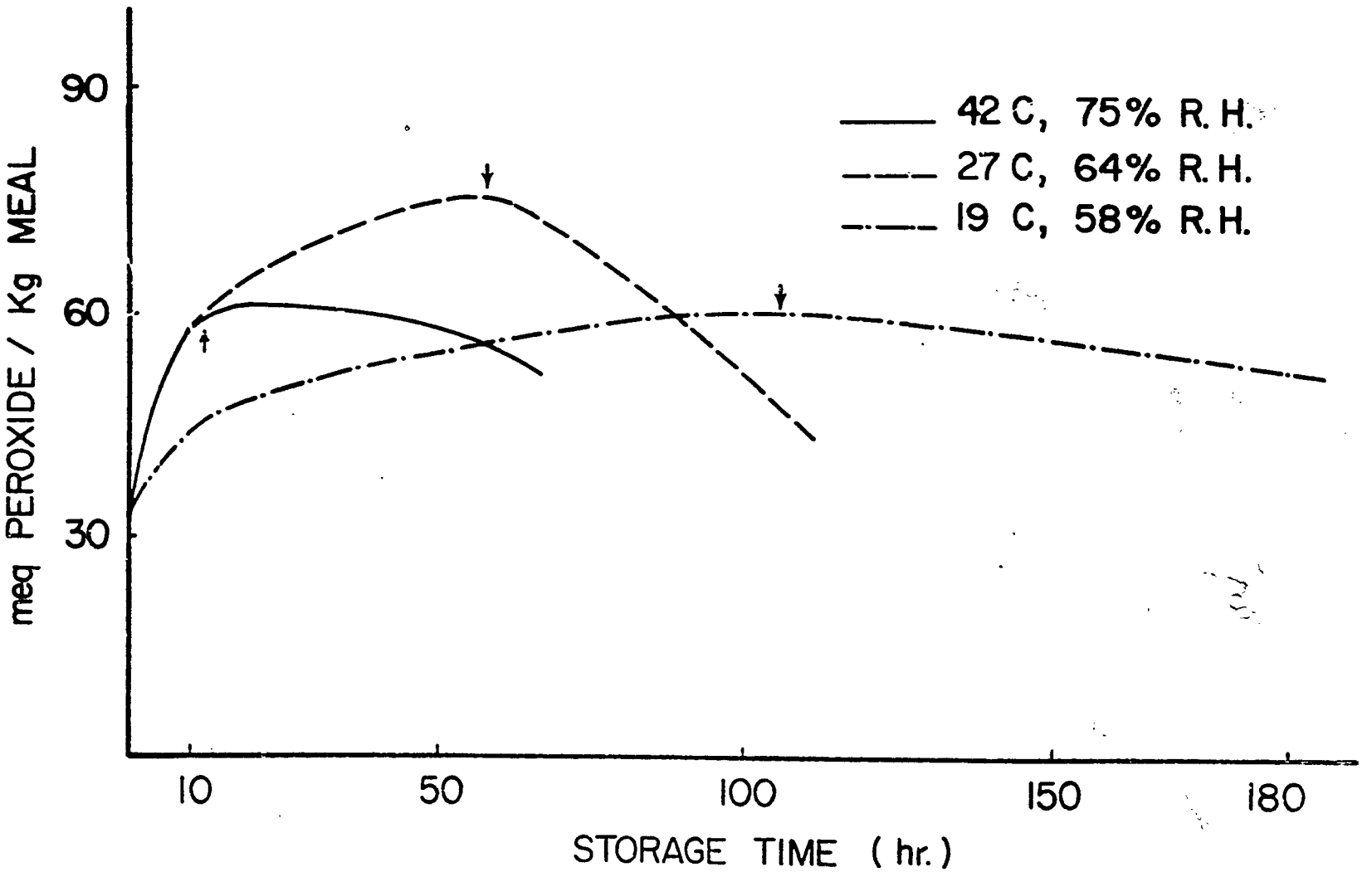


Figure 2. Changes in peroxide values of millet meal during storage. Arrows designate time when panelists first detected an odor change.

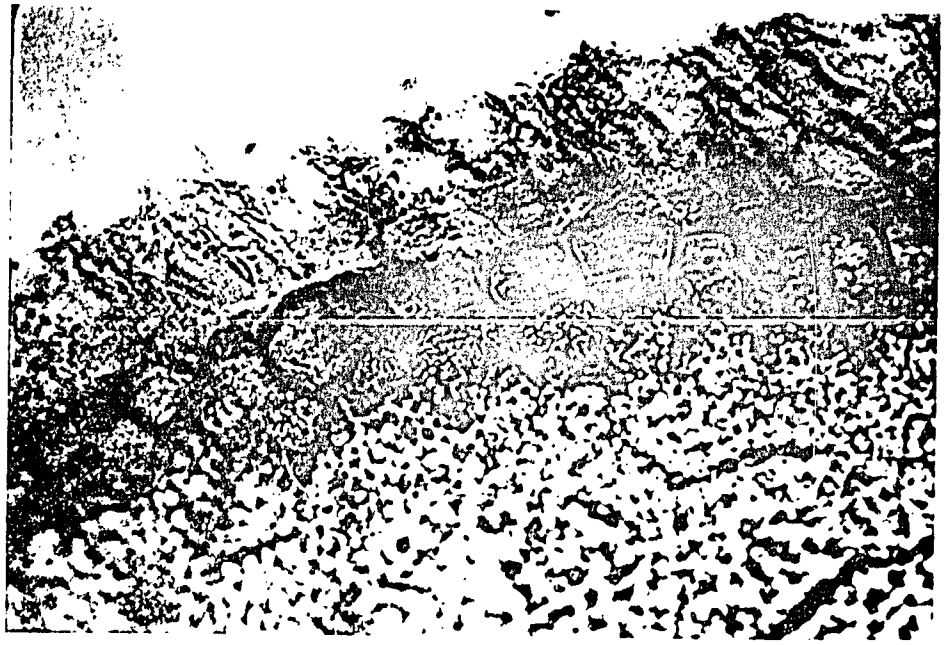


Figure 3. Histochemical location of lipase activity in the pericarp (P), aleurone (A), and sub-aleurone (Sb) layers of pearl millet.

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

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

Using twelve (12) lines of pearl millet grown in Kansas, an initial screening was conducted to determine the relative susceptibility of these lines to insect infestation when the millet was stored in the head or in the threshed form. On-farm storage of millet in the head is the most common form of storage, whereas there is speculation that millet stored in the threshed form might be less susceptible to insect infestation, especially when stored in large bulks.

The three species of insects selected and previously shown to be well adapted to infesting pearl millet were the Angoumois grain moth (*Sitotroga cerealella*), the rice weevil (*Sitophilus oryzae*), and the red flour beetle (*Tribolium castaneum*). These three species represented three general groups of insects that infest cereal grains; an internal infesting moth, and internal infesting beetle, and an external infesting beetle, respectively.

Threshed millet was obtained by hand threshing. Nine 25-gram replicates of each line were placed in small jars and preconditioned in a controlled storage room at 27 ± 1° C and 65 ± 3% RH for one month prior to infestation. Twenty-six unsexed rice weevils and 26 unsexed red flour beetles were placed in each of 3 replicates of the threshed millet. Parent weevils and beetles were between 1 and 2 weeks old. Five Angoumois grain moth adults (3 female, 2 male) less than 24 hours old were placed in the remaining 3 jars of threshed millet.

One head per line per replicate was placed in a quart jar fitted with a filter paper and wire screen lid. The heads were preconditioned in the same manner as the threshed millet. Three replicates of each of the lines were infested at the rate of one insect per gram of seed weight of the head with rice weevils or red flour beetles. One adult Angoumois grain moth per 5 grams of seed weight in a ratio of 3 female to 2 male per replicate was placed in three of the replicates.

Infested samples were maintained in a controlled environment at 27 ± 1° C and 65 ± 3% RH for two months. At the end of this infestation period, the total average insect population per line in threshed and head millet was determined for each species of insect. The results indicate that red flour beetle populations did not increase to any extent in either the threshed or head millet of lines tested. However, the rice weevil and Angoumois grain moth populations did increase in both the threshed and head millet forms of storage.

On the average, rice weevil populations increased to a greater extent in threshed millet when compared to head millet. The Angoumois grain moth, on the other hand, increased to a slightly greater extent on the head millet when compared to the threshed.

Table 1. Average number and range of insects produced in 12 lines of threshed and head forms of pearl millet.

Threshed	Average (all cultivars)	Range
Red Flour Beetle	28/replicate	26-34
Angoumois Grain Moth	81	23-119
Rice Weevil	368	140-542
HEAD		
Red Flour Beetle	25	24-28
Angoumois Grain Moth	102	55-170
Rice Weevil	207	106-526

Certain lines appear to be more resistant to the insects than others and certain lines more susceptible. For example, HMP 550 C_2SO, plot series 23 (1978) appeared, in general, to be somewhat resistant to both rice weevil and Angoumois grain moth in both the threshed and head forms. Line $71\text{-}1^2\text{-}DA_1$ x $MS3A^4$ showed resistance to rice weevils in both the threshed and head form but was susceptible to Angoumois grain moths in both forms of storage. Line PI 307697 (South Africa) appears to be somewhat resistant to both rice weevils and Angoumois grain moths in the threshed form but susceptible in the head form to both species.

Both the threshed and head forms of storage and the resistance/susceptibility factor of various lines of pearl millet studies are continuing.

TABLE 2. NUMBER OF ADULT INSECTS IN 12 PEARL MILLET LINES WHEN INFESTED WITH RICE WEEVIL (RW), RED FLOUR BEETLE (RFB) AND ANGOUMOIS GRAIN MOTH (AGM) AND STORED IN-HEAD VERSUS THRESHED FOR TWO MONTHS.

LINE IDENTIFICATION	AVERAGE NUMBER OF ADULTS PER 25-GRAM SAMPLE					
	THRESHED			IN-HEAD		
	RFB	AGM	RW	RFB	AGM	RW
PI 286864 (Nigeria)	26.0	99.3	350.3	25.0	77.9	136.3
RMP - 1 (5) C_1	26.0	113.0	448.0	26.1	111.4	133.5
$71\text{-}1^2\text{-}DA_1$ x $MS3A^4$, Cross #402	30.3	123.0	333.0	25.1	85.5	189.2
$71\text{-}1^2\text{-}DA_1$ x (3A x 71-2) ($MS3A^2$)	29.0	73.3	292.3	26.4	106.8	129.5
PI 295157 (Rhodesia)	26.7	77.3	537.0	25.3	98.8	526.3
HMP 550 C_2S0, Plot series 23 (1978)	26.7	62.0	140.7	28.0	55.1	128.1
71 x 1^2 x $DA_1{}^2$ x $MS3A^4$ (Note below)	26.0	111.7	362.3	24.5	82.4	396.8
HMP 550 C_2S0, Plot series 21 (1978)	26.0	56.7	456.3	24.9	91.3	157.1
SERERE 3A (Uganda)	26.0	38.3	542.3	25.3	87.7	203.5
PI 307697 (South Africa)	33.6	23.7	289.0	24.9	170.4	214.4
PI 286959	26.0	76.7	346.3	24.4	63.4	160.7
$71\text{-}1^2\text{-}DA_1$ x $MS3A^4$	31.0	119.3	250.3	25.3	169.4	106.3
Total	333.3	974.3	4357.8	305.2	1200.1	2482.1
Average	27.8	81.2	362.7	25.4	100.0	206.8

Note: 71 x 1^2 x $DA_1{}^2$ x $MS3A^4$ (Greenhouse 1977-1978 → 1417 ♀ x 1160 ♂ → Cross #501.

VII. Financial Status

Financial status of the project at the end of the second fiscal year

1 October 1978 - 30 September 1979

Category	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