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INHERITANCE AND IMPROVEMENT OF PROTEIN QUALITY AND CONTENT IN SORGHUM BICOLOR (L.) MOENCH

January 1, 1971 - December 31, 1971

Report No. 8

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REPORT SUMMARY

A. Statistical

1. Project Title: Inheritance and Improvement of Protein Quality and Content in *Sorghum bicolor* (L.) Moench.

2. Contractor and Mailing Address: Purdue Research Foundation
Lafayette, Indiana 47907

3. Principal Investigator: R. C. Pickett, Department of Agronomy

4. Contract Number: AID/csd-1175

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9. Total expenditures through previous contract year: $681,298.41

10. Total expenditures for current year: 4-1-71 through 11-30-71 $176,126.79

11. Estimated expenditures for next contract year: $243,795.00

B. Project Summary

Inheritance investigations to date for protein content and amino acid composition have shown that these are quantitatively inherited with an extremely wide range of levels of each existing in all of the major races of sorghum.

Biological results (rat feeding) have shown great variation related inversely with polyphenol (tannin) content. Variations in protein fractions are being related with these polyphenol levels and rat feeding results.

Over 10,000 sorghum lines from the world collection have been screened at Purdue University and Puerto Rico and a large number of other sorghum breeding sources for protein, yield and phenotypic acceptability in tropical as well as temperate locations. The selections that have been distributed include 500 lines for breeding source materials to 148 locations in 56 countries. These cooperators have selected lines for release and use in breeding nurseries. They are requesting and are being sent additional source materials including segregating populations. An elite set of 20 lines is being released to key U.S. and overseas cooperators to study their responses to location and fertility differences in relation to protein quality, yield and disease and insect resistances. Rat and poultry feeding studies have been based on protein (including fractions), amino acid, and polyphenol (tannins) content in relation to yield potential, environmental interaction, phenotypic acceptabilities and inheritance patterns. These results indicate the strong potential in the present genetic pool for selections and recombinations that will result in higher yields of more nutritious grain sorghum lines for food and feed uses in LDCs. Hybrids are being studied for use where seed production is feasible and for line evaluations and inheritance studies.

Data on chemical composition, inheritance and performance of all selected lines from Purdue University and selected by cooperators around the world is being circulated to the mailing list of 650 sorghum workers for their use in further research work and utilization.

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I. GENERAL BACKGROUND

The need to understand the factors influencing low production of sorghum grain and to identify the inheritance patterns for the development of high quality grain sorghum protein for the improvement of human diets resulted in the initiation of this project in 1966. Sorghum is a major source of food in many lesser developed areas of Africa and Asia. The need for improvement of its protein quality and quantity is of major importance since sorghum is the third most important food crop in the world. As general economic conditions improve in an area, the significance of sorghum as a feed grain for livestock dietary protein production is greatly increased.

Protein is deficient in the diets of many humans today. Protein percentages in sorghum range from under six percent to over 18 percent in various experimental grain types. The average protein in most grain sorghums and other cereal grains in commercial production is ten percent or below.

Protein quality is of major concern along with quantity in human diets and in non-ruminant animal feeding. Certain amino acids such as lysine, threonine, tryptophan, isoleucine, (isoleucine/leucine) and methionine plus cystine must be present in sufficient quantities along with the other essential amino acids, but these tend to be deficient in many of the cereal grains, sorghum included, in use in the world. The amount of variation in certain amino acids is known to be considerable in sorghum, but the inheritance pattern was unknown as was the relationship among the levels of the various amino acids and the total available protein.

II. STATEMENT OF PROJECT OBJECTIVES AS STATED IN THE CONTRACT

This project is designed to find, produce and distribute sorghum lines with the wide environmental adaptation and the best combinations of:

1) protein quantity,
2) grain yield,
3) protein quality (amino acid composition) and
4) grain digestibility.

For maximum potential usefulness over the world a wide diversity of sources are retained with variations in height, seed color, taxonomic group and other characters of interest.

Research objective 1 - to screen for high lysine and nitrogen levels in selected lines from the world collection and various breeding programs in the U.S., Africa and India. Crosses and inbreds from them would also be examined to determine the inheritance pattern.

Research objective 2 - to examine threonine, tryptophan, methionine and isoleucine (high ratio with leucine) contents and determine the complete amino acid distribution on select high lysine lines and recombined lines and hybrids among them. The inheritance of the levels of each will be analyzed.

Research objective 3 - to recombine the lines with highest levels of essential limiting amino acids with highest level protein content possible in high yielding inbred lines and hybrids. The treatment and environmental interactions will be studied on select lines and hybrids.

Research objective 4 - to determine biological or nutritional value of high protein, high quality amino acid selections.

Research objective 5 - to study the chemical nature of proteins on sorghum endosperm and embryo. Sorghum selections with the greatest differences in amino acid composition would also be tested.

Research objective 6 - to systematically disseminate research results in timely manner to all significant sorghum research programs at home and abroad.

Research objective 7 - to distribute and to arrange for effective utilization by sorghum researchers in the developing nations the experimental materials selected for outstanding yield and nutritional quality potential.

Research objective 8 - to encourage investment in sorghum improvement programs in the developing nations and to assist in planning new or expanded research programs.

Research objective 9 - to disseminate to interested workers abroad significant results obtained by other scientists pursuing the improvement of protein quality and quantity in other crops.

Research objective 10 - to develop effective cooperative work, particularly complementary and supplementary studies, with key sorghum research programs around the world.

III. CONTINUED RELEVANCE OF OBJECTIVES

The five objectives as stated in 1966 when the project was initiated and as enlarged to ten in 1969 are still relevant to the implementation of the research for sorghum protein quantity and quality improvement. As the project is being extended for the 1972-77 period the objectives are being rephrased into four research objectives with the utilizations of the research findings being described in the plan of work.

IV. PROGRESS TO DATE

A. Findings and Accomplishments

1. Research objective 1 - to screen for high lysine and nitrogen levels in selected lines from the world collection and various breeding programs in the U.S., Africa and India. Crosses and inbreds from them would also be examined to determine the inheritance pattern.

   a) The classification of lines into races by Drs. Harlan and deWet of the University of Illinois is a useful tool to insure adequate representation of protein sources. (B-14, C-11)*

   b) Over 70 percent of the first 10,000 lines of the India Sorghum (IS) Collection have been grown and analyzed for protein one or more times, identifying lines which differ greatly in protein quantity. (B-22, C-10)

* Indicates appendix section and page number.

c) One or more complete amino acid determinations have been made on over 700 IS lines and over 700 other sources identifying the variation in individual amino acid levels for utilization in inheritance investigations, breeding programs and feeding trials. In addition, several hundred lysine determinations have been completed. (B-22, C-10)

d) Protein levels ranging from 7 - 19 percent in grain samples have been found, lysine values in the range of normal corn have been found, but levels comparable to high lysine corn have not been identified to date. (B-1, B-5, earlier reports)

e) Twenty lines were selected from 500 lines entered in international observation nurseries and Indiana tests. These lines have a wide range of adaptability and a potentially high level of protein quantity and potentially superior quality. They were selected for international yield trials at 15 overseas locations and for entry into further detailed inheritance investigations. (B-5, B-48)

f) One hundred lines, that have not previously been distributed, with high protein quantity and with identified amino acid contents are being selected for distribution to all cooperators for environmental interaction evaluations.

g) Phenotypic characteristics useful for screening purposes to identify protein quantity or quality were not found in the selections included in a diverse sample of 24 male parent lines studied by Bantayehu Gelaw. (A-1)

h) Most of the presently collected items from the accessible major sorghum producing areas of the world are represented in our working inventory. (B-22, C-31)

i) Three-row or larger plots were found to be essential to screen the selected lines and hybrids for reliability and repeatability of protein quantity and quality potentials. Competitive effects in single row plots were found to give excessive variation in the determinations. (B-79)

2. Research objective 2 - to examine threonine, tryptophan, methionine and isoleucine (high ratio with leucine) contents and determine the complete amino acid distribution on select high lysine lines and recombined lines and hybrids among them. The inheritance of the levels of each will be analyzed.

a) The study by race (Harlan and deWet) of over 400 complete amino acid determinations from selections grown over a six year period from various locations showed the frequency of the races selected, the range of protein and the range of individual amino acids for each race. The continued classification by race will be a useful tool in planning inheritance studies. Complete amino acid analyses have been summarized for all that have been run on high protein selections from both collection and breeding sources. (B-14,B-22)

b) The variability of protein and amino acid content of the endosperm contributed greatly to the whole seed variability. The embryo portion of the lines selected contained significantly

higher amounts of protein than the endosperm. The embryo also contains a significantly improved amino acid profile when compared to the endosperm. (B-43)

c) The percent oil in the whole seed is highly correlated with the percent protein in the whole seed. The percent protein in the embryo is nearly double the percent in the endosperm. Some amino acids such as lysine have a higher content in the embryo as compared to endosperm portions of the seed. Other amino acids such as leucine have a much higher percent in the endosperm portion of the grain. Selection for percent oil (embryo size) will tend to increase the content of some amino acids such as lysine and decrease the content of other amino acids such as leucine in the grain. There was noted a significant variation in endosperm percent protein. There was a significant difference in most amino acid percentages found between the embryo and endosperm. (B-43)

d) Correlations among essential amino acids were generally positive. Few negative correlations were found among the amino acids studied by Bantayehu Gelaw from 24 parents and their 72 hybrids. The yield of grain and percent protein were significantly and negatively correlated in the lines ($r = -.414^{**}$) and in the hybrids ($r = -.254^{*}$). Grain yield and percent lysine in protein were not significantly correlated in the parents nor in the hybrids. (A-1, B-63)

3. Research objective 3 - to recombine the lines with highest levels of essential limiting amino acids with highest level protein content possible in high yielding inbred lines and hybrids. The treatment and environmental interactions will be studied on select lines and hybrids.

   a) The magnitudes of error variance and coefficients of variability have indicated that three-row plots are required to insure adequate sampling for yield and protein determinations. Remnant seed from these plots is useful to adequately maintain seed inventories at a very small cost. (B-79, B-54)

   b) Twenty lines selected for yield potential, environmental adaptability and protein quality from 500 lines observed in international locations and tested at three Indiana locations are being entered into detailed inheritance studies and random mating population development. (B-48)

   c) The soft starch ("opaque") lines studied to date indicate a normal distribution of protein amount and quality, thus this character has not been useful as studied to date, as in *Zea mays*. (B-61)

   d) Bagging and flag leaf removal significantly decreased yield and increased percent protein, 100 seed weight, and methionine as a percent of protein. Other amino acid percentages were not significantly altered but were either increased or decreased slightly in almost every case. These findings indicate the necessity for sampling from several open pollinated panicles

for use in all quality determinations and yield estimates. (B-53)

e) The percent crude protein, lysine as percent of sample and seed weight decreases from top to bottom of panicles while percent oil increases. This indicates the need for consistent uniform panicle sampling procedures to minimize experimental error. (B-58)

f) Preliminary results from four inbred lines and four hybrids with above average yields of grain indicate a positive correlation between plant crude protein at an early vegetative stage of plant development and grain crude protein at maturity. (B-36)

g) Environmental studies in 1970 at six locations showed a significant genotype by environmental interaction for percent crude protein, protein yield, grain yield, percent lysine of sample and percent oil. The size and nature of interactions from the combined 1970 and 1971 results will be indicative of further types of inheritance parameter studies required and the way breeding materials should be released to LDCs. (B-72)

h) A high protein, high lysine restorer (R-line) population and a high protein, high lysine non-restorer (B-line) population were initiated using "Coes $\underline{ms}_3$" (male sterile gene) and selections of additional elite lines for entry into the random mating populations were made. (B-75)

i) Analysis was completed on "An Investigation of the Transmission of Protein, Lysine, Oil and Certain Other Characteristics from Sudangrass Lines to Cultivated Grain Sorghum", a study by Sam Mukuru. Sudangrass pollinator lines had significantly

more panicles per plot, higher percent protein and oil than grain sorghum male parent lines. However, sudangrass lines were significantly less than grain sorghums in grain yield, weight per 100 seeds and percent lysine. The superiority or inferiority of sudangrass for most traits was transmitted and maintained in their offspring. (A-21)

j) The analysis of the study by Bantayehu Gelaw was completed on "Relationships of Certain Morphological Characteristics with Grain Yield and Quality of Phenotypically Diverse Lines and Hybrids in Sorghum bicolor (L.) Moench". Significant variations were: early vigor, days to 50% flowering, leaf number, flag leaf length, flag leaf width, flag leaf area, length of third leaf from the top, width of third leaf, area of third leaf, plant height, stem diameter, head exertion, panicle length, tillering, lodging, number of heads per plot, threshing percent, grain yield, percent protein (non-defatted), percent protein (fat-free), percent lysine and percent oil. The results of the combining ability analysis of variance of the 72 F_1 hybrids indicated that GCA (general combining ability) was predominate to SCA (specific combining ability) for almost all the characters studied. Heterosis over the better parent ranged from -36.10 to 39.04 percent for grain yield. The range of heterosis for percent protein was from -31.34 to 15.20 percent while that for lysine was -16.28 to 30.88 percent. The heterosis values for oil ranged from -23.35 to 7.23 percent. (A-1)

k) Selections based on seed size, yield, seed color (polyphenols), height and other desirable characteristics were made in 28 bulk populations. (B-75)

l) Individual plant selections from hand emasculated crosses between lines selected for high protein quantity and quality were made in F_2 and F_3 generations. These selections will be used for the study of inheritance patterns and the first distribution to LDCs of segregating material selected for nutritional quality. (B-75)

m) Yield and quality evaluations on 30 F_1's and their parents are being completed on selected high quality lines and their hybrids from hot water emasculations. (B-75)

n) Lines identified as flowering or non-flowering in the high night temperature greenhouse and their Redlan hybrids gave the same response in 1971 as in 1970. (B-62)

o) Data is being accumulated on yield and quality variability found among parents and their F_1 and F_2 generations from 1971 trials. (B-75)

p) A second year's data related to plant population density in relation to tillering, grain yield, protein amount and quality, seed size and panicle size is being analyzed.

q) 1971 data related to canopy structure of height mixtures based on 1970 results studied by Dr. Raymond Bula of the Purdue University Agronomy Department are being analyzed in relation to environmental factors influencing sorghum protein yield. (B-23)

r) Data from trials to measure hybrid response to high population and high fertility are being analyzed.

4. Research objective 4 - to determine biological or nutritional value of high protein, high quality amino acid selections.

a) Based on previous quality studies over 40 entries were increased to amounts sufficient to initiate replicated rat and chick digestibility trials. Fractionation and structural studies are also now possible on these elite selections. (B-34)

b) Polyphenol contents (tannins) have high negative correlations with *in vitro* dry matter disappearance percentages (r^2 = .72, r^2 = .93 and r^2 = .81 from three studies) and weight gain of rats (r = -.502). The latter is biased upward due to methods used for selecting feeding samples. (B-81)

c) The use of only protein amount and amino acid content of samples, without consideration of polyphenol content is unreliable for rat or chick growth predictions. Therefore, polyphenolic level of all samples are being determined as an additional criterion of selection for feeding trials. (B-81, B-6)

d) Variations in amino acid levels in chick blood plasma were inversely related to amounts of polyphenols in grain fed, indicating uptake or assimilation rate differences associated with amounts of polyphenols found in grain samples. Rates of gain and feed efficiency were adversely influenced by feeding grains high in polyphenols or by addition of tannic acid to

chick rations. In other work done by the Purdue University Animal Science Department, supplementation of a diet high in polyphenols with individual amino acids to the level found in corn, overcame a large part of the poor growth rate found when supplemented only with soybean oil meal. (B-6)

e) Silage samples with variable polyphenol contents harvested from the 1970 crop were fed by Dr. Victor Lechtenberg of the Purdue University Agronomy Department to yearling wethers. Data collected support the premises that the process of ensiling inactivates the adverse influences of high polyphenols on sheep performance. (B-19)

f) Numerous polyphenol determinations measured in catechin equivalents/100 g dry weight have been completed. These evaluations are being used to identify samples low in polyphenols to select potentially highly digestible grain samples for rat growth trials and other biological tests. (B-6, B-53, B-81, B-86)

g) Data from work coordinated with the Animal Science Department indicates the necessity for sorghum grain rations to contain less than 1.0 percent polyphenol in order to produce chick weight gains comparable to normal corn. (B-6)

h) Cooking grain sorghum samples containing high levels of polyphenols did not improve the rate of weight gain for rats and autoclaving did not improve the weight gain of chicks. Work completed to date showed cooking to actually decrease the rate of gain for rats. (B-32, B-6)

5. Research objective 5 - to study the chemical nature of proteins in sorghum endosperm and embryo. Sorghum selections with the greatest differences in amino acid composition would also be tested.

   a) Sorghum proteins were separated into five fractions using the Landry and Moureaux procedure. The distribution of the nitrogen in the five fractions is variable, with fractions I and V being inversely related for nutritionally good and poor samples respectively of sorghum grain. The polyphenols (tannins) apparently influence the fractionation of sorghum proteins. From this work, the techniques of protein fractionation need to be evaluated for high and low polyphenol samples. (B-25)

   b) Grain samples were supplied to the USDA Chemical Reactions and Structure Investigations Cereal Properties Laboratory at Peoria, Illinois for examination. Microscopic examinations did not reveal distinguishing structural characteristics that could be related to the sample differences in digestibility of protein by chicks. Analysis for percent alcohol-soluble protein and percent amylose showed no correlations with digestibility. One sample (IS6992) with above average lysine content was observed histologically to have smaller than normal size protein bodies. (B-17)

   c) See 2.(c) for amino acid distribution of the embryo and endosperm. (B-43)

6. Research objective 6 - to systematically disseminate research results in timely manner to all significant sorghum research programs at home and abroad.

   a) Printouts of the first 12,250 IS Collection items with the place of origin are available and were supplied to those who requested them. (C-9)

   b) Summarized data have been sent to all cooperators as reported in annual reports and in reply to direct requests.

   c) Field data such as days to flower, height, yield potential, sensitivity to day length and temperature, restoration and laboratory analysis on all lines and hybrids grown in Indiana and Puerto Rico are available for one or more years. Included are protein yield, percent oil, amino acid content and rat or chick performance data on selected lines and hybrids.

   d) Data received from seed distributions are available and are being summarized for cooperator utilization in selecting their breeding materials and our identification of environmentally stable entries. (B-5)

   e) A sorghum field day was conducted for sorghum workers at Lafayette. This was attended by over 100 people representing personnel in most current sorghum breeding activities from three foreign countries and nine U.S. states. (C-12)

   f) The project personnel participated in the Purdue University Agronomy Farm Field Day for Indiana farmers where over 1,500

were in attendance. Personnel have participated in other Indiana farm field days and extension agent training sessions throughout the year. (C-27)

7. Research objective 7 - to distribute and to arrange for effective utilization by sorghum researchers in the developing countries the experimental materials selected for outstanding yield and nutritional quality potential.

   a) A new selection of 100 high protein lines with above average protein yield potential representing a wide array of phenotypic diversity for breeding materials was distributed to over 100 cooperators in 56 countries. Data has been returned from earlier distributions by 24 cooperators to date with many cooperators left to harvest their growouts. (C-29)

   b) Another selection of an additional set of high protein lines with a high yield potential was selected for distribution from 1971 field and laboratory data. This breeding source selection will include highly selected segregating materials for the first time.

   c) Twenty high yielding lines selected from international observation nurseries and Indiana yield trials have been entered into replicated yield trials. Distribution to 15 cooperators overseas was made. These locations have been carefully chosen to allow for fertility and environmental variations and to insure a good probability for effective management and data collection. These selections will be evaluated at selected locations for insect and disease resistance. (B-48)

8. Research objective 8 - to encourage investment in sorghum improvement programs in the developing nations and to assist in planning new or expanded research programs.

a) In April 1971 the project director worked with the University of Puerto Rico Agricultural Experiment Station Director and his representative to draw up a project for Puerto Rico on sorghum improvement. This project was designed to work on a year-round evaluation and breeding program for tropical sorghum development and to supplement and complement projects at Purdue University, the University of Nebraska Project on Sorghum Physiology, the program by USDA and the Texas Agricultural Experiment Station on sorghum conversion (tropical to temperate), and related work. (C-21)

b) The workshop planned for sorghum workers in Brasil and surrounding countries was initiated. A tentative plan was critically reviewed by AID/Washington, AID/Brasil, the Ford Foundation in Brasil and the Brasilian Ministry of Agriculture. This Ministry agreed to be the host for the workshop now planned for mid-1972. The conference plan and proposed list of invitees is in the appendix. This conference is an outgrowth of considerable encouragement by this project over the last five years to new sorghum improvement programs in Fortaleza, Recife (new phase), Cruz das Almas, Viçosa, Matão (new phase), Sementes Agroceres in São Paulo, as well as Venezuela, Colombia, Ecuador, Peru,

Bolivia, Chile, Argentina (protein investigations by government programs and commercial companies) and preliminary trials in Uruguay, Paraguay and Guyana. (C-15)

c) As a result of providing source materials, management suggestions, and continued research planning, new inputs were made into sorghum testing and improvement programs in Nicaragua, Costa Rica, Guatemala, Dominican Republic and Jamaica.

d) Additional sorghum collections were requested and are being made in Mali and Korea.

e) Additional research on protein improvement in sorghum was encouraged in India through providing amino acid analyses to a student working on an inheritance study with the All-India sorghum scheme and participation in the International Sorghum Conference in October 1971 at Hyderabad, India.

f) Other sorghum protein research was begun at Hissar, Ludhiana, Pantnagar and Jabalpur in India through providing source materials and research planning for dual purpose fodder and grain types. If successful these could replace a large acreage of the fodder types in North India that now produce no grain.

g) Sorghum research expansion was aided through seed materials sent, correspondence, and research planning for programs in Korea, Japan, Indonesia (Sumatra), Thailand, Ethiopia, Mali, Upper Volta, Senegal, Uganda, Nigeria, Ghana, Turkey, Pakistan, Afghanistan, Congo, Sudan, South Africa, Cameroons, Australia and the Philippines.

9. Research objective 9 - to disseminate to interested workers abroad significant results obtained by other scientists pursuing the improvement of protein quality and quantity in other crops.

   a) Consultation was continued with the staff concerned with grain protein improvement on rice at IRRI, wheat and maize at CIMMYT, wheat and sorghum at Nebraska, and maize at Purdue, as well as portions of work at Texas, Arizona, Kansas, Alabama, Georgia and other experiment stations. Considerable encouragement was given to various experiment stations to invest further in grain protein improvement on these major cereals as well as the grain legumes, root and tuber crops and millets (*Pennisetum typhoides* primarily) in addition to sorghum. Visits were held at several major meetings in the U.S. where workers convened and at IRRI.

   b) Some of the findings in sorghum on the variability in embryo size and composition with very high protein levels and excellent amino acid composition have led to increased investigations of this in other cereals.

   c) The environmental interactions with protein on other cereals have been very helpful in designing the sorghum trials in various countries.

   d) Biological testing procedures using voles, mice, and rats with various cereals have also been very helpful in designing evaluation procedures for sorghum.

10. Research objective 10 - to develop effective cooperative work, particularly complementary and supplementary studies with key sorghum research programs.

a) This objective was worked on this year primarily by visiting the All-India Coordinated Program and the World Sorghum Conference in Hyderabad, India which was attended by workers from all key locations in Africa, Asia and the U.S. Consultations were held individually with the key leaders to determine what the limiting factors were on studies affecting sorghum grain protein improvement. Individual seed requests were taken and plans laid for the first yield trials of high protein lines to be distributed in 1972. (B-48)

b) Correspondence, seed distribution to cooperators and planning with visiting scientists made up the program for South America in 1971. Plans were laid for a sorghum workers workshop for key workers in South America to be held in Brasil in 1972. (C-15,16)

c) Data was received and is being processed from all key cooperators.

d) A meeting was held in June in Urbana, Illinois with the World Sorghum Germplasm Committee with Dr. J. R. Harlan as chairman. This committee's work and the new "Classification of the Races of Sorghum" will be distributed to all cooperators. (C-11)

B. Significance of Findings.

The correlation of polyphenol content with rat weight gains made possible the use of this test (Vanillin HCl catechin equivalent) to screen high protein quantity and quality samples to nominate select lines for feeding tests. The significant shifts noted in protein fractions (using the Landry and Moureaux procedure) that appear related to rat weight gains, merits a detailed and wider investigation as a tool to help explain the nature of the effects of the polyphenols and other factors on nutritional values of sorghum grains. (B-81, B-25, B-86)

The differences in levels and correlations of plant vegetative crude protein contents to ultimate grain crude protein contents will be investigated further. This may provide a way to identify high protein plants in segregating and non-segregating populations for early identification of potential plant selections for mass selection for improved protein, inheritance studies, and hybrid development. (B-36)

The supplementation of chick rations with selected amino acids and soybean oil meal resulted in favorable growth response in the presence of high levels of polyphenols in the grain sorghum. This strengthens the need for continuing investigations toward amino acid balance and the interaction of polyphenols with individual amino acids when combined in diets. (B-6)

The data and seed inventories now available are sufficient to insure an opportunity for a comprehensive selection regarding origin, race, phenotypes and quality for population, mutation, selected breeding

and inheritance programs. This can insure a more comprehensive estimation of protein inheritance parameters and quality improvement procedures.

Studies conducted since the initiation of this project include the measurement of variability in protein amount and quality induced by height of adjacent row, plant populations, genotype by environment interaction, maturity, sampling position from a panicle and bagging treatments. These have resulted in more repeatable sampling procedures which include increased plot size, sorting into height groups and sampling of a minimum of ten panicles from competitive plants for all chemical and biological evaluations.

Indiana locations are useful for inheritance studies and for selecting high quality breeding materials to be subjected to insect damage, disease infection and other stress environments. Lines selected from the Indiana locations have positively correlated with selections made at international locations indicating that selections made in Indiana have a relatively wide range of adaptation and can indicate potential production levels due to the low levels of disease and insect stress during the normal Indiana growing season. (B-1, B-48)

C. Side Effects.

The utilization of remnant seed from plots large enough to insure reliable protein quantity and quality estimates has provided a seed inventory useful for readily supplying selected and source

breeding materials to plant breeders.

Selections from lines distributed by this project have been utilized by breeders and released in their areas. This has resulted in an immediate economical response in many LDCs and other areas of the world. (C-6)

The observations of work conducted at Purdue University and sorghum management suggestions were utilized extensively by Indiana farmers in 1971 when sorghum acreage increased 150 percent. (C-27)

Nurseries have been available to plant breeders to visit to identify forage qualities such as a counterpart for the brown midrib mutant (with low lignin and higher digestibility) of corn.

In 1971, U.S. breeders and related persons were given the opportunity to observe many selections from the world collection under relatively unstressed climatic conditions at Purdue University. Many lines had high yield performance and maximum height expression. (C-12)

Classification according to race (Harlan and deWet), using panicles supplied by this project, should result in the isolation of several hundred lines representing the variability of cultivated grain sorghums. (C-11)

D. Significant Modifications Made in Research Design.

The previous years' extensive data and seed supply resulted in an increased utilization of the Animal Science Department by increasing the emphasis on biological quality evaluations by use of rats, chicks

and laboratory procedure correlations and development.

Comparison of in vitro dry matter disappearance, polyphenol variations as measured by catechin equivalents, amino acid supplementation, and fractionation of protein of samples showing good and poor rat gains were possible on selections made from lines and hybrids for a more adequate sampling of the potential genetic pool.

Yield estimates of entries being evaluated for improved protein are obtained so that selections can be made on protein yield as well as protein percent.(B-51)

Plot size was increased to a minimum length of fifteen feet with three rows per plot for each height and maturity group entry. This procedure increased repeatability for chemical and biological evaluations by reducing border effects and providing sufficent amounts of seed for biological evaluations. (B-79)

E. Suggested Modifications.

The original design of the project is still valid and a sharpening of the techniques to accomplish the objectives more readily might be done by:

a) Making additional intercrosses among lines which are superior in content of one or more essential amino acids.

b) Utilization of the race identification system to insure variation in crossing block entry selection and to attempt to associate patterns of protein inheritance to races or origin.

c) Utilizing polyphenol levels in grains in conjunction with protein quantity and quality for biological testing.

d) Utilizing protein fractionation techniques to identify shifts in protein fractions as influenced by polyphenols or changes in quality genes.

e) Utilization of panicle branches to speed sample verification, race identification and some phenotypic selection for grain characters.

f) Utilization of adequate seed inventory records and storage to increase efficiency of seed quality maintenance and processing procedures.

g) The expansion of computerization processes to produce field books and the complete accessibility to past and current data for planning and distribution of data has been augmented by assignment of a post-doctorate position to full time responsiblities in this area.

h) Selection of verified protein quality lines with significant economic potential for inheritance studies, mutation induction and identification, random mating population establishment and genetic by environmental interaction studies can proceed more rapidly to describe the sorghum inheritance patterns involved and to develop higher levels of sorghum protein production and utilization.

V. DISSEMINATION AND UTILIZATION OF RESEARCH RESULTS

A. Efforts Made to Disseminate Results.

The seventh annual report was completed and distributed to all cooperators. The summaries of data related to origin, chemical analysis and field data have been more nearly completed and segments requested have been provided to interested cooperators. The following seminars and conferences were participated in by the project director with resulting summaries and publications.

a) Sorghum Breeding for Improved Protein Content, Amino Acid Composition, Yield and Digestibility. AID Workshop on Improving the Nutritional Quality of Cereals Through Breeding and Fortification. December 1970 at Annapolis, Maryland.

b) Sorghum Management and Improvement. University of Kentucky staff seminar. January 1971 at Lexington, Kentucky.

c) Lecture and discussion on "Inheritance and Improvement of Protein Quality and Content in Sorghum bicolor (L.) Moench" at a seminar on Progress in Developing High-Protein Sorghum Cultivars for the LDCs. March 1971 at Washington, D. C.

d) Sorghum Protein Quantity and Quality Inheritance and Improvement Project. Workshop on Developing an International Improvement Program on Sorghum and Millets. April 1971 at Washington, D. C.

e) Sorghum Nutritional Quality Improvement. International Sorghum Conference. October 1971 at Hyderabad, India.

B. Evidence That Findings of This Project Are Being Used in Both LDCs and the U.S.A.

Seed sent to cooperators to date has been almost exclusively materials used as sources of lines for breeding nurseries. Some few lines have been increased directly as varieties for increase and testing. These include four varieties in Sumatra, Indonesia and one released named ("ICA-Marupaanste") variety in Colombia. The primary use of seeds distributed is that of selecting the lines that show adaptation, necessary resistances, and superior yield potential for use by cooperators in breeding programs. Where the program can, they analyze for protein level themselves, while almost all amino acid analyses are done on seed sent back to Purdue along with nitrogen and oil determinations where requested. In some cases where many seed lots were returned for analysis (eg. 100 or more) nitrogen was determined first and only the superior ones submitted for the more expensive complete amino acid analyses.

The mailing list of over 650 persons has grown significantly in 1971 with many names and addresses being changed. There are many on the list who want the Purdue University research results only and do not receive seed. This information distribution is a distinct and significant function of this project.

A seed distribution list is maintained of what seed is sent to each cooperator each year and when information and seed for analysis is returned.

In 1971 for the first time 100 high protein lines were yield tested and 20 selected for protein yield tests with about 20 key cooperators in the U.S., South America, Africa and Asia. These tests have been specifically requested by each key cooperator.

C. New or More Effective Ways to Expand the Use of Research Results.

Workshops were planned in the 1971 budget for the first time. Plans were developed during the year for a workshop for sorghum workers in Brasil and other countries in South and Central America. This is now tentatively planned for June 1972. Another workshop for Southeast Asia in the fall of 1972 is in early stages of preparation.

An International Agriculture Publications Series is tentatively planned for Purdue University's work on corn and sorghum. This would give a much wider worldwide distribution of certain classes of information to interdisciplinary groups.

More frequent reports are envisioned in the form of completed studies as they are analyzed. Separate distribution will be given to research workers for studies that stand alone. Many will be submitted to research journals but others will be distributed ahead of this as "preliminary reports - not for publication."

VI. STATEMENT OF EXPENDITURES AND CONTRACTOR RESOURCES

A. Project Expenditures to Date.

Contract AID/csd-1175 entitled "Inheritance and Improvement of Protein Quality and Content in Sorghum bicolor (L.) Moench". Project Director, R.C. Pickett.

Budget Catgories	Accumulated Obligation Prior Years of Project to end of FY-70	Past year (FY-71) Budget from 4-1-71 3-31-72	Total Actual Expenditures as of 11-30-71	Estimated Expenditures thru end of funding period
1. Salaries	261,625.00	99,800.00	68,824.06	30,941.96
2. Contract Services	133,730.00	36,500.00	26,485.50	5,000.00
3. Allowances	11,987.00	5,300.00	2,582.01	1,800.00
4. Travel	32,154.00	5,000.00	3,599.47	1,500.00
5. Material and Supplies	48,462.00	11,000.00	11,619.32	2,866.07
6. Overhead	144,379.00	59,580.00	47,451.01	18,565.18
7. Fees (Workshops, Seminars)		5,000.00	-	3,000.00
8. Other Direct Costs				
(Computer Services)	1,639.00	2,000.00	549.94	200.00
(Winter Nursery)	13,600.00	6,820.00	5,122.85	-
9. Non-expendable equipment	45,526.00	9,000.00	9,892.63	-
Totals	693,102.00	240,000.00	176,126.79	63,873.21

B. Significant Problems and Accomplishments in the Progress of the Project.

The most serious physical problem which evolved during this year has been the lack of a work area and temporary storage space adjacent to the seed storage building. The volume of seed in inventory and the need to sample large volumes of seed from the inventory for chemical testing, planting, biological evaluation and distribution has made the present work space inadequate for these procedures. The provision of work space by an additional structure attached to the present building is essential for an efficient operation.

The problems of planning in advance for travel outside the U.S. have been complicated by present procedures required for travel approval. Communications with people being visited or the establishment of contacts for workshops continues to be complicated without personal contacts well in advance of training sessions.

The earlier availability of a relatively narrow sorghum genetic base for use related to inheritance of quality and genotype by environment interaction studies has resulted in contradictory and a limited amount of research data. The distribution of the world collection has been very recent, but its total distribution is inconsistent and incomplete. Current developments would point to the release of numerous new lines and hybrids (such as yellow endosperm types) which are of interest to United States producers, but the problem of the pattern of protein quantity and quality inheritance as related to new selections and adaptation to diverse environments is still not clearly defined. The selection of genotypes for stable protein quality and quantity

for screening and breeding programs in specific environments, and for the successful improvement of food supplies remains a persistent problem.

The complexity of isolating the individual factors which influence protein yield and quality, grain yield, growth responses, bird resistance, weather resistance and human preferences appears to be further complicated by the inheritance pattern of sorghum not following the expected theoretical degree of recombinations in the segregating generations. The establishment of useful segregating populations in areas of least stress to insure maximum recombination and preservation of all the genetic courses before selecting for testing in adverse environments has not been fully completed. The presently established computerization of existing data related to a broad base of protein quality genetic sources and the securing of the collection data from 1971 field plots could only now result in carefully selected establishment of population materials for given purposes.

The need of meeting human acceptance and adequate dietary requirements has not been possible to test directly, due to limited use of rat or other known biological tests to use to screen for potential materials and then the establishment of adequate inventories of the required grain. The wide distribution of selected genetic sources to cooperators for their local selection, for immediate adaptation and acceptability evaluation has been our most successful attempt at human evaluation but remains inadequate and difficult to assess and interpret due to

variable management procedures followed in each locality.

The present establishment of virtually complete accessibility to extensive laboratory and field data across the major portion of the collection lines and hybrids has been a major accomplishment. The accumulation from screening programs of an adequate working and almost complete inventory for significant use in protein quality and inheritance studies has greatly expanded the range of quality factors which are usable. This will now make possible the identification and the initiation of selections for entry into the breeding programs, lines with individual amino acid variability to attempt to produce improved quality protein sources and varieties.

The initiation this year of identifying the collection items by races, as suggested by Drs. J. R. Harlan and J. M. J. deWet, is facilitating the assurance of adequate representation of genetic sources for identification of protein quality inheritance factors.

The utilization of computerized field books with improved subsampling and inventory procedures has resulted in more timely laboratory evaluations and the generation of pertinent data for reporting and planning. The development of field instruction books for each team of workers resulted in reduced labor costs, more individual responsibility and motivation, and enabled more efficient field operations from planting through threshing. This has resulted in these operations being accurately completed well ahead of schedule even with a very sizable acreage involved (55 acres in plots).

The automation of the amino acid analyzer enabled a 50 percent reduction in labor and resulted in the potential output of over 100 complete amino acid analysis per month. This has greatly increased the potential identification of protein quality factors based on selection of individual amino acid variability for biological testing and breeding programs.

VII. WORK PLAN AND BUDGET FORECAST

A. Anticipated Results for the Coming Year.

We will be able to select another group of lines having high protein yield and quality adaptable to both termperate and tropical regions. This set will be nominated to others for disease and insect resistance evaluation. There will also be an initial selection of superior lines from the Puerto Rico growout. This will be the first selection for release of this type tropical material by this project.

More complete data including response to nitrogen fertilization from 12 - 15 tropical locations can be expected to be returned by mid 1973.

The influence of polyphenols and related compounds upon the distribution of amino acids in protein fractions should be identified. Approaches for overcoming adverse affects through supplementation or processing will be evaluated.

The relationship of protein fraction differences in seed portions (pericarp, endosperm and embryo) and in different genotypes will be studied.

Feeding tests will identify nutritionally high quality lines based on whole grain, supplementation, iso-nitrogenous and standardized base rations. Ways to overcome adverse responses associated with polyphenols are anticipated.

Recombination studies will show the inheritance patterns of specific crosses and the potential level of the most desired recombinants. Identified segregating populations will be made available to plant breeders.

The establishment of high protein quantity and quality types in random mating segregating $\underline{ms}_3$ populations will provide a source of broad genetic base materials from which specific selections can be made in the diverse ecological regions of the world.

A complete summary of the status of investigations to date of the IS Collection will be completed.

The potential usefulness of measuring nitrogen content of immature vegetative plant parts as a tool for predicting mature grain protein levels will be determined.

Specific adaptability of lines for an ecological region will be identified from data supplied by international cooperators.

Quality and inheritance factors will be more completely evaluated as related to race classification and origin.

Cooperators should be able to utilize the potential breeding materials and data from the project by the development of a catalog or suitable materials, along with the release of information related to data on file and how to obtain such data from the project.

It is anticipated that workshops in Brazil and Southeast Asia will facilitate the utilization of the presently available data and information in those areas.

Sorghum production in Indiana will continue to increase above the average and local demands for information and research regarding sorghum quality will be stimulated by utilization of animal science research facilities.

The initiation of the identification of a representative diverse elite collection containing the major phenotypes and genotypes of the total collection for establishment of a smaller sized "working pool" of germplasm is feasible. Breeders recognize the limitations of small numbers which contain most of the desirable inheritable characteristics when dealing with such a large volume of collection items.

B. Plan of Work for the Coming Year.

"Inheritance and Improvement of Protein Quality and Content in Sorghum bicolor (Linn.) Moench". Contract AID/csd-1175

1. Objective 1 - Identify sorghum lines with improved protein quality and quantity utilizing both chemical and biological methods.

   a) Continue screening new collection items at Purdue to determine the entries that will flower in temperate zones (cycle year 1). The non-flowering entries will be planted in Puerto Rico for additional screening (cycle year 2).

   b) Continue sampling from collections previously grown, breeding materials including bulks, F_2, F_3 and selected populations (cycle year 2).

   c) Continue preliminary protein yield tests at three diverse Indiana locations with overseas cooperators (cycle year 3) who have agreed to our experimental design and data collection and reporting procedures.

   d) Continue advanced protein yield trials at three Indiana locations with selections from 500 lines in the 1971 preliminary trials. The selections are to be based on lines with superior protein yield and grain yield comparable to present commercial hybrid checks.

   e) Initiate protein yield trials with select cooperators in the U.S. and overseas using approximately 20 carefully tested lines from the 1971 advanced yield trials. This is the first year seed from selected lines has been available for this purpose (cycle year 5).

   f) Initiate larger plot testing of the non-flowering collection entries at the breeding nursery located at the Lajas Experiment Station under contract with the University of Puerto Rico. This will insure adequate sampling for protein evaluations of this material. The use of six acres is planned to include work in cycle years 2,3 and 4 as follows:

      i) Evaluate in one-row plots a moderate number of entries from new collection items (cycle year 2).

      ii) Based on previously grown single-row protein information, select several hundred lines to be grown in three-row plots to increase seed, to obtain a yield estimate, for chemical and biological sampling and for preliminary crossing to identify B and R lines.

iii) Approximately 150 lines will be selected for protein quantity and quality from the 1971-72 three-row plots for replicated trials. These lines will be crossed onto cytoplasmic male steriles for hybrid evaluations and also crossed on a segregating temperate ms_3 population.

2. Objective 2 - Identify the chemical nature and composition of the protein fractions of selected sorghum genotypes and correlate the grain fraction composition with nutritional quality.

   a) Sorghum types showing major differences in nutritional value based on rat feeding tests will be separated into five soluble fractions using the Landry-Moureaux method. The fractions will be subdivided further by chromatography to obtain individual proteins. These proteins will be characterized by physical and chemical methods and their biological value determined (cycle year 4 and 5).

3. Objective 3 - Ascertain the role of various chemical components of sorghum grain such as polyphenols (tannins), protein quality and carbohydrate availability in monogastric animal nutrition.

   a) Advisory personnel in human and monogastric animal nutrition will be utilized including the requested additional one-half time staff position from the Animal Science Department for assistance with the evaluations to be undertaken with rats and other non-ruminants.

   b) Lines with superior performance for yield and protein combination will be subjected to amino acid analysis, polyphenol (tannin) tests and rat feeding. Seed for these tests will be provided from protein yield testing in cycle years 3, 4 and 5 in both temperate and tropical areas. The primary locations will be three in Indiana and the Puerto Rico winter nursery. Seed from other locations will be limited to protein determination, amino acid analysis and polyphenol tests.

   c) Study the influences and control mechanisms of polyphenols or other substances that reduce grain sorghum protein utilization.

4. Objective 4 - Determine the mechanism of inheritance of high nutritional quality and develop breeding methods and materials including populations with improved biological quality for potential utilization in developing countries.

   a) Evaluate F_2, F_3, F_4 and F_5 families from crosses of high x high, high x low and low x low protein content.

b) Relationship of protein, yield and limiting amino acid contents will be studied on highest yield material selected from final evaluation trials.

c) The inheritance of protein fractions (relative amounts) and composition (amino acid, oil, etc.) will be studied on selected breeding sources.

d) The inheritance of grain fractions (their proportion and composition) as related to nutritional quality will be investigated.

e) The inheritance of grain size and composition as related to protein yield, plant population and grain fractions will be studied.

f) The inheritance of the ability of plants to take up nitrogen differentially under various nutrient levels and balances will be investigated as related to grain protein quantity and quality.

g) We will attempt to correlate various aspects of nutritional quality with origins and races.

h) Continue to study the environmental effects on protein yield and nutritional quality. All selections grown at multiple locations will be analyzed for genotype x environment interactions.

i) Random mating base populations will be developed which will allow for a description of the genetic parameters of quality.

   i) Continue development of high protein, high lysine male sterile (ms_3) populations at Puerto Rico and Purdue.

   ii) Initiate new ms_3 populations for:

      - high yield with best combinations of nutritional quality holding several diverse (type, race, origin, B and R) groups separately.
      - highest nutritional quality based on rat feeding data.
      - improving limiting amino acid composition and balance.
      - wide environmental adaptation.

   iii) Solicit cooperation for subjecting these populations to insect and disease stress areas to increase the frequency and recombine genes for resistantance in high nutritional quality material.

j) Enter selected lines from the 1971 advanced protein yield trials into recombination studies (cycle year 5).

5. Information and Germplasm Utilization and Dissemination.

a) Make available and distribute collected and developed information for improved management and high performance of sorghums, distribute selected germplasm to established programs and interested cooperators, and develop cooperative programs to test, screen and exchange breeding materials.

i) Breeding and evaluation material will be distributed to cooperators as follows:

- Selected diverse lines for breeding sources will be sent to cooperators requesting seed. Instructions for management, data collection and return of select grain samples useful for our study will accompany the seed shipment. Seed of selected lines and all data will be returned for analysis.
- Populations and segregating materials.
- All lines going to advanced yield trials will be sent for resistance studies, e.g., anthracnose (Georgia), Shoot fly (India and Africa) etc., as such trials can be arranged.

ii) Print and distribute catalogues or suitable materials to enable adequate utilization of data related to origin, composition, inheritance and nutritional quality of populations and collection items.

iii) Ph.D. degree programs with thesis on the work related to this project will be continued at about the level of six candidates at a time.

iv) Non-degree programs (number determined largely by cooperators) with response by this project to the following:

- Continuation of visitors from many countries.
- Short term AID-supported individuals and groups.
- Longer term (6 months to 1 year) visiting professors and others.
- Commercial company and other trainees.
- Special research problems by superior Purdue undergraduate students.
- Post-doctorates (three positions funded by this project).

v) Workshops.

- Continue to implement a sorghum workers workshop to be conducted in Brazil as planned for February 1972 and postponed until mid-1972.
- Initiate and develop plans for a workshop to be held in S. E. Asia as soon as feasible to be followed by one in Africa (possibly Ethiopia).

vi) The initiation of opportunities to share findings and problems with co-workers will be promoted by visits to the Texas sorghum programs, Nebraska, attendance at relevant seminars and conferences, inviting co-workers to visit the project's nursery and laboratories, Purdue Agronomy Farm Field Day participation and continued cooperation with the Indiana Agricultural Extension Service.

FIVE-YEAR WORK CYCLE FOR PURDUE-AID SORGHUM IMPROVEMENT PROJECT

	LAFAYETTE	WINTER NURSERY-PUERTO RICO
Cycle Year 1	Identify day-length sensitive group Select phenotypic diversity (short rows)	
Cycle Year 2	Flowering group (3-row) a. increase seed (working source) b. clean-up lines c. yield estimate d. laboratory analysis e. phenotype data f. light crossing	Non-flowering group (one row) a. increase seed b. chemical analysis c. select phenotypic diversity d. light crossing e. rate yield f. cleanup line
Cycle Year 3	Preliminary yield (replicated trials) (several locations) a. heavy crossing b. chemical analysis and feeding c. some lines distributed to overseas cooperators with samples returned for chemical analysis	Yield evaluation trials (3-row) a. seed for distribution to other tropical locations with samples returned for chemical analysis b. Preliminary yield evaluation and samples for chemical test c. crossing
Cycle Year 4	Advanced yield trials a. evaluation of lines by hybrids b. inheritance studies c. distribution d. chemical analysis and feeding	Advanced yield trials (replicated 3-row) a. evaluation of lines b. seed increase c. chemical analysis and feeding d. make male sterile hybrids
Cycle Year 5	Advanced breeding and testing to develop lines for: a. varieties b. chemical analysis and feeding c. populations and recombinations (advance generations in Puerto Rico) d. hybrids as parents e. recombination with sources of disease and insect resistances and other adaptative characters and preferences. f. selections, crossing and seed increase to be advanced in Puerto Rico and the greenhouse.	Release Program and hybrid evaluation a. release of lines to temperate type conversion program b. release to tropical populations c. evaluation of hybrids

Laboratory Analysis Sequence:

Nitrogen
↓
IVDMD[1] or Polyphenol ("tannin"), nitrogen lysine, oil
↓
Complete amino acid analysis
↓
Rat feeding, chickens and others

[1] *In vitro* dry matter disappearance

C. Significant Factors Promoting and Impeding Progress.

The assignment of one full-time post-doctorate position to data handling should provide the resources needed to handle, sort and provide for the dissemination of information as it becomes available.

The completion of uniform computerization procedures of data has enhanced the data inventory availability. This helped identify the origins with field data, laboratory data, cooperator data and working seed inventories. The release of data can now become more current to cooperators and interested breeders requesting specific information which is available, but was formerly difficult to separate.

The completion of the dehumidifying and air conditioning of the present seed storage area, and the provision of an adjacent work and temporary rodent protected storage area, would greatly facilitate the processing of protein quality sample preparation, seed packeting for planting and subsampling procedures. Seed amounts are now largely held in a current inventory, but the access to them is not efficient due to the shortage of work space near the storage area.

The continued and increased cooperation with the Purdue University Animal Science Department by financial support, as indicated, will provide additional opportunities for nutritional quality investigations and the use of staff expertise. Consultations on nutritional problems will be continued utilizing human nutritionists, small animal specialists and related staff.

The utilization of regional and overseas key cooperators, at a limited number of locations, with specific management instructions and with replicated trials will be possible for the first time with the completion of the present plans. This enhances the potential screening of source materials for inheritance patterns that respond greatly or to a lesser degree to varying environments. The specific and broad based human acceptability objectives for a given area will also be tested.

The provision of increased support for biological testing, the identification of factors and their control which influence protein quality, and the use of presently available seed and data inventories should all enable more rapid progress to be made toward the identification of protein quality inheritance parameters.

The complexity of environmental and cultural management influences on protein quantity and quality, grain yield and other phenotypic responses has resulted in the necessity of eliminating as many factors as possible to begin to identify quality inheritance patterns. This has resulted in the need for testing in similar environments to estimate inheritance patterns and to test in diverse environments to estimate phenotypic stability. This makes the size of production areas large and the quantity of data and seed handling cumbersome. The bordering, population density and spacing, basal tillering, day length, and temperature influences further complicate the environmental interactions.

The added digestibility problems related to pigmentation and

polyphenols (tannins) with the complexity of amino acid balance and protein quantity complicates the illucidation of protein inheritance in sorghum as compared to other cereal crops. This has resulted in increased effort being made to study protein inheritance patterns in low polyphenol (tannins) types.

The difficulty experienced in accomplishing timely operations in Puerto Rico for specific breeding material evaluations or increases has resulted in a less rapid screening process. Thus, screening for and selecting from the diversity available in the temperate non-flowering sections of the collection has been delayed due to inadequate supervisional help at the operational field level in a tropical location. More direct supervision from Purdue University staff and the employment of local Puerto Rico staff or the utilization of an additional tropical location could expedite this segment of the program.

Identifiable phenotypic characteristics associated with protein quality or quantity have not been found to date, thus the necessity for chemical and biological evaluations of large numbers of samples to insure the inclusion of the identifiable qualities is costly and time consuming.

D. Plans for Dissemination and Utilization of the Expected Results.

The utilization of sorghum newsletters, project reports, special publications, formal journal publications, professional meetings, field days, newspapers and personal consultations will be increased

in volume. This will be possible due to the increasing volume of pertinent material now in the project inventory of data and more personnel assigned to its utilization. The proposed establishment of workshops, the continuation of degree and non-degree programs, the use of yield trials in overseas locations, and the continued distribution of identified potential breeding materials with supporting data related to quality will result in a wider and more complete dissemination of information. It will also identify for others the types of information available on potential breeding materials and will stimulate a greater utilization of presently accumulated data. The maintenance of regular correspondence and the establishment of a Purdue University International Series of research publications will facilitate the release of developments not best adapted to formal journal publications. The provision of seed lots for breeding and selection purposes as a by-product of the plots required for adequate quality sampling to United States and overseas sorghum workers is not costly to this project and enables the dissemination of the genetic materials not currently readily available from any other source. The utilization of this material is very helpful for immediate human acceptance by individual selection, testing and use.

The utilization of information indicating the areas of the world needing further collection of germplasm and the cooperation with the world committee on sorghum germplasm so that all races are adequately represented in the collection will be continued to insure as complete an array of germplasm for its use in understanding the inheritance patterns of protein nutritional quality.

E. Proposed Budget for 1972-73.

"Inheritance and Improvement of Protein Quality and Content in Sorghum bicolor (Linn.) Moench"
Contract AID/csd-1175

FY 1972-73
J. D. Axtell,
Project Director

Line item	Category	% of effort	Proposed Budget
1	Salary and Wages:		
	Staff, Agronomy Professor - Project Director	80	14,300
	Staff, Biochemistry	5	1,420
	Staff, Agronomy - Assistant Project Director	100	11,250
	Post-doctorate, Agronomy	100	10,000
	Post-doctorate, Agronomy	100	10,000
	Post-doctorate, Biochemistry	100	9,500
	Research Graduate Assistant, Agronomy	75	5,000
	Research Graduate Assistant, Animal Science	50	3,080
	Laboratory Technician, Agronomy	100	7,000
	Laboratory Technician, Agronomy	100	6,500
	Laboratory Assistant Technician, Agronomy	30	1,800
	Laboratory Technician, Biochemistry	50	2,500
	Field Technician, Agronomy	40	3,200
	Administrative Assistant, Agronomy	100	6,100
	Student Assistants and Hourly Labor		10,200
			101,850
2	Indirect costs (62.8% of total of 1)		63,962
3	Salary related costs		8,183
4	Permanent Equipment (Seed storage/work building)		4,000
5,6	Expendable Supplies: Agronomy 7,800; Biochemistry 2,000; Animal Science 1,000		10,800
7	Winter Nursery		8,000
8	Travel		4,000
0	Computer Services		2,000
10	Sub-contract Services		29,000
11	Publications		2,000
12	Workshop, Seminars		10,000
	GRAND TOTAL		$ 243,795

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FOR

A. Research Data from Completed Studies.

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2. An Investigation of the Transmission of Protein, Lysine, Oil and Certain Other Characters from Sudangrass Lines to Cultivated Grain Sorghum. Sam Mukuru. (Abstract of 1970 M.S. Study)..... A-21

A. Research Data From Completed Studies.

1. Relationships of Certain Morphological Characters with Grain Yield and Quality of Phenotypically Diverse Lines and Hybrids in Sorghum bicolor (L.) Moench. Bantayehu Gelaw (Summary and Conclusion of 1970 Ph.D. Study.)

Twenty-four phenotypically diverse lines of sorghum which included all height and maturity groups and general morphological traits were used as male parents in this study. These lines were selected partly from the world's sorghum collection and partly from those entries that had survived considerable screening in previous thesis studies.

Three cytoplasmic male sterile lines, namely, CK-60, Martin and Redlan, were used as female parents. The three female parents were selected on the basis of their widespread adaptation and use for commercial hybrid seed production.

Each of the 24 male parent lines was crossed with the three female parents in 1969. In 1970, the 72 F_1's and the 24 male parents along with the three male fertile versions of the male steriles (B-lines), and three commercial check varieties, namely, RS610, BR64 and NK300 were planted in a randomized complete block design with a split-plot feature, replicated four times. Each plot was 15 feet (457.5 cm) long and 30 inches (76 cm) apart with a 3.5 feet (106.75 cm) alley and a population of approximately 120,000 plants per acre (300,000 plants per hectare) or about seven plants per foot (30.5 cm) of row.

Both male and female parents were considered to be fixed and represent the entire population about which inference can be made. Blocks (replications) were also considered to be fixed.

Either directly by measurement or indirectly by calculation, the following characters were studied: early vigor, days to 50% flowering, leaf number, flag leaf length, flag leaf width, flag leaf area, length of third leaf from the top, width of third leaf, area of third leaf, plant height, stem diameter, head exertion, panicle length, tillering, lodging, number of heads per plot, threshing percent grain yield, percent protein (non-defatted), percent protein (fat-free), percent lysine and percent oil.

A standard analysis of variance was run for all characters studied. A combining ability analysis of variance was used for the F_1 hybrids for estimating general and specific conbining ability. In this analysis, the male and female effects estimate GCA while the male x female interactions express SCA.

Estimates of general and specific combining ability effects for both male and female parents were calculated for grain yield, percent protein, percent lysine and percent oil.

Heterosis was presented in two forms. The grand mean of each character for the hybrids was compared to the parental grand mean for all the variables studied while the performance of each individual hybrid was compared to the better parent for yield, percent protein, percent lysine and percent oil.

Intercharacter phenotypic, genotypic and environmental correlation coefficients were calculated for the parental and F_1 generations, separately.

Significant and highly significant genotypic differences were found for all characters studied among the 24 male parents, the three "B" lines and commercial check varieties. Significant differences existed between replications of the same female parent for days to 50% flowering suggesting that these two variables were measured with a high degree of precision. This was shown by the low C.V. values of 2.2% and 3.4% for days to 50% flowering and percent oil, respectively.

Highly significant differences were detected between each male parent and the three F_1 hybrids having the same male parent in common and among the three F_1 hybrids themselves for all the characters studied except for threshing percent. The three F_1 hybrids having the same male parent did not differ in threshability from each other and from their male parent.

The lowest coefficients of variation (C.V.) were obtained for days to 50% flowering and percent oil and the highest for head exertion, tillering, and lodging in both parental and F_1 generations. Head exertion, tillering and lodging are extremely variable varietal characters in sorghum and vary with environment. The coefficients of variation for yield, percent protein, and percent lysine in the parental generation were 14.1%, 7.4% and 15.9% respectively.

The results of the combining ability analysis of variance of the 72 F_1 hybrids indicated that GCA was predominant to SCA for almost all of the characters studied. Therefore, additive gene action was very important in the expression of each character and that these characters lend themselves to breeding procedures that utilize additive gene actions.

Both GCA and SCA were important in the expression of days to 50% flowering, leaf number, panicle length, lodging, percent oil, and percent protein, hence, breeding systems which utilize both additive and nonadditive gene actions should be most effective in the improvement of these characters.

Estimates of general and specific combining ability effects revealed that hybrids having Redlan as their female parent yielded the most while GCA estimates for males showed that line 009 was the highest contributor to yield. The results of this study substantiated the hypothesis that higher yielding inbred lines of sorghum do not necessarily produce superior hybrids and the poorer performing inbreds do not always make inferior hybrids, hence, the necessity for stringent testing of inbreds for their ability to produce good hybrids is inevitable.

Martin was found to be the most important female contributor to percent protein while line 012 was the best male parent for this character. CK-60 was more important in influencing percent lysine than the other two females while line 004 was the highest contributor among the males. Martin and line 004 were the best contributing female and male parents, respectively, for percent oil.

Grain yield for the 72 F_1 hybrids ranged from 4282-8639 kg/ha while the range for their parents was from 4418-7536 kg/ha. The range for percent protein was from 7.75-12.60% for hybrids and 10.30-14.85% for their parents. Values for lysine ranged from 1.61-2.67% for the hybrids and from 1.54-2.55% for their parents. Percent oil ranged from 2.95-4.05% for hybrids and 2.77-4.50% for their parents.

Heterosis over the better parent ranged from -36.10 to 39.04 for grain yield. The range for percent protein was from -31.34 to 15.20% while that for lysine was from -16.28 to 30.88%. The values for oil ranged from -23.33 to 7.23%.

Compared to the grand mean values of their parents, hybrids were more vigorous, 0.64 days earlier in maturity, had 3.70 more leaves, shorter but wider flag leaves, smaller flag leaf area, longer and wider third leaves from the top, and greater third leaf area. Hybrids were 35.10 cm taller, 2.46 cm thinner in stem diameter and possessed more head exertion and panicle length. However, hybrids exhibited fewer tillers, fewer number of heads per plot, slightly higher threshing percent and lower percentages of protein and oil, but they lodged more, had 11.48% higher grain yield and 5.44% more lysine.

Table 1. Analysis of variance for 21 characters of the 24 male parent lines and their 3 male sterile F_1 hybrids with test of significance between each male parent and its 3 F_1 hybrids

Source	df	Mean Squares					
		Early vigor	Days to 50% flowering	Leaf number	Flag leaf length	Flag leaf width	Flag leaf area
Replications	3	25.6067**	206.5373**	6.4371**	18.3291	0.9643	1154.8696
Male parents	23	2.9564	490.4455**	20.2163**	127.0820**	3.3933**	3580.4905**
Error (a)	69	2.0017	14.6931	1.1817	42.9963	0.4996	1114.1571
Entries	3	143.9887**	315.8498**	4.9224**	1353.9787**	4.4376**	25696.8410**
Male parents X Entries	69	1.5358**	51.6143**	3.1403**	27.2234**	0.3946**	760.5292**
Error (b)	216	.7097	2.9389	0.7025	16.9113	0.1805	417.4964
Total	383						
C. V. (a)		27.09%	5.09%	8.97%	20.26%	13.83%	33.08%
C. V. (b)		16.13%	2.27%	6.92%	12.70%	8.31%	20.25%

Source	df	Mean Squares					
		Length of 3rd leaf	Width of 3rd leaf	3rd leaf area	Plant height	Stem diameter	Head exertion
Replications	3	266.5216*	0.3494	1078.6696	192.9871	0.0127	93.7148*
Male parents	23	231.3590**	3.0868**	8468.6631**	22075.9855**	0.3181**	232.6776**
Error (a)	69	82.7468	0.6665	3269.7521	524.1763	0.0934	33.1929
Entries	3	248.7739**	4.4370**	15249.4345**	25442.4090**	0.6302**	885.2974**
Male parents X Entries	69	75.3295**	0.6993**	3188.5428**	1444.4696**	0.0652**	33.3827**
Error (b)	216	37.2892	0.2301	1269.3073	211.7616	0.0394	19.4098
Total	383						
C. V. (a)		15.69%	12.62%	25.20%	14.45%	18.94%	43.58%
C. V. (b)		10.53%	7.41%	15.70%	9.18%	12.29%	33.32%

Table 1. (continued)

Source	df	Mean Squares			
		Panicle length	Tillering	Lodging	No. of heads per plot
Replications	3	11.2902	1.6068	1.5278	2975.6042**
Male parents	23	179.5456**	3.9265**	50.0254**	3012.4765**
Error (a)	69	8.9239	1.4220	1.3720	416.0534
Entries	3	18.9173**	88.3290**	50.8125**	5406.1319**
Male parents X Entries	69	15.0396**	3.0355**	5.2292**	759.7406**
Error (b)	216	2.8495	1.2398	0.3715	225.1064
Total	383				
C. V. (a)		13.31%	68.03%	43.24%	19.63%
C. V. (b)		7.52%	63.52%	22.50%	14.44%

Source	df	Mean Squares			
		Threshing %	Grain yield	Protein (non-defatted) %	Oil %
Replications	3	511.8759**	980564.57	1.5587	0.0079
Male parents	23	170.5915**	2780143.15**	5.5594**	0.8322**
Error (a)	69	56.8448	1248985.98	1.0383	0.0282
Entries	3	53.5450	26672823.68**	33.1752**	0.8055**
Male parents X Entries	69	36.9627	1932989.18**	1.5257**	0.0814**
Error (b)	216	35.1324	893471.45	0.7001	0.0179
Total	383				
C. V. (a)		10.43%	16.92%	10.37%	4.79%
C. V. (b)		8.20%	14.31%	8.52%	3.82%

Table 1. (continued)

Source	df	Mean Squares: Protein (fat-free) %	Mean Squares: Lysine %
Replications	1	0.0033	0.2283
Male parents	23	3.8877**	0.2629**
Error (a)	23	0.5956	0.0725
Entries	3	23.6379**	0.2354**
Male parents X Entries	69	1.1685**	0.0532
Error (b)	72	0.4456	0.0461
Total	191		
C. V. (a)		6.87%	12.70%
C. V. (b)		5.94%	10.13%

* Significant at the .05 level

** Significant at the .01 level

Table 2. Combining ability analysis of variance for 21 characters of the 72 male sterile F_1 hybrids grown in Purdue Agronomy Farm in 1970

Source	df	Mean Squares				
		Early vigor	Days to 50% flowering	Leaf number	Flag leaf length	Flag leaf width
Replications	3	21.2732**	155.0776**	6.0224*	47.8450	1.0965*
Male Effects (GCA)	23	2.3762	481.4564**	19.4138**	100.2347**	1.9306**
Error (a)	69	2.1089	17.3505	1.4910	33.6653	0.3776
Female Effects (GCA)	2	6.3368**	146.0139**	3.8679**	10.8400	0.9463**
Male X Female Effects (SCA)	46	0.4709	6.0791**	1.8888**	8.7553	0.1090
Error (b)	144	0.5532	1.5439	0.5830	13.7619	0.[illegible]572
Total	287					
C. V. (a)		31.44%	5.59%	10.15%	19.03%	12.26%
C. V. (b)		16.10%	1.66%	6.34%	12.16%	7.91%

Source	df	Mean Squares				
		Flag leaf area	Length of leaf	Width of leaf	3rd leaf area	Plant height
Replications	3	1599.6106	501.6763**	0.1192	6040.4594	234.9694
Male Effects (GCA)	23	2407.5038**	265.6797**	1.6845**	8554.4371**	22123.7268**
Error (a)	69	785.0817	96.2291	0.5235	3150.9274	652.1488
Female Effects (GCA)	2	750.6615	39.3375	0.9455**	252.1117	993.3801**
Male X Female Effects (SCA)	46	199.3200	28.3026	0.1480	1145.1018	182.7510
Error (b)	144	303.7389	22.8116	0.1726	907.5634	148.8014
Total	287					
C. V. (a)		30.19%	17.15%	11.36%	25.44%	15.34%
C. V. (b)		18.78%	8.35%	6.52%	13.65%	7.32%

Table 2. (continued)

Source	df	Mean Squares				
		Stem diameter	Head exertion	Panicle length	Tillering	Lodging
Replications	3	0.0532	70.5364*	13.6826	0.6424*	1.4861
Male Effects (GCA)	23	0.2271**	122.1278**	92.7557**	0.3948*	61.9946**
Error (a)	69	0.0791	22.0981	5.9810	0.2269	1.7180
Female Effects (GCA)	2	0.2686**	249.0973**	13.8884**	0.7222*	3.9688**
Male X Female Effects (SCA)	46	0.0350	13.9457	2.7232*	0.1969	0.8058**
Error (b)	144	0.0381	11.1949	1.9435	0.1817	0.3125
Total	287					
C. V. (a)		17.18%	32.22%	10.97%	37.37%	42.79%
C. V. (b)		12.35%	22.93%	6.25%	33.44%	18.25%

Source	df	Mean Squares				
		No. of heads per plot	Threshing %	Grain yield	Protein (non-defatted) %	Oil %
Replications	3	2483.3194**	471.2543**	941654.19	2.2657	0.0097
Male Effects (GCA)	23	2604.2893**	138.7580**	3396307.53**	3.8478**	0.4894**
Error (a)	69	415.0586	56.6286	1346220.11	0.8795	0.0274
Female Effects (GCA)	2	6352.1910**	12.9289	1691845.93	10.1252**	0.9982**
Male X Female Effects (SCA)	46	239.7816	39.4362	1383047.10	0.6786	0.0223*
Error (b)	144	216.5902	36.6739	943959.65	0.7149	0.0159
Total	287					
C. V. (a)		19.28%	10.36%	17.02%	9.81%	4.70%
C. V. (b)		13.93%	8.34%	14.15%	8.84%	3.58%

Table 2. (continued)

Source	df	Mean Squares: Protein (fat-free) %	Mean Squares: Lysine %
Replications	1	0.0544	0.0702
Male Effects (GCA)	23	2.1848*	0.1713*
Error (a)	23	0.3494	0.0640
Female Effects (GCA)	2	8.1384*	0.3145**
Male X Female Effects (SCA)	46	0.8423*	0.0463
Error (b)	48	0.4677	0.0389
Total	143		
C. V. (a)		5.41%	11.87%
C. V. (b)		6.26%	9.25%

* Significant at the .05 level

** Significant at the .01 level

GCA General Combining Ability

SCA Specific Combining Ability

Table 3. Estimates of general and specific combining ability effects for grain yield of the 72 F_1 hybrids grown in Purdue Agronomy Farm in 1970

Males	Females: CK-60 ms	Martin ms	Redlan ms	General Effects of Males
	Specific Effects			
029001	390.1111	94.0902	-484.2014	-618.6944
003	117.5278	-147.2431	29.7153	507.1389
004	-511.4722	196.0070	315.4653	564.6389
005	103.0278	-472.9931	369.9653	381.1389
008	-412.7222	789.7569	-377.0347	63.3889
009	-488.7222	-334.7431	823.4653	852.1389
010	-124.7222	-68.7431	193.4653	560.8889
012	923.6945	603.4235	-1527.1181	-305.5277
013	-552.0556	-72.5765	624.6319	-315.7777
015	196.6111	-440.6598	244.0486	-99.4444
016	-211.4722	101.2569	110.2153	658.1389
018	-1481.8889	456.0902	1025.7986	-947.6944
021	524.7778	-474.7431	-50.0347	485.3889
022	60.9444	126.4235	-187.3681	-473.7777
023	431.8611	181.8402	-613.7014	287.0556
024	128.2778	-65.4931	-62.7847	-173.8611
025	495.8611	-523.1598	27.2986	-733.1944
026	-348.6389	-227.6598	576.2986	510.3056
027	-249.9722	405.0069	-155.0347	-896.8611
932032	-84.0556	-109.5765	193.6319	153.2223
033	-466.5556	61.4235	405.1319	227.7777
034	711.3611	-26.4098	-684.9514	276.5556
035	352.5278	-97.99[illegible]	-254.5347	-684.3611
036	495.6944	46.67[illegible]	-542.3681	176.9723
	General Effects of Females			
	-150.1111	48.1598	101.9514	

Table 4. Estimates of general and specific combining ability effects for percent protein (non-defatted) of the 72 F_1 hybrids

Males	Females: CK-60 ms	Martin ms	Redlan ms	General Effects of Males
	Specific Effects			
029001	0.0205	0.0726	-0.0931	0.6868
003	0.0455	-0.7024	0.6569	-0.7132
004	-0.0212	0.0210	-0.0097	0.0034
005	-0.0212	0.2060	-0.1847	0.4784
008	-0.0962	-0.2690	0.3653	0.5534
009	0.0039	0.4060	-0.4097	-0.8466
010	0.5796	0.4476	0.1319	-0.1132
012	0.0038	0.4060	-0.4097	0.7784
013	-0.3462	0.4810	-0.1347	0.0784
015	-0.0544	-0.2774	0.3319	0.6118
016	0.5788	-0.2190	-0.3597	-0.3216
018	0.2621	-0.1107	-0.1514	0.2701
021	0.7872	-0.2357	-0.5514	-0.3049
022	-0.3961	0.0810	0.3153	-1.0716
023	0.3205	-0.1274	-0.1931	-1.3882
024	-0.5628	-0.1857	0.7486	0.2701
025	0.1872	-0.1607	-0.0264	0.2201
026	0.4205	0.2976	-0.7181	-0.1382
027	-0.3628	-0.1607	0.5236	0.3951
932032	-0.1711	0.1310	0.0403	0.4284
033	0.3372	-0.4357	0.0986	-0.1799
034	0.1711	-0.0190	0.1903	-0.0716
035	-0.2045	0.3226	-0.1181	0.5118
036	0.0205	0.0226	-0.0431	-0.1382
	General Effects of Females			
	-0.3372	0.3107	0.0264	

Table 5. Estimates of general and specific combining ability effects for percent lysine of the 72 F_1 hybrids

Males	Females: CK-60 ms	Marvin ms	Redlan ms	General Effects of Males
	Specific Effects			
029001	-0.1034	-0.0003	0.1035	-0.3287
003	0.0166	0.7497	-0.1665	-0.0637
004	-0.1234	-0.1403	0.2635	0.3563
005	0.2716	-0.1053	-0.1665	-0.0787
008	-0.0084	0.1497	-0.1415	-0.0837
009	-0.2400	0.0381	0.2019	0.1479
010	0.1016	-0.0653	-0.0365	-0.1237
012	-0.0317	-0.0236	0.0552	-0.0354
013	0.2616	-0.1453	-0.1165	-0.1037
015	0.0400	0.1181	-0.1581	-0.2871
016	-0.1650	-0.1069	0.2522	-0.0171
018	-0.0284	-0.0003	0.0285	-0.0437
021	0.0383	-0.1236	0.0852	0.2096
022	-0.0117	0.0814	-0.0698	-0.0004
023	0.0566	-0.0003	-0.0565	0.2413
024	0.0850	0.0831	-0.1681	0.0279
025	0.0800	-0.6219	0.0369	0.1479
026	-0.1234	-0.0103	0.1355	0.1413
027	-0.0957	0.0964	0.0002	0.1146
932032	0.0533	0.1064	-0.1598	-0.0404
033	0.0283	0.0464	-0.0748	-0.0104
034	0.0266	0.0397	-0.0665	0.1863
035	-0.1934	-0.0953	0.2885	-0.2587
036	0.0650	0.0231	-0.0881	-0.0971
	General Effects of Females			
	0.0817	-0.0014	-0.0802	

Table 6. Estimates of general and specific combining ability effects for percent oil of the 72 F_1 hybrids

Males	Females: CK-60 ms	Martin ms	Redlan ms	General Effects of Males
	Specific Effects			
029001	0.0803	0.0094	-0.0895	-0.0188
003	-0.0697	-0.0156	0.0855	-0.0688
004	0.0136	-0.0073	-0.0062	0.4479
005	-0.0447	-0.0656	0.1105	0.0062
008	0.0470	0.0261	-0.0728	-0.0355
009	-0.1114	0.0667	0.0438	-0.1771
010	-0.0280	0.0261	0.0022	0.0605
012	0.0886	-0.0073	-0.0812	0.1729
013	0.0636	-0.1073	0.0438	0.2979
015	0.0720	-0.0489	-0.0228	0.0145
016	-0.0447	0.0094	0.0355	-0.0688
018	0.0053	0.0094	-0.0145	0.0562
021	0.1053	-0.1156	0.0105	-0.0188
022	-0.0447	0.0344	0.0105	-0.4688
023	-0.0280	-0.0239	0.0522	0.0895
024	-0.0030	-0.0239	0.0272	-0.1855
025	-0.2030	0.1261	0.0772	-0.3105
026	0.0886	-0.0073	-0.0812	0.0229
027	0.0553	0.0094	-0.0645	0.1062
932032	-0.0030	0.0011	0.0022	-0.0105
033	0.0386	-0.0323	-0.0062	0.3229
034	0.0303	0.0344	-0.0645	0.0062
035	-0.0447	0.0594	-0.0145	-0.2688
036	-0.0614	0.0427	0.1880	0.1470
	General Effects of Females			
	0.0197	0.0906	-0.1105	

Table 7. Mean values for grain yield, percent protein, percent lysine and percent oil of the 24 male parent lines, the 72 male sterile F_1 hybrids, the 3 "B" lines of the male steriles and the 3 check varieties[1/]

Rank	Yield		Protein (non-defatted)		Protein (fat-free)[2/]		Lysine[2/]		Oil	
	Entry	(Kg/ha)	Entry	%	Entry	%	Entry	%	Entry	%
1	Rx009	8639.25	[illegible]	14.85	005	13.00	Rx004	2.57	027	4.50
2	Rx026	8050.25	[illegible]	14.75	001	12.42	021	2.55	Mx004	4.05
3	Rx004	7843.75	[illegible]	14.15	008	12.32	023	2.55	Cx004	4.00
4	[illegible]	7769.00	[illegible]	13.95	034	12.12	Cx023	2.51	013	3.97
5	Rx016	7732.00	[illegible]	13.80	015	11.55	026	2.50	Mx033	3.90
6	Cx021	7721.75	[illegible]	13.80	M"B"	11.45	Cx021	2.46	Cx033	3.90
7	Rx010	7723.00	M"B"	13.30	016	11.40	Cx004	2.45	Cx013	3.90
8	Rx005	7719.75	M"B"	13.00	[illegible]	11.20	Cx025	2.44	M"B"	3.87
9	Cx034	7649.50	[illegible]	12.60	024	11.17	Cx034	2.43	M"B"	3.85
10	Mx004	7670.50	[illegible]	12.55	Mx012	11.05	009	2.41	Rx004	3.85
11	Mx016	7669.25	[illegible]	12.50	004	10.95	Cx005	2.41	Mx036	3.80
12	022	7529.25	[illegible]	12.35	033	10.80	Rx009	2.40	Rx013	3.80
13	Mx005	7500.[illegible]	024	12.35	Mx035	10.70	Mx023	2.37	Cx012	3.80
14	Cx025	7430.[illegible]	M"B"	12.25	Mx001	10.62	Cx013	2.37	Mx012	3.77
15	Mx009	7427.[illegible]	[illegible]	12.25	009	10.62	Mx034	2.36	012	3.77
16	Mx010	7402.00	Mx001	12.25	Rx024	10.60	025	2.36	Rx013	3.75
17	Rx021	7399.00	013	12.25	Mx005	10.55	Rx021	2.35	RS-610	3.72
18	Cx036	7384.25	012	12.20	Rx015	10.52	Mx004	2.35	CK-60"B"	3.72
19	Mx023	7378.75	Mx008	12.20	Rx027	10.50	Mx027	2.34	Mx033	3.72
20	Cx003	7336.25	Mx015	12.05	Rx008	10.50	NK-300	2.33	Mx027	3.72
21	Cx012	7329.75	Rx008	11.95	Mx032	10.42	Rx026	2.33	033	3.72
22	Rx032	7310.50	Rx001	11.95	Mx013	10.42	Cx024	2.33	004	3.72
23	Rx013	7272.50	033	11.95	018	10.35	Mx009	2.32	Cx027	3.70
24	Mx003	7269.75	Rx00[illegible]	11.90	027	10.27	Rx016	2.31	036	3.70

Table 7. (continued)

Rank	Entry	Yield (Kg/ha	Entry	Protein (non-defatted) %	Entry	Protein (fat-free)[2] %	Entry	Lysine[2] %	Entry	Oil %
25	Mx012	7207.75	Mx013	11.85	Mx015	10.20	RS-610	2.30	Mx023	3.67
26	Cx005	7195.75	Mx012	11.85	Mx010	10.20	022	2.29	Mx018	3.67
27	Mx026	7192.50	Cx012	11.85	023	10.20	Mx026	2.26	018	3.67
28	R"B"	7176.50	009	11.80	Rx001	10.17	Mx024	2.24	RS-610	3.65
29	NK-300	7164.25	Rx025	11.75	Mx008	10.15	Rx025	2.24	Mx034	3.65
30	Mx034	7160.00	018	11.75	012	10.12	Rx023	2.24	Cx026	3.65
31	Cx016	7158.25	03[illegible]	11.70	Mx027	10.10	Cx033	2.23	005	3.65
32	Cx010	7147.75	016	11.70	M"B"	10.07	Cx027	2.23	Mx026	3.62
33	Rx033	7141.00	036	11.65	Rx032	10.05	Cx026	2.23	Cx036	3.62
34	Mx036	7133.50	Rx036	11.60	Mx026	10.02	018	2.23	Cx021	3.62
35	R"B"	7101.50	Mx00[illegible]	11.60	Mx018	10.02	Cx032	2.23	C 15	3.62
36	NK-300	7118.75	02[illegible]	11.55	Cx012	10.00	BR-64	2.22	R"B"	3.60
37	Rx015	7108.25	Mx03[illegible]	11.50	036	10.00	Mx021	2.22	R"B"	3.60
38	RS-610	7085.50	Mx00[illegible]	11.50	035	10.00	Mx003	2.22	CK-60"B"	3.60
39	Cx009	7075.00	Cx00[illegible]	11.50	Rx035	9.97	Mx022	2.21	Cx032	3.60
40	Rx018	7041.75	RS-61[illegible]	11.45	Rx012	9.95	M"B"	2.21	Cx003	3.60
41	005	7002.50	BR-6[illegible]	11.30	Mx024	9.95	032	2.21	Mx001	3.60
42	010	7003.00	Rx034	11.30	Mx025	9.92	Cx022	2.20	Cx023	3.60
43	Mx032	6953.50	Cx018	11.30	Cx001	9.92	Mx032	2.20	Cx018	3.60
44	Mx021	6920.50	Cx02[illegible]	11.30	Mx004	9.90	Mx008	2.20	C 001	3.60
45	CK-60"B"	6912.25	Rx03[illegible]	11.25	Rx005	9.87	Cx010	2.19	Cx036	3.57
46	Cx026	6873.25	Cx015	11.25	NK-300	9.82	016	2.19	Mx015	3.57
47	Mx005	6818.00	010	11.25	Rx025	9.77	Cx036	2.18	Mx010	3.57
48	Cx015	6808.75	NK-300	11.20	Mx034	9.77	Rx034	2.17	Cx034	3.57
49	Cx032	6780.75	Rx027	11.20	Cx015	9.77	Rx027	2.17	015	3.57
50	Cx004	6764.75	Rx024	11.20	RS-610	9.75	Mx033	2.17	Rx023	3.55
51	Mx033	6743.50	Mx036	11.20	R"B"	9.75	Cx003	2.17	Mx016	3.55
52	RS-610	6727.75	021	11.20	Mx036	9.75	Mx025	2.16	Mx005	3.55
53	Rx024	6727.00	R"B"	11.15	Cx018	9.75	BR-64	2.16	C 008	3.55

Table 7. (continued)

Rank	Entry	Yield (Kg/ha)	Entry	Protein (non-defatted) %	Entry	Protein (fat-free)[2] %	Entry	Lysine[2] %	Entry	Oil %
54	Mx024	6670.50	Mx032	11.15	026	9.75	Cx012	2.15	BR-64	3.52
55	Cx024	6666.00	Mx016	11.15	Rx034	9.70	013	2.15	Rx005	3.52
56	Rx008	6650.00	032	11.15	Rx018	9.70	Cx018	2.14	Mx003	3.52
57	Rx023	6637.00	Mx026	11.10	Cx021	9.70	033	2.14	Cx032	3.52
58	Rx036	6598.00	Mx025	11.10	022	9.70	Cx009	2.12	026	3.52
59	Mx022	6562.50	Rx022	11.05	Cx009	9.67	Cx008	2.12	Rx012	3.50
60	Rx034	6555.25	Rx012	11.05	Cx005	9.67	012	2.12	Mx009	3.50
61	027	6541.50	Mx034	11.05	Cx025	9.62	RS-610	2.11	Cx005	3.50
62	Mx013	6521.50	Mx027	11.00	CK-60"B"	9.60	Mx013	2.09	BR-64	3.47
63	CK-60"B"	6490.25	Cx009	11.00	Rx010	9.60	Rx035	2.08	Mx021	3.47
64	Cx001	6483.00	Rx032	10.95	Rx004	9.57	Rx012	2.07	023	3.47
65	Cx025	6474.25	Rx013	10.95	032	9.57	Mx012	2.07	Rx027	3.45
66	028	6443.00	Rx010	10.95	021	9.57	CK-60"B"	2.06	Rx018	3.45
67	Mx018	6418.25	Cx004	10.95	R"B"	9.55	Mx036	2.06	Cx010	3.45
68	Mx027	6418.00	Cx004	10.95	Rx013	9.52	034	2.05	Rx003	3.42
69	Mx001	6335.25	026	10.85	Rx003	9.52	004	2.04	Mx025	3.42
70	Cx035	6379.75	003	10.85	Cx035	9.52	Rx018	2.04	Cx016	3.42
71	Mx015	6369.25	Cx018	10.80	Rx033	9.50	Cx016	2.03	008	3.42
72	RS-610	6366.25	Mx022	10.75	Cx026	9.50	027	2.03	Rx032	3.40
73	Cx008	6362.25	CK-60"B"	10.70	Cx032	9.47	010	2.03	Cx021	3.40
74	032	6356.75	025	10.70	Cx016	9.47	Mx016	2.01	Rx015	3.40
75	Rx022	6302.50	023	10.70	Mx009	9.42	R"B"	2.00	Mx035	3.40
76	Cx022	6298.75	022	10.70	025	9.42	CK-60"B"	2.00	Mx024	3.40
77	021	6275.00	RS-610	10.55	Rx036	9.40	NK-300	1.98	Cx003	3.40
78	Rx025	6257.75	Mx024	10.55	Cx033	9.37	Rx022	1.98	001	3.40
79	BR-64	6189.00	Cx027	10.55	Mx021	9.32	003	1.98	Rx016	3.37
80	Mx035	6127.50	Cx016	10.50	Mx016	9.32	Rx033	1.97	Rx034	3.35
81	013	6044.00	Cx009	10.50	Mx033	9.25	Cx015	1.97	Rx026	3.35
82	Rx035	6024.75	Rx005	10.45	Cx027	9.25	Mx015	1.96	Rx010	3.35

Table 7. (continued)

Rank	Entry	Yield (Kg/ha)	Entry	Protein (non-defatted) %	Entry	Protein (fat-free)2/ %	Entry	Lysine2/ %	Entry	Oil %
83	Cx033	6017.25	NK-300	10.40	Cx004	9.20	Mx005	1.95	Cx024	3.35
84	005	6006.25	Cx032	10.40	CK-60"B"	9.17	Mx010	1.94	032	3.32
85	023	6002.75	Rx016	10.35	NK-300	9.12	024	1.92	Rx008	3.30
86	035	5925.25	CK-60"B"	10.30	Cx036	9.10	Rx024	1.91	Rx001	3.30
87	Rx027	5911.75	Cx034	10.25	DS-610	9.02	Rx010	1.89	035	3.30
88	018	5896.25	BR-64	10.20	Cx034	8.97	035	1.89	NK-300	3.27
89	012	5879.50	Cx026	10.20	010	8.97	Mx013	1.88	Rx009	3.27
90	Rx001	5860.75	Cx024	10.20	003	8.97	Rx036	1.87	034	3.27
91	Cx013	5843.75	Cx013	10.20	Cx013	8.95	036	1.86	NK-300	3.25
92	M"B"	5834.50	Cx005	10.20	Cx016	8.90	Rx032	1.85	[illegible]	3.25
93	001	5817.25	[illegible]	10.15	Cx024	8.90	Rx013	1.83	[illegible] 009	3.25
94	025	5774.50	Cx003	10.10	Mx022	8.87	Rx008	1.83	024	3.25
95	Mx025	5653.50	Mx009	10.05	Rx022	8.82	Rx001	1.83	Cx035	3.22
96	Cx027	5564.75	Cx036	10.05	Rx026	8.72	Rx003	1.82	016	3.22
97	033	5515.75	Cx021	10.05	Rx021	8.72	Rx005	1.81	Rx025	3.17
98	024	5459.50	Rx004	10.00	BR-64	8.67	Mx001	1.80	Mx022	3.17
99	M"B"	5331.00	Cx022	9.90	Cx003	8.55	Cx001	1.78	021	3.17
100	008	5313.75	Mx003	9.85	Cx010	8.52	Mx035	1.78	010	3.17
101	009	5165.50	Cx010	9.85	Mx003	8.45	M"B"	1.77	Rx005	3.12
102	Rx012	5131.00	Rx021	9.80	BR-64	8.37	Cx035	1.76	009	3.10
103	016	5087.25	Mx021	9.70	Cx009	8.37	R"B"	1.74	Cx025	3.02
104	004	4992.50	Rx009	9.60	Mx023	8.35	005	1.74	Cx022	3.02
105	036	4892.00	Rx026	9.50	Rx009	8.32	001	1.71	003	3.02
106	034	4552.50	Mx023	9.50	Cx023	8.15	Rx015	1.61	Rx022	2.95
107	015	4417.75	Cx023	9.10	Rx023	8.00	015	1.59	025	2.95
108	Cx018	4282.00	Cx003	9.10	Cx022	7.75	008	1.54	022	2.77

Table 7. (continued)

	Yield (Kg/ha)	Protein (non-defatted) %	Protein (fat-free)2/ %	Lysine2/ %	Oil %
Dunnett's t.05a/	1376.87	1.22	1.40	0.45	0.19
Dunnett's t.01	1791.27	1.59	1.85	0.59	0.25
Tukey's w.05b/	2276.74	1.98	2.34	0.68	0.29
Tukey's w.05c/					
CK-60 ms	2788.99	2.57	2.68	0.74	0.35
Martin ms	2644.46	2.01	2.60	0.98	0.35
Redlan ms	2948.61	2.34	2.55	0.86	0.42
Tukey's w.05d/	2416.22	2.44	3.56	1.33	0.38

1/ The 3 "B" lines of the male steriles and the 3 check varieties grown in double entries per replication

2/ Mean values for % protein (fat-free) and % lysine averaged over 2 replications

a/ Dunnett's procedure used for comparing the means of each of the 3 F_1 hybrids having a common male parent against the means of the respective male parents

b/ Tukey's w- procedure used for comparing the means of each of the 3 F_1 hybrids having a common male parent

c/ Tukey's w- procedure used for comparing the means among the 24 F_1 hybrids having a common female parent

d/ Tukey's w- procedure used for comparing the means among the 24 male parents, the 3 "B" lines of the male steriles and the 3 check varieties

2. An Investigation of the Transmission of Protein, Lysine, Oil and Certain Other Characteristics from Sudangrass Lines to Cultivated Grain Sorghum. Sam Mukuru (Abstract of 1970 M.S. Study).

Eleven grain sorghum and thirty-five sudangrass lines were each crossed to the Redlan cytoplasmic male sterile line. Four of the grain sorghum lines and eight of the sudangrass lines were also crossed to the Martin cytoplasmic male sterile line. All the F_1 hybrids, pollinator lines, Redlan and Martin "B" lines and four checks were planted in 1970 at the Purdue University Agronomy Farm. There were three replications in a randomized complete block design. Several agronomic characteristics were recorded in the field and laboratory on a plot basis.

There were significant differences between grain sorghum male parents and sudangrass male parents for most characters recorded. Sudangrass pollinator lines had significantly more panicles per plot, percent protein and oil than grain sorghum male parent lines. However, sudangrass lines were significantly less than grain sorghums in yield, weight per 100 seeds and percent lysine. The superiority or inferiority of sudangrass for most traits was transmitted and maintained in their offsprings.

Variation among sudangrass male lines ranged from 10.47 to 16.53 for percent protein; 3.60 to 6.02 for percent oil. However, these ranges were reduced among their F_1 hybrids and were 8.83 to 13.67 for percent protein and 3.69 to 4.59 for percent oil. The genetic factors which control several traits in grain sorghum and sudangrass appear

to be similar in the manner in which they are transmitted to their offspring but are different in magnitude.

The Redlan x sudangrass F_1 hybrids per se were significantly better than the Redlan "B" line for percent protein and percent oil but significantly less for weight of 100 seeds. No significant differences were obtained for yield and percent lysine though there were some individual F_1's that outyielded Redlan "B" line by far.

In general the Redlan x sudangrass F_1 hybrids had longer and broader leaves and thicker stems than their male sudangrass progenitors. However, panicle shape resembled that of sudangrass lines though weight of seeds approximated that of the grain sorghum parent.

Significance was indicated more often for GCA than for SCA indicating that additive gene action was more important in the expression of most traits studied. However, for weight of 100 seeds, days to half bloom and percent oil, SCA was also significant which suggests that both additive and non-additive gene action appeared to influence the expression of these traits.

The expression of hybrid vigor for grain sorghum and sudangrass was similar for each character studied except that the mean percent heterosis was higher for sudangrass than for grain sorghum with the exception of lysine. This is probably to be expected because of the genetic diversity between the two groups.

Percent protein and lysine were negatively and significantly correlated for sudangrass F_1 hybrids ($r = -.788$) and sudangrass male

parents. Percent protein and oil were significantly correlated for grain sorghum male parents ($r = .487$). A positive and significant association was obtained between protein and weight of 100 seeds for sudangrass F_1 ($r = .571$) and grain sorghum parents ($r = .568$). Oil content and weight of 100 seeds were negatively and significantly correlated among sudangrass male parents ($r = -.341$) but positively and significantly correlated among grain sorghum male parents ($r = .707$). All correlations were computed using nonsegregating populations and may be somewhat different in segregating populations.

Table 1. Grand means and ranges for five characters of 35 sudangrass parents, 35 Redlan x sudangrass F_1 hybrids, 8 Martin x sudangrass F_1 hybrids, 11 grain sorghum parents, 11 Redlan x grain sorghum F_1 hybrids and 4 Martin x grain sorghum F_1 hybrids 1970. Lafayette

Characters		Sudangrass			Grain sorghum		
		Parents	Redlan F_1 hybrids[1]	Martin F_1 hybrids[1]	Parents	Redlan F_1 hybrids[1]	Martin F_1 hybrids[1]
Yield in kg/ha	Grand mean	3232	4801	4442	5135	5739	5361
	Ranges	1525 - 4898	1242 - 6915	3288 - 5264	2129 - 7455	4123 - 6707	4921 - 5882
Weight in grams of 100 seeds	Grand mean	1.23	2.09	2.05	2.86	3.00	2.88
	Ranges	0.93 - 2.07	1.51 - 2.61	1.82 - 2.22	2.41 - 3.67	2.67 - 3.45	2.65 - 3.11
Percent Protein	Grand mean	12.39	10.65	11.20	10.47	9.55	10.12
	Ranges	10.47 - 16.53	8.83 - 13.67	10.53 - 12.30	8.27 - 12.57	8.20 - 12.30	8.27 - 11.20
Percent lysine	Grand mean	2.25	2.27	2.24	2.45	2.45	2.32
	Ranges	1.87 - 2.67	1.84 - 2.73	2.00 - 2.38	2.26 - 2.73	2.08 - 2.69	2.03 - 2.52
Percent oil	Grand mean	4.68	4.18	4.36	3.76	3.64	3.61
	Ranges	3.60 - 6.02	3.69 - 4.59	3.97 - 4.59	2.66 - 5.33	3.07 - 4.10	3.57 - 4.10

Table 2. Analysis of variance for 9 characters of all 116 sudangrass and grain sorghum lines and hybrids: 1970, Lafayette, Indiana

Source of Variation	df	Mean Squares			
		Panicles/Plot	Grain Yield	Threshing	Weight of 100 Seeds
Replication	2	12,880.34**	39,708,857**	6,225.39**	0.0181
Among entries	115	15,393.12**	5[illegible],513,391**	179.28**	1.4531**
Among sudangrass male parents	34	10,446.32**	2,226,016**	157.23**	0.1927**
Among Redlan x sudangrass F_1 hybrids	34	1,123.08	3,747,958**	93.95	0.1063**
Among Martin x sudangrass F_1 hybrids	7	431.75	2,308,290**	32.17	0.0669**
Among grain sorghum male paretns	10	744.09	6,058,805**	257.87**	0.3068**
Among Redlan x grain sorghum F_1 hybrids	10	7,037.09**	2,141,851*	68.27	0.1706**
Among Martin x grain sorghum F_1 hybrids	3	157.11	478,729	46.93	0.1355**
Among "B" lines	3	484.55	1,757,637	131.54	0.0097
Among checks	7	16,753.80**	5,988,145**	167.79*	2.6661**
Sudangrass male parents vs grain sorghum male parents	1	535,020.19**	90,957,734**	1,210.77**	66.7694**
Redlan x sudangrass F_1 hybrids vs Redlan x grain sorghum F_1 hybrids	1	2,923.04	22,124,495**	55.74	20.8056**
Martin x sudangrass F_1 hybrids vs Martin x grain sorghum F_1 hybrids	1	10,344.01*	6,744,852**	48.18	5.5334**
"B" lines vs checks	1	4,851.12	4,790,028*	51.85	0.0460
Sudangrass and grain sorghum Redlan F_1 hybrids vs sudangrass and grain sorghum Martin F_1 hybrids	1	515.12	2,185,437	0.90	0.0164
Sudangrass and grain sorghum male parents vs Redlan and Martin F_1 hybrids	1	610,975.49**	126,273,393**	5,494.43**	36.7147**
Sudangrass and grain sorghum male parent plus their Redlan and Martin F_1 hybrids vs "B" lines and checks	1	12,184.29**	928,264**	19.17	2.7160**
Error	230	1,674.18	1,004,634	65.61	0.0206
CV		30.72	24.05	12.14	7.12

* Significant at .05 level ** Significant at .01 level