AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523

BIBLIOGRAPHIC INPUT SHEET

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Batch #24

1. SUBJECT CLASSIFICATION

A. PRIMARY: Serials — Y-AF30-0170-0000

B. SECONDARY: Agriculture--Plant breeding--Cereals--Sorghum

2. TITLE AND SUBTITLE

Inheritance and improvement of protein quality and content in Sorghum bicolor (L.) Moench; annual report,1973

3. AUTHOR(S)

(101) Purdue Univ. Dept.of Agronomy

4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1974	83p.	ARC 633.174.P985b

7. REFERENCE ORGANIZATION NAME AND ADDRESS

Purdue

8. SUPPLEMENTARY NOTES *(Sponsoring Organization, Publishers, Availability)*

(Adm.and research summaries)

9. ABSTRACT

10. CONTROL NUMBER	11. PRICE OF DOCUMENT
PN-RAB-403	
12. DESCRIPTORS	**13. PROJECT NUMBER**
Proteins Sorghum	**14. CONTRACT NUMBER** CSD-1175 Res.
	15. TYPE OF DOCUMENT

AID 590-1 (4-74)

ANNUAL REPORT

on

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

January 1, 1973 - December 31, 1973

Report No. 10

NOT FOR PUBLICATION

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Contract csd/1175

Submitted to:

Agency for International Development
Department of State
Washington, D. C.

REPORT SUMMARY

A. 1. Project Title and Contract Number: "Inheritance and Improvement of Protein Quality and Content in Sorghum bicolor (L.) Moench". Contract No. PRF-AID/csd-1175.

2. Principal Investigator: John D. Axtell, Department of Agronomy Contractor and Mailing Address: Purdue Research Foundation, Purdue University, W. Lafayette, Indiana 47907.

3. Contract Period (as amended): July 1, 1966 to March 31, 1975.

4. Period covered by report: January 1, 1973 to December 31, 1973.

5. Total AID funding of contract to date: $1,422,390.00.

6. Total expenditures and obligations through previous contract year: $1,172,419.00.

7. Total expenditures and obligations for current contract year: $250,642.98.

8. Estimated expenditures for next contract year: (4-1-74 to 3-31-75): $285,000.00.

B. Narrative Summary of Accomplishments and Utilization: Grain sorghum is a major source of carbohydrate and protein for many millions of people in the developing world. It is generally recognized that the nutritional quality of many sorghums now being consumed is relatively poor when compared to other major cereals. This project has identified some of the problems responsible for this poor nutritional quality through a closely coordinated interdisciplinary approach by animal nutritionists, biochemists and plant geneticists. Protein quality is limited by the low lysine content of the sorghum grain, which reflects the high prolamine content of the endosperm. The tannin compounds present in the grain of some cultivars substantially reduce protein availability, which indirectly has a major negative effect on the nutritional quality of grain sorghum. During the past year significant progress has been made toward the understanding and alleviation of both of these limiting factors.

Two high lysine sorghum lines from the tropical highlands of Ethiopia have been identified by research conducted on this project. Inheritance studies demonstrate that the increased lysine concentration of each line is controlled by a single recessive gene. The biological value of the high lysine sorghum is double or triple that of average sorghum grain. This and related discoveries provide the tools needed to potentially upgrade the nutritional status of millions of sorghum-consuming people in developing countries.

A second set of entries in an International Protein Yield and Quality Trial nursery has been established at approximately 21 locations throughout the world to determine the adaptability of improved germplasm and to monitor progress made in the improvement of nutritional quality. Research information has been distributed through seminars, journals, publications and annual reports. Graduate student and post-doctorate training programs continue to supply needed trained scientists for sorghum improvement programs in temperate and tropical areas of the world.

PERSONNEL

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Department of Animal Science (Cooperating Staff)

Dr. W. R. Featherston (Professor)

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Mr. W. D. Armstrong (Graduate Student)*

* Graduate students that are conducting research pertinent to the objectives but not financially supported by this contract.

A. GENERAL BACKGROUND

Sorghum is the fourth most important cereal crop in the world, being surpassed only by rice, wheat and corn in world-wide importance. In Africa and much of Asia it is the principal source of energy for many millions of people and provides a major source of protein in the human diet. Though it is considered relatively high in carbohydrates and a fair source of total protein compared to most cereal crops, the protein quality is the poorest of the major cereals with regard to amino acid balance and total digestibility.

The purpose of this project is to develop and release for utilization in the LDCs superior varieties or lines of sorghum with genetically controlled higher protein content, improved amino acid balance and total digestibility. Thousands of lines from the world sorghum collection and the various breeding programs are being evaluated for levels of total protein and for quality by chemical and biological means. The more promising strains are recombined in various ways to improve further the amount and quality of protein in breeding populations. The parameters of inheritance of the high nutritional quality factors are in the process of being determined. Lines which do not produce seed at Purdue are sent to Puerto Rico for multiplication. There these lines are screened for improved yield for the tropics and seed returned to Purdue for screening of nutritional characteristics. Selected germplasm and supporting cultural practice information are provided to established programs and interested cooperators to test, screen and to assist in the exchange of breeding materials. Graduate degree and non-degree training programs at Purdue are developed and regularly conducted

to increase the research capacity of developing nations with the desire to improve the nutritional quality of their sorghum.

B. STATEMENT OF PROJECT OBJECTIVES AS STATED IN THE CONTRACT.

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

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.

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.

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.

Objective 5 - Disseminate research information and germplasm with superior nutritional quality for utilization in the LDCs.

C. CONTINUED RELEVANCE OF OBJECTIVES

The identification of a high lysine gene in sorghum during 1973 necessitates some shift in emphasis during the 1974-75 contract year. The hl gene present in IS 11758 and IS 11167 germplasm from Ethiopia is associated with a floury endosperm phenotype. A major research effort

in 1974 will be directed toward two important objectives. First, an attempt will be made to identify modifier genes in world sorghum germplasm which will shift the endosperm phenotypes of high lysine kernels from floury to vitreous types. Second, an endosperm mutant has been identified in sorghum which is similar to the sugary-2 gene in maize known to improve kernel characteristics in $\underline{su}_2$, $\underline{su}_2$, $\underline{o}_2$, $\underline{o}_2$ combinations. Kernel characteristics of double mutant (hl, hl, "$\underline{su}_2$" "$\underline{su}_2$") genotypes will be evaluated in sorghum during 1974.

D. ACCOMPLISHMENTS TO DATE

1. Findings.

The major research achievement during 1973 was the identification of a high lysine mutant gene (hl) that substantially improves the protein quality and biological value of sorghum grain. The average whole grain lysine concentration of high lysine lines IS 11167 and IS 11758 was 3.34 and 3.13 (g/100 g protein) at 15.7 and 17.2% protein, respectively. Both lines were also high in percent oil. Carbohydrate analyses of whole grain samples of the two high lysine lines were similar to that of normal sorghum grain except for a slight increase in sucrose concentration.

Inheritance studies suggest that the increased lysine concentration of each line is controlled by a single recessive gene, although it is not known whether the genes from both lines are allelic. The high lysine gene(s) present in IS 11167 and IS 11758 from Ethiopia is (are) herein designated as hl. The endosperm of kernels homozygous for the hl gene

is partially dented.

The biological value of the high lysine lines was much higher than that of average sorghum lines. In a 28-day isonitrogenous feeding experiment the weight gain of weanling rats was three times higher on an IS 11758 ration and twice as high on an IS 11167 ration as weight gains on rations prepared from normal sorghum lines. When fed rations without any dilution except the usual 2% vitamin and 4% mineral supplementation, rats gained 94 g on high lysine sorghum (IS 11758) and 28.5 g on our current best nutritional quality sorghum lines (IS 2319), versus 91.5 g on opaque-2 corn (Zea mays L.) and 30.2 g on normal corn in a 28-day feeding trial. Feed efficiency ratios for this trial were 3.0 for high lysine sorghum, 6.8 for IS 2319, 3.4 for opaque-2 corn, and 7.4 for normal corn.

It should be emphasized that no information is available on the yield potential of IS 11167, IS 11758 or other hl/hl lines or hybrids that may be derived from them in the future. The dented, floury endosperm phenotype may pose agronomic problems similar to those encountered in other cereals containing mutant genes for improved quality. The identification of a high lysine gene in IS 11167 and IS 11758, however, represents a significant step toward improvement of the nutritional quality of grain sorghum.

2. Interpretation of Data and Supporting Evidence.

Sixty-two floury endosperm lines were identified from the world sorghum collection on the basis of endosperm phenotype. Floury grains have a soft, chalky white endosperm when longitudinal sections are examined. It is important to use fully mature kernels for this classification, because

seed of normally vitreous genotypes may also appear floury when immature. The protein and lysine concentrations of whole grain samples from single analysis of each of these selected lines are shown in Figure 1. Two floury lines, IS 11167 and IS 11758, of Ethiopian origin were markedly different from the other lines. Most of the floury endosperm sorghum lines, however, had normal amounts of protein and lysine. This parallels the situation in corn, where many genes express floury/opaque endosperm phenotypes but only opaque-2, opaque-7, and floury-2 have a pronounced effect on lysine content.

The chemical composition and seed characteristics of whole grain samples of IS 11167 and IS 11758 in comparison with averages of normal sorghum lines are presented in Table 1. The lysine concentration (percent of sample) of both high lysine lines was approximately double that of the average for sorghum. Tannin (expressed as catechin equivalents) in both Ethiopian high lysine lines was low, and fell below the level known to interfere with protein availability in monogastric animals. The high percent oil and increased percent germ of the high lysine grain may be in part a consequence of the dented endosperm phenotype. Even though the endosperm of IS 11167 and IS 11758 was partially dented, the 100-seed weight of both lines was nearly equivalent to the average of 31 lines and hybrids of normal sorghum. Several endosperm mutants with shrunken kernel phenotypes have been studied in maize and all are characterized by a variable but substantial reduction of starch content in endosperm tissue, with a concomitant accumulation of total sugars and/or water soluble polysaccharides. The data (Table 1) demonstrate that the starch concentration of

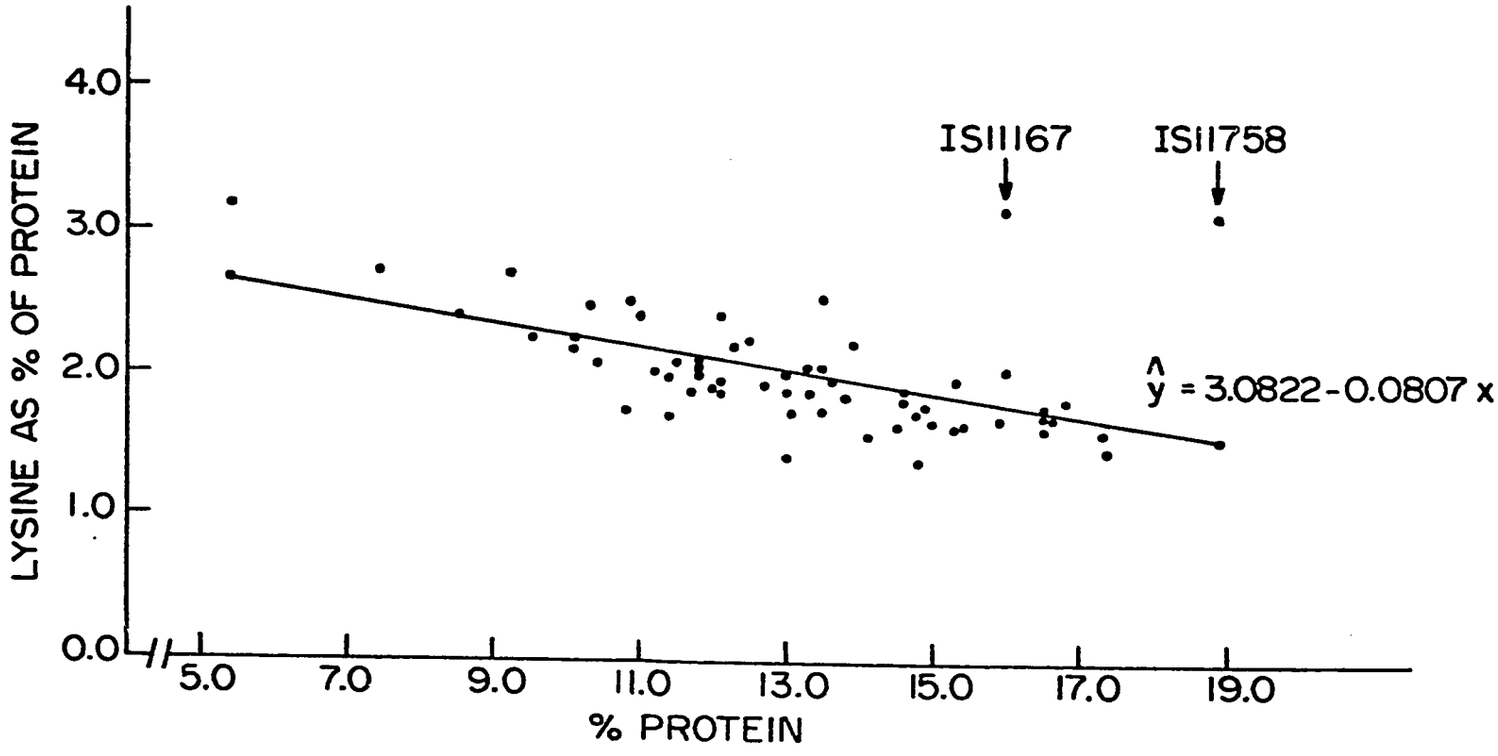

Figure 1. Regression of lysine (single analyses) on percent protein for 62 floury endosperm lines selected from the world sorghum collection.

Table 1. Chemical composition and seed characteristics of whole grain samples of high lysine and normal sorghum lines.

Character:	High lysine lines[1] IS 11167	IS 11758	Normal Sorghum
Protein Composition			
Protein (%)	15.70	17.20	12.70[2]
Lysine (g/100 g protein)	3.33	3.13	2.05[2]
Lysine (% of sample)	0.52	0.54	0.26[2]
Protein per seed (mg)	4.38	4.21	3.53[2]
Lysine per seed (mg)	0.15	0.13	0.07[2]
Chemical Composition			
Catechin equivalent	0.34	0.37	0.38[3]
Oil (%)	5.81	6.61	3.32[2]
Seed Characteristics			
Percent germ	14.60	16.30	10.10[4]
Seed weight (g/100 seeds)	2.78	2.45	2.75[2]
Carbohydrate Composition			
Reducing sugars (% of sample)	0.38	0.32	0.34[5]
Sucrose (% of sample)	3.08	2.61	1.03[5]
Total sugars (% of sample)	3.46	2.93	1.34[5]
WSP (% of sample)	0.91	1.01	1.11[5]
Starch (% of sample)	58.90	57.80	60.80[5]
Amylose (% of starch)	25.00	26.20	25.00[5]
Total carbohydrates (% of sample)	63.27	61.74	63.25[5]

[1] Protein composition data are based on the average of six analyses per line. Chemical composition, seed characteristics and carbohydrate composition data are based on single analysis.

[2] Average of 31 genotypes over six locations and two years.

[3] Average of 300 low tannin lines in the world sorghum collection.

[4] Average of four lines.

[5] Values based on one normal line, (IS 8313).

whole grain samples of both high lysine lines was nearly equivalent to that of the normal check line. There was no change in the relative amounts of reducing sugars or water soluble polysaccharides in the high lysine lines, but there was a slight increase in sucrose concentration. An increase in sucrose of similar magnitude has also been reported for opaque-2 corn. The dented endosperm phenotype associated with the high lysine characteristic in the original Ethiopian sorghum lines, and also in F_1 panicles segregating for the hl gene may be due to a pleiotropic effect of the hl gene itself or, alternatively, it may be a consequence of linked modifier genes that alter the normal plump configuration of the sorghum grain. The complete absence of vitreous starch in hl hl hl endosperm tissue may influence the normal conformation of the grain.

Phenotypic classification of kernels was carried out on F_2 seeds derived from crosses between genetic male sterile "normal" plants (PP3Rms_3) and each high lysine sorghum line. Normal (low lysine) kernels were plump with a vitreous endosperm while high lysine kernels were floury with a partially dented endosperm. All F_1 seeds obtained from ms_3 x IS 11167 and ms_3 x IS 11758 crosses had a vitreous endosperm. Chi-square analysis of F_2 segregation ratios (Table 2) indicated a good fit, 3 vitreous:1 floury ratio, for progeny of both crosses. The results of this study suggest that the high lysine character is inherited as a simple recessive.

Data on protein and lysine concentration of endosperm tissue from vitreous and floury F_2 kernels borne on F_1 panicles (Table 3) provide critical evidence of the effect of the allele on lysine, because genetic background differences should be randomized between normal and mutant

Table 2. Segregation ratios of F_2 kernels from crosses between normal (PP3R$\underline{ms}_3$) and high lysine sorghum lines.

F_1 cross		Number of F_2 kernels				
Female	Male	Vitreous	Floury	Total	X^2*	Prob.
PP3R$\underline{ms}_3$	x IS 11167	3593	1167	4760	0.592	0.25-0.50
PP3R$\underline{ms}_3$	x IS 11758	2376	815	3191	0.497	0.25-0.50

* Based on 3:1 expected ratio.

Table 3. Protein and lysine concentration of defatted endosperm tissue of segregating F_2 vitreous and floury kernel classes derived from crosses between normal (PP3R$\underline{ms}_3$) and high lysine sorghum lines.

Cross	Panicle number	F_2 seed class	Percent protein	Lysine (g/100 g protein)	Lysine (percent of sample)
PP3R$\underline{ms}_3$ x IS 11167	1	vitreous	9.8	1.68	.165
	1	floury	10.1	2.83	.286
	2	vitreous	10.6	1.37	.145
	2	floury	11.2	2.24	.251
Mean		vitreous	10.2	1.52	.155
		floury	10.6	2.53	.268
PP3R$\underline{ms}_3$ x IS 11758	1	vitreous	12.2	1.10	.134
	1	floury	14.8	2.29	.389
	2	vitreous	10.4	1.36	.141
	2	floury	11.9	2.78	.331
Mean		vitreous	11.3	1.23	.137
		floury	13.3	2.54	.360

classes. The average lysine concentration (expressed as percent of protein) of the endosperm of vitreous kernels from both crosses was 1.38% compared to 2.53% for the endosperm of floury kernels, which represents an average increase in lysine of 83%. The increases are more pronounced when lysine is expressed as percent of dry sample because of the consistently higher percent protein of floury endosperm tissue. The protein and lysine concentrations of embryo tissue from segregating F_2 normal and floury mutant kernels was 24.1 vs 24.4% protein and 5.11 vs 5.60% lysine (expressed as percent of protein), respectively. Therefore, the primary effect of the hl allele on protein and lysine concentrations of sorghum kernels was confined to endosperm tissue.

The amino acid compositions of defatted endosperm tissue of grain from vitreous and floury classes from segregating F_2 seeds are presented in Table 4. Lysine, arginine, aspartic acid, glycine, and tryptophan were consistently higher in the floury endosperm class. Glutamic acid, proline, alanine, and leucine were lower in the floury endosperm class. The shift in amino acid pattern in the floury endosperm class was comparable to that reported for the opaque-2 mutant in corn.

The data suggest that the increased amount of lysine in IS 11167 and IS 11758 is controlled by a single recessive gene. Because the high lysine genes present in both Ethiopian lines were similar in their effect on protein and lysine, the gene symbol hl is herein assigned to both pending completion of allelism tests.

Table 4. Amino acid (duplicate runs, g/100 g protein) and protein content of defatted endosperm tissue from segregating F_2 vitreous and floury seed classes derived from crosses between normal (PP3R$\underline{ms}_3$) and high lysine sorghum lines.

	PP3R$\underline{ms}_3$ x IS 11167		PP3R$\underline{ms}_3$ x IS 11758	
Amino Acid	Vitreous	Floury	Vitreous	Floury
Lysine	1.20	2.18	1.30	2.59
Histidine	1.99	1.91	1.94	2.04
Arginine	2.55	3.66	2.77	4.44
Aspartic Acid	5.56	7.49	6.14	7.24
Threonine	2.56	3.01	2.75	3.11
Serine	3.74	4.09	3.84	3.99
Glutamic Acid	26.68	23.98	27.99	20.82
Proline	7.92	6.91	8.35	6.39
Glycine	2.17	2.97	2.37	3.40
Alanine	10.15	9.65	10.50	8.68
Cystine	2.07	1.52	1.83	1.76
Valine	4.35	4.98	4.71	4.78
Methionine	1.60	1.52	2.11	1.93
Isoleucine	3.90	4.16	4.05	3.99
Leucine	15.72	14.33	15.93	12.62
Tyrosine	4.28	4.32	4.54	4.24
Phenylalanine	5.45	5.45	5.52	5.24
Tryptophan	0.92	1.21	0.93	1.74
Percent protein	9.75	10.75	9.69	12.06
Leucine/isoleucine	4.03	3.44	3.93	3.16

Biological Value

Experiment 1: Based on their improved amino acid composition, the high lysine sorghum lines should have a higher biological value than the average sorghum. Therefore, the biological value of two high lysine lines, three normal sorghum lines, and a casein-bearing diet were compared. IS 2319 has good nutritional quality and was used as the best check line in nutritional studies at Purdue. All grain rations were fed as isonitrogenous diets at approximately 10% protein except for the casein diet, which was fed at 13.3% protein.

Data on the chemical composition of whole grain samples and composition of the rations, as well as rat weight gain, feed efficiency ration (FER), and protein efficiency ratio (PER), are given in Table 5. The average initial weight of weanling rats was 47.2 g. There was no significant difference in average initial weight between groups of rats placed on different diets. Weight gain on the IS 11758 diet was nearly double that of IS 2319 and three times higher than the average of normal sorghum lines. Gain in weight of rats on the IS 11167 rations was 71% of gain on the IS 11758 ration. However, it was significantly ($P < .01$) superior to the control sorghum lines, and was 36% better than IS 2319 in terms of rat weight gain. The PER values for both high lysine sorghum lines were higher than the average PER for normal sorghum, but were lower than that for casein.

Experiment 2: This experiment was designed to compare the biological value of a high lysine sorghum line and other grain diets when fed at their inherent grain protein levels. Because sorghum grain is consumed by large numbers of people, it is important to evaluate the nutritional value of the

Table 5. Biological values of isonitrogenous (10% protein) diets prepared with high lysine and normal sorghum lines in a 28-day rat feeding experiment.

Source	Composition of grain		Composition of feed			Weight gain (g)	FER	PER
	Percent protein	Lysine (g/100 g protein)	Percent protein	Lysine g/100 g protein	Lysine Percent of sample			
High lysine lines:								
IS 11167	16.6	3.36	10.1	2.81	.284	34.5	5.6	1.78
IS 11758	18.0	3.38	10.0	3.15	.315	48.8	4.9	2.06
Normal lines:								
IS 2319	12.7	2.30	10.9	2.25	.245	25.3	7.5	1.24
IS 2520	13.3	1.85	11.2	1.76	.197	10.3	13.3	0.61
IS 1269	14.8	2.10	10.7	2.01	.215	14.0	13.3	0.74
Mean of normal lines:	13.6	2.08	10.9	2.01	.219	16.5	11.3	0.86
Casein	91.0	8.00	13.3	7.36	.979	85.8	3.5	2.20
C.V.,%						31.0		
S.E. of individual line mean						4.6		
LSD 5% (between individual line means)						13.4		
LSD 1% (between individual line means)						18.2		

whole grain in a monogastric test animal. IS 11758 was compared with two normal sorghum lines (IS 2319 and IS 1484), opaque-2 corn, normal corn, and a casein diet. Opaque-2 corn was included in this trial as a cereal with good nutritional quality. Protein and lysine concentrations of the rations and the 28-day rat weight gain and FER values are presented in Table 6. Weight gains at 7-day intervals through the 28-day feeding trial are also given in Figure 2.

The rat weight gains show that the biological value of IS 11758 was four times higher than the average of two normal sorghum lines and over three times higher than IS 2319 when fed at whole grain protein levels (Table 6, Figure 2). When compared to the corn diets, the IS 11758 diet fed at 18.4% protein was equivalent to the opaque-2 corn diet containing 12.1% protein. The FER value of the high lysine sorghum ration indicated that less than half as much feed was required per unit gain than was needed on normal sorghum diets. These two experiments demonstrate unequivocally that the two Ethiopian high lysine sorghum lines are substantially superior in biological value to any sorghum line currently identified.

It should be emphasized that no information is available on the yield potential of IS 11167, IS 11758, or other hl/hl lines or hybrids that may be derived from them in the future. The dented, floury endosperm phenotype may pose agronomic problems similar to those encountered in other cereals containing mutant genes for improved quality. The identification of a high lysine gene in IS 11167 and IS 11758, however, represents a significant step toward improvement of the nutritional quality of grain sorghum.

Table 6. Biological values of 94% whole grain rations prepared from high lysine sorghum, normal sorghum, opaque-2 corn and normal corn in a 28-day rat feeding experiment.

Source	Composition of grain		Composition of feed			Weight gain (g)	FER
	Percent protein	Lysine (g/100 g protein)	Percent protein	Lysine g/100 g protein	Lysine Percent of feed		
High lysine line:							
IS 11758	18.4	3.38	18.4	3.17	.583	94.2	3.0
Normal sorghum:							
IS 2319	12.7	2.30	12.6	2.23	.281	28.5	6.8
IS 1484	14.0	1.93	12.6	2.01	.253	19.2	8.5
Mean for normal sorghum:							
	13.3	2.11	12.6	2.12	.267	23.9	7.6
Opaque-2 corn	12.5	4.00	12.1	3.89	.47	91.5	3.4
Normal corn	9.4	2.73	8.6	2.90	.249	30.2	7.4
Casein	91.0	8.00	17.2	6.42	1.104	181.2	2.0
C.V.,%						16.7	
S.E. of individual line mean						5.0	
LSD. 5% (between individual line means)						14.7	
LSD. 1% (between individual line means)						19.9	

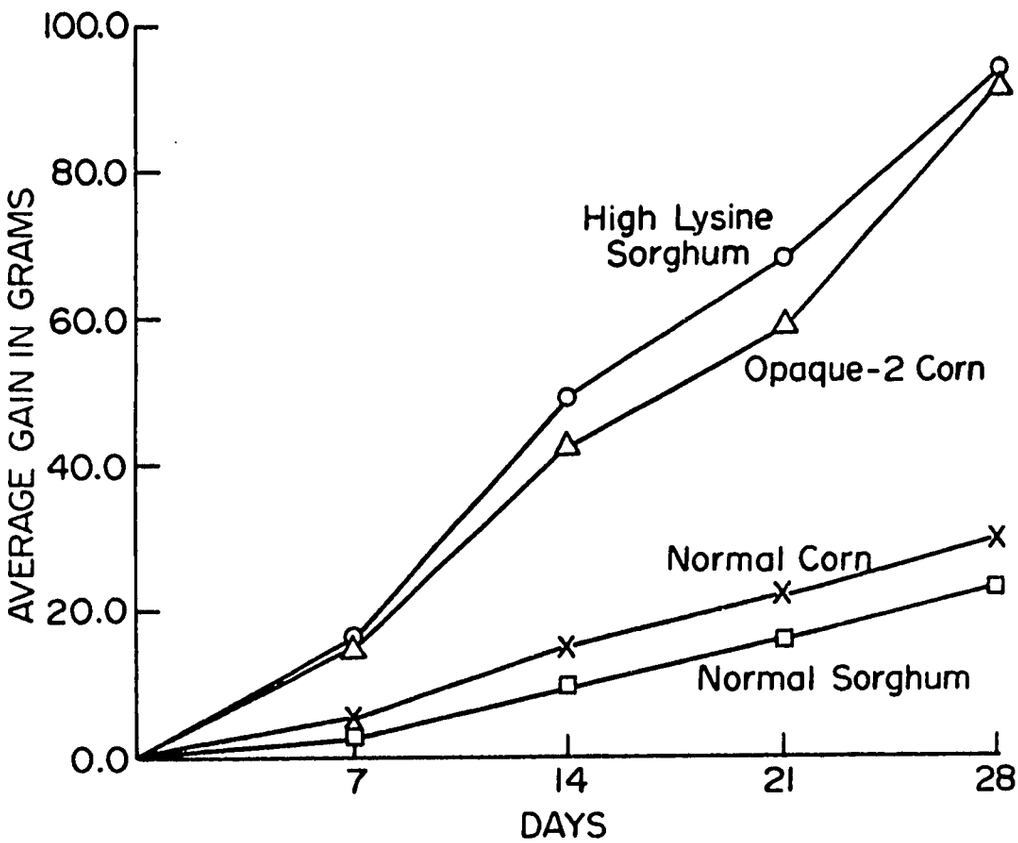

Figure 2. Average weekly cumulative weight gains of weanling rats fed rations composed of 94% whole grain, 2% vitamins, and 4% minerals.

3. Research design.

The ninhydrin technique developed by Drs. Mertz, Jambunathan and Misra (Rapid ninhydrin color test for screening high lysine mutants of maize, sorghum, barley and other cereal grains. Cereal Chemistry 51:2), is being evaluated in sorghum as a potentially useful method for rapid identification of mutants which block prolamine synthesis. Preliminary evidence suggests that both high lysine lines from Ethiopia are identifiable using this technique.

E. DISSEMINATION AND UTILIZATION OF RESEARCH RESULTS

1. Dissemination of Results.

a. Research report.

The 1972 annual research report was sent to over 560 cooperators who requested it from 81 countries. A computerized mailing list of interested sorghum workers was furnished to ICRISAT, AID, the Texas sorghum program and others who requested a listing of current workers in sorghum production.

b. High lysine discovery.

The high lysine sorghum discovery by this project was officially announced at the State Department in Washington by AID administrator John Hannah on September 28, 1973. Simultaneously, Purdue University Office of Agricultural Information announced the discovery. The technical research article appeared in Crop Science 13:535-539. (See Section H. Appendices for samples of news releases and other related articles.)

Mass media coverage of the discovery resulted in more than 91 news articles and 16 editorials. The news coverage was frequently given front page placement, most notably in the Washington Post, the New York Times, San Francisco Chronicle and the Chicago Tribune. Virtually every major daily newspaper in the United States carried the story, usually giving the story at least a three-column head and some 15-column inches of print. Aggregate minimum circulation of the story was more than 16.8 million.

The Voice of America broadcast the story worldwide, as did BBC, based on a telephone interview with Dr. Axtell. Dr. Oswalt was featured on a 30-minute TV agricultural feature called "Urban-Suburban", originating in Dayton, Ohio. Several other reporters have interviewed staff personnel resulting in a TV documentary by the American Chemical Society called "Men and Molecules" and various journal articles, including Prairie Farmer, Farm Journal, The Drover's Journal, The Messenger, AID-Front Lines, War on Hunger, The Hog Farmer, Agricultura de las Americas and Science.

The following research workers have received the high lysine gene materials: R. Schaffert and M. Faris, Brazil; the President of Niger; S. Mukuru, Uganda; G. Chen, Malaysia; L. House, Lebanon; H. Doggett, ICRISAT-India; O. Webster, Puerto Rico; E. Johnson, Mexico; F. Miller, Texas; G. Dalton, Texas (Pioneer); R. Brawn, Illinois (Funk); G. Liang, Kansas; N. Koepp, Texas (Growers Seed Assoc.); P. Menge, Minnesota (Northrup, King); G. Robison, Nebraska (DeKalb); H. Kim, Korea; P. Rotar, Hawaii; W. Golden, Ceylon;

B. Maunder, Texas (DeKalb); B. Wiseman, Georgia; F. Sands, Virgin Islands; J. Monyo, Tanzania; and R. Nunes, Brazil. Additional breeder supplies have been requested and will be sent in 1974 as far as seed and facilities can accomodate. Accompanying each of these has been a request for return to us of environmental data and general observations as they grow and work with these breeder supplies of seed. In order to accomodate the demands for seed and also to evaluate the adaptation and yield potential of the high lysine lines increases have been made in Puerto Rico and are being made in Brazil, Ethiopia, Sudan and India.

c. Seminars and papers presented.

Seminars on protein quality improvement in sorghum were presented by the Director at Texas Tech University, ICRISAT-India, College of Agriculture at Alemaya, Ethiopia; and at ALAD in Lebanon. Within Purdue University seminars were given by project personnel in the Agronomy, Animal Science and Horticulture departments. Papers were presented at the American Society of Agronomy meetings and American Society of Animal Science meetings as well as the Sorghum Research Workers Conference in Oklahoma. The project director participated in the AID-sponsored Fortification Workshop in Washington, D. C.

d. Selected germplasm utilization.

The First International Protein Yield Trials (Study 298) iniated in 1972 have resulted in the collection of data that has identified lines having a wide adaptation selected by cooperators for use in their related programs. Tables 1, 2 and 3 show the adapta-

Table 1. Summary of Study 298 days to flower, height and grain yield for 15 locations reporting all data.

Entry No.	Ident.	15 Locations			5 Indiana Locations			10 Other Locations		
		Flower days	Ht. (cm)	Yield kg/ha	Flower days	Ht. (cm)	Yield kg/ha	Flower days	Ht. (cm)	Yield kg/ha
1	954114	75	115	3045	84	125	4507	70	110	2314
2	954255	73	114	3693	86	125	5825	67	109	2627
3	954063	71	125	4540	78	135	6740	68	120	3442
4	932127	69	134	3936	75	145	5771	66	129	3019
5	RS610*	64	122	4630	70	125	6605	61	120	3642
6	BR64*	73	141	4881	85	145	6490	67	139	4077
7	IS7822	69	136	3880	75	144	5823	66	132	2910
8	954062	73	152	4132	82	172	6641	69	143	2877
9	932296	73	151	3724	82	167	5379	69	143	2897
10	IS8361	72	173	3591	77	181	4417	70	169	3178
11	932075	72	168	3330	80	185	4233	68	160	2878
12	956036	75	171	3674	82	179	5717	71	167	2652
13	954130	74	152	3496	84	164	5597	74	146	2446
14	954206	76	170	4061	86	190	6195	74	160	2993
15	954164	77	162	3733	85	180	5696	74	154	2751
16	NK300*	73	177	6043	76	188	9267	71	172	4431
17	IS2319	79	224	2511	87	242	4269	75	215	1633
18	954104	79	193	3240	86	213	5178	75	184	2272
19	932062	83	229	3412	89	234	5827	80	227	2204
20	IS9198	90	230	2860	101	241	4844	85	224	1867
21	IS7579	83	238	3421	86	256	5209	80	229	2527
22	IS9569	84	233	3201	89	238	5907	81	231	1848
23	932027	83	233	3212	89	235	5864	80	232	1886
24	IS4225	72	246	4715	83	284	8310	67	228	2917
Ave.		75.7	174.6	3790	83.3	187.1	5846	71.9	168.4	2762
C.V. (%)		3.1	7.4	20.7	2.5	6.1	16.0	3.4	8.2	25.7
LSD (.05)		5.9	25.5	1535	4.1	22.3	1230	4.7	27.1	1393

Correlation of yield in Indiana with other locations: r = .615.

* Commercial U.S. hybrids, all other entries are lines.

Table 2. Summary of study 298 protein and protein yield.

298 Entry No.	Ident.	No. of Locations Reporting	% Protein Ave.	% Protein Range	Protein yield (kg/ha) Ave.	Protein yield (kg/ha) Range	Protein yield (kg/ha) Rank	Grain yield Rank
1	954114	11	10.95	10.8-13.5	354	59- 778	17	22
2	954255	11	11.48	10.3-12.5	397	51- 797	12	12
3	954063	11	10.74	8.7-12.6	480	107- 956	4	5
4	932127	12	10.22	8.8-12.3	425	128- 834	7	8
5	RS610*	12	10.30	8.5-13.2	479	106- 771	5	4
6	BR64*	12	9.94	8.1-11.4	566	177-1498	2	2
7	IS7822	12	10.21	9.5-11.3	404	112- 967	10	9
8	954062	12	10.91	8.4-11.7	454	99- 966	6	6
9	932296	11	10.39	8.8-11.7	357	62- 743	16	11
10	IS8361	10	11.63	9.1-15.0	370	82- 634	14	14
11	932075	10	10.66	9.2-11.8	364	91- 857	15	18
12	956036	11	10.48	9.5-11.6	410	70- 991	9	13
13	954130	11	11.67	9.0-13.8	404	66- 867	10	15
14	954206	10	10.43	9.1-12.2	415	124- 716	8	7
15	954164	11	11.79	8.3-13.6	378	29- 723	13	10
16	NK300*	11	10.85	8.8-13.2	710	193-1776	1	1
17	IS2319	10	12.70	11.0-15.1	297	95- 874	22	23
18	954104	10	11.03	8.5-12.6	345	124- 718	19	19
19	932062	9	11.23	9.4-13.6	288	71- 957	23	17
20	IS9198	8	10.50	7.1-12.1	223	19- 768	24	24
21	IS7579	8	10.48	8.5-12.4	346	167- 738	18	16
22	IS9569	9	11.82	8.7-14.8	322	98-1051	21	21
23	932027	8	11.68	8.3-13.8	329	118- 923	20	20
24	IS4225	9	11.28	9.5-12.9	507	31-1904	3	3
Average			10.97	7.1-15.1	401	19-1904		

Correlation of P yield with grain yield: r = .933.

* Commercial U.S. hybrids, all other entries are lines.

Table 3. Summary of study 298 lodging, disease, insect, bird damage and catechin equivalents for all locations reporting this information.

Entry No.	Ident.	Average ratings (1)				
		Lodging	Disease	Insect	Bird Damage	C.E. (2)
1	954114	0.5	5.0	5.0	1.0	0.23
2	954255	0.7	5.0	4.0	1.5	3.35
3	954063	0.5	5.0	4.0	1.4	0.23
4	932127	1.0	6.0	5.0	2.0	0.98
5	RS610*	0.7	5.5	3.7	1.2	0.48
6	BR64*	0.2	4.0	3.7	0.6	8.10
7	IS7822	1.0	5.6	4.2	2.6	1.79
8	954062	1.0	6.0	4.2	1.6	0.21
9	932296	2.5	5.3	4.0	1.4	0.62
10	IS8361	2.0	6.0	4.4	1.4	0.56
11	932075	2.3	6.0	4.3	2.2	0.44
12	956036	1.0	5.8	3.7	1.4	1.32
13	954130	0.5	5.7	3.1	1.2	0.18
14	954206	1.1	4.9	4.3	0.8	0.21
15	954164	1.4	6.1	3.4	0.8	0.29
16	NK300*	2.5	6.5	3.9	1.0	4.01
17	IS2319	3.8	6.1	4.4	2.0	0.58
18	954104	2.7	5.1	4.4	0.9	0.28
19	932062	3.3	5.2	5.1	1.4	3.22
20	IS9198	2.2	4.6	4.9	0.6	7.60
21	IS7579	3.9	5.0	4.4	1.2	0.27
22	IS9569	3.4	6.3	5.4	0.8	3.16
23	932027	3.5	5.4	5.1	0.8	2.85
24	IS4225	4.5	6.3	4.3	1.6	2.46

* Commercial U.S. hybrids, all other entries are lines.

(1) Number of locations reporting ratings were 9,8,7,5, and 1 for lodging, disease, insect, bird damage and catechin equivalents, respectively. Ratings were 0 (free) to 9 (severe) for all factors.

(2) Catechin equivalents (C.E.) indicate tannin levels of the whole grain as determined by a methanol extract.

bility and the summary of quality and yield performance of the 21 lines and three hybrid checks. Cooperators indicated from one to nine of these tested varieties were selected at each location for their study or increase for release to farmers. A second trial (398) was sent to cooperators requesting additional selected germplasm in 1973. A survey of cooperators was conducted in 1973 to evaluate further the usefulness to cooperators of these replicated yield trials. It showed the following results which indicate an increased interest in such trials for 1974 (study 498).

Continent	No. of cooperators	No. of sets of seed requested
Africa	8	13
Asia	8	13
N. America	4	5
S. America	6	23

Of the returns received from the survey, only two were unable to continue the trials. This was due to staff going for training, but they indicated a desire to continue the trial upon their return to their stations. All other locations gave a positive reply and requested sample sets for the upcoming season.

Data returned enables this project to identify widely adapted varieties that are distinctly different and which can be utilized in random-mated populations and breeding programs. These selections are potentially useful as normal protein phenotypes which can be improved by introduction of the high lysine mechanism, and thus improve nutritonal grain quality which would be useful for direct consumption by monogastric animals and humans. This distribution

of germplasm has identified a widely adapted set of genotypes that can be recognized by local groups of people as being similar to the type they produce and would select for food useage in a given area.

2. Evidence and Cases Where Findings are Being Used in LDCs and the U.S.

Correspondence was increased with over 68 people in 39 countries making contact for data and information. The findings of the improved grain quality by this project have resulted in extensive inquiry for seed and data regarding protein quality as well as other agronomic and nutritional factors related to all aspects of grain sorghum production and consumption. This has resulted in an increased involvement of staff time in this type of correspondence and the development of specific data or information requested by LDCs and U.S. researchers. Correspondence with cooperators has been very helpful to staff personnel by keeping them in direct contact with the problems of those in the LDCs and other research stations in the U.S.

The following requests for specific data illustrate the types of correspondence and requests that have been made throughout this year.

- Dr. Schaffert in Brazil has continued to request seed with known quality and phenotypic characteristics.

- Dr. Waldren in Kansas has discussed with us potential drought resistant types as indicated by our International Sorghum Protein Quality and Yield Trial Data.

- Mr. Miller in Texas again requested protein data on lines and the computer program we use for our breeding records.

- Dr. Faris in Brazil has continued to request all our material and has put it into his breeding program in the Ford Foundation sponsored sorghum improvement program in Northeast Brazil.

- Dr. Whiteman of Botswana has selected IS 3977, 932354, IS 0628, 954030, 954015 and IS 0508 as elite selections for their breeding programs and potential release for farmer usage. This example is indicative of selections made from the genetic material supplied to cooperators.

- Dr. Ahluwalia of India requested forage types with known superior quality and 14 selections were sent to him along with relative data.

- Dr. Anders in Tonga was having difficulty getting seed to set on lines that we had sent him in the International Protein Yield and Quality Trial; we suggested it might be due to midge. He treated these lines for midge and was able in the next growth cycle to get a good set with yield data.

- Dr. Pollamer in Germany requested high and low tannin selections, their evaluation, and the procedures for tannin determinations.

- Dr. Baghel of India, Dr. Ibrahim of Egypt and Dr. Izuno of Pakistan all requested and received white pearly seeded types of known protein, yield potential and phenotypic data. Dr. Ibrahim, while studying with this project, had assembled this type of material.

- Dr. Mehansho of Ethiopia was interested in evaluating tannins and requested the procedure and chemicals used in estimating catechin equivalents.

- Dr. Laborde in Argentina was assisted in assembling information regarding seeders or planters.

- Dr. Artola in Uruguay with a particular interest in B restoration lines received from this project a selection of B lines with known protein quality and other types of phenotypic characters along with a random mating population for his study and selection.

- Dr. Park in Korea is interested in broom corn and requested information on what we have regarding the collection and their quality. He reported that IS 8766 was being recommended to farmers for 1973 use.

- Potential commercial hybrids adapted to Paraguay were requested by Dr. Unruh. He received from this project the shorter varieties from our International Protein Quality and Yield Trials.

- Through the efforts of the Southern Baptist Convention missionary group and AFRICARE, the President of Niger has requested seed and data from this project. Sent to him for use in his research program were both the high lysine varieties and other identified high protein selections.

- Throughout this year we have had contact with Dr. R. Cummings and Dr. H. Doggett of ICRISAT in India and its program developments. We have furnished data, germplasm and related information that they have requested for establishment of their laboratories, breeding stock and data library. In excess of 1000 samples of germplasm containing segregating materials, including the hl gene, have been sent at their request for evaluation at their location in Hyderabad, India.

- Dr. L. House of the Arid Lands Agricultural Development Program in Lebanon has visited the project and received upon request, germplasm and data of high quality lines.

- Inquiries relating to protein quality have been made from England, Germany, France, Canada and Denmark to which we have responded with appropriate data.

- Numerous sorghum research people in the U.S. and the commercial hybrid producers have made inquiries regarding results of our research in relation to protein quality, tannins and potential resistances to disease, insects and environmental conditions.

- Project visitors included: H. Doggett, ICRISAT-India; G. Walker, North Carolina; G. Palmer, Illinois; K. Whigham, Illinois; C. Hittle, Illinois; J. Manbula, Nigeria; R. Cummings, ICRISAT-India; C. Pi, Taiwan; G. Sastry, England; A. Shepherd, Kenya; V. Deshmukh, India; W. da Silva, Brazil; W. Trevisan, Brazil; B. Majisu, Kenya; M. Faris, Brazil; P. Sun, Taiwan; H. Nasr, Lebanon; J. Monyo, Tanzania and R. Schaffert, Brazil. They discussed problems, received data, germplasm and procedures relevant to adaptation in LDC programs and involvement.

3. Plans to Use Research Data More Effectively.

a. Cooperative efforts will continue with ICRISAT, IITA, ALAD, CIMMYT and with work being done in Puerto Rico, Texas and Nebraska in developing and identifying improved germplasm and for more efficient utilization and distribution of improved selections. A more efficient system of putting together data and the retrieval of such data is still needed to improve the utilization of known facts.

b. The completion of a simplified nursery handbook outlining field management schemes and systems for note-taking and data handling

will be completed.

c. The development and conduction of seminars and workshops related to production and management factors contributing to protein and nutritional quality improvement in Africa and Asia in cooperation with ICRISAT will be continued.

d. Selected persons from the LDCs involved in the research and training program will be trained in sorghum breeding and quality improvement here at Purdue.

e. The increasing number of requests for data and germplasm indicate a strong need to develop a more extensive utilization program to complement the research project. Such a program would avoid present conflict of research staff usage of time for utilization purposes, but would facilitate contact with LDC needs, workshop planning and conduction, and provide additional staff to enable utilization of research findings and germplasm. This would require funding in addition to the present research project.

4. Involvement of LDC or U.S. Personnel and Institutions.

a. Extensive correspondence involving germplasm and factors in nutritional quality resulted from the continued wide distribution of research reports and news coverage. The increased number of visitors from the LDCs to our laboratories and their direct contacts with the program have continued to be an important method of disseminating ideas, materials and findings.

b. Correspondence with individual workers from each of the following countries was answered by sending data, information and

germplasm as specifically requested with often more than one round of correspondence with a given worker. Locations involved included: Argentina (4), Bangladesh (1), Brazil (5), Botswana (1), Canada (1), Ceylon (1), Denmark (2), Egypt (2), England (4), Ethiopia (3), France (4), Germany (2), India (8), ICRISAT-India (2), Israel (1), Jamaica (1), Kenya (2), Korea (3), Liberia (1), Malawi (1), Malaysia (1), Nigeria (2), Lebanon (1), CIMMYT-Mexico (1), Peru (1), Philippines (1), Pakistan (1), Paraguay (1), Senegal (1), Tanzania (1), Tonga (1), Turkey (1), Thailand (1), Uruguay (2), Venezuela (1), Virgin Islands (1), Alabama (1), Arizona (2), California (1), Colorado (2), Georgia (2), Illinois (3), Indiana (2), Iowa (1), Kansas (3), Maryland (1), Mississippi (1), Michigan (2), Missouri (1), Minnesota (1), Nebraska (8), Ohio (1), Oklahoma (1), New York (3), Pennsylvania (1), Puerto Rico (1), South Dakota (2), Texas (10), Virginia (1), Hawaii (1). This represents 39 countries, 24 states or territories, 68 people outside the continental United States and 52 different people within the U.S. This is more than 65 separate programs we have been in direct contact with this past year.

c. Cooperation with the USDA in Puerto Rico has continued as this project is furnishing them with data and seed of the Cameroun collection for their inventory purposes.

d. Dr. Helmi Ibrahim from Egypt, sponsored by FAO, spent one year with this project gaining experience in sorghum production and evaluation. He returned to the Egyptian sorghum breeding program.

e. Graduate students Rameshwar Singh of India and Sam Mukuru of Uganda completed their Ph.D. programs under the direction of this

project and returned to their respective research programs.

f. The six-month training program for Joash Arogun in preparation for his employment with the National Accelerated Food Production Program in Nigeria is another indication of the role this project has played in the training of personnel for work in other countries. Seed for extensive testing in the Nigerian program was selected by Mr. Arogun.

g. Lussewa Bakari M.H., an undergraduate student from Tanzania, conducted a special problem in the greenhouse and field comparing seedling vigor with tannin, protein and lysine content of the seed and also seed size. During this study he followed the project's training program from seed packet preparation, field book preparation to pollination to gain experience in sorghum breeding and production.

h. Presently one student from India (D. P. Mohan), two students from the U.S. (John Clark and Paul Christensen) and one from Brazil (R. Nunes) are undergoing graduate training programs with this project at Purdue University.

i. Cooperation with Texas, Arizona and Georgia in disease and insect evaluations on selected material, and the testing of protein quality of converted lines from Texas has been continued.

5. Material Produced by this Project.

Under separate cover four copies of publications, seminar reports, news articles and selected examples of utilization and dissemination of research findings have been forwarded.

F. STATEMENT OF EXPENDITURES AND OBLIGATIONS AND CONTRACTOR RESOURCES.

Category	Total Budget Amount 4/1/73-3/31/74	To Date 4/1/73-12/31/73	Estimated 1/1/74 3/31/74	Total Actual and Estimated
Salaries & Wages	$116,469	$ 76,041.23	$28,590.04	$104,631.27
Overhead	73,143	47,753.85	17,954.55	65,708.40
Salary Related Cost	8,659	5,954.26	2,490.51	8,444.77
Non-Expendable Equipment	4,000	852.00	2,200.00	3,052.00
Expendable Equipment & Supplies	8,000	12,529.65	5,847.20	18,376.85
Winter Nurseries	6,500	-0-	12,563.00	12,563.00
Travel & Subsistence	4,000	6,336.65	2,834.74	9,171.39
Computer Service, Publications, and Workshops	8,000	1,329.22	2,165.98	3,495.20
Subcontract Analysis	21,200	7,995.97	17,204.13	25,200.10
Total	$249,971	$158,792.83	$91,850.15	$250,642.98

G. WORK PLAN AND BUDGET FORECAST FOR 1974-75.

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

a. Chemical analysis of the world collection of sorghum lines in our inventory for tannin, lysine and protein content will continue.

1. Tannin content will be estimated as catechin equivalents which has been a reliable assay that is consistently negatively correlated with rat response.

2. The high tannin sorghum lines will be analyzed for lysine content using short column ion-exchange chromatography on the Beckman amino acid analyzer.

3. The low tannin sorghum lines will be screened for lysine content using the dye-binding technique and a newly developed ninhydrin method followed by rat feeding trials on the best entries.

b. Evaluate M_3 progeny from low tannin sorghum genotypes treated with chemical mutagens in 1972 for isolation of low prolamine (high lysine) endosperm mutants and other potentially useful mutants.

c. Continue evaluation of approximately 100 sorghum lines released by the USDA Texas conversion program for protein, lysine and tannin content. Nutritional quality will be verified with rat feeding trials on the most promising lines.

d. Evaluate a technique for total sulfur determination of sorghum grain as a means of estimating sulfur-bearing amino acid content of sorghum lines.

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. Use of ninhydrin test to identify high lysine sorghum. Explore the possibility of recommending this method as a fast screening procedure to identify high lysine sorghum in the field in LDCs and in grain elevators. Compare the results obtained with high and low tannin sorghums.

b. Fractionate normal and high lysine sorghum into five protein fractions using the Landry-Moreaux method and determine the amino acid composition of each of the protein fractions.

c. Compare the disc electrophoretic patterns obtained with the protein fractions of normal and high lysine sorghum. Determine the molecular weights of the major bands obtained with individual protein fractions.

d. If major differences are exhibited in the disc electrophoretic patterns for the normal and high lysine sorghum, sub-fractionate each of the protein fractions using column chromatography and identify and characterize the new for missing proteins in high lysine sorghum as compared to normal sorghum.

e. Conduct similar studies with sorghum IS 4526 (similar to sugary-2 in maize) and with the double mutant (hl + IS 4526) and other sugary mutants.

f. Evaluate the digestibility of carbohydrates in waxy and sugary lines.

g. Determine protein efficiency rates (PER) and feed efficiency rates (FER) of selected normal and high (hl) sorghums (both high and low tannin types) in the weanling rat.

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. Study the influence of dietary supplementation of methyl group donors, specifically methionine and choline, on the chick's utilization of sorghum grain containing high levels of tannic acid.

b. Compare the nutritive quality of low and high tannin sorghum grain from which the tannin containing testa layer has been removed by chemical and physical means.

c. Evaluate the biological value of high lysine sorghum grain in poultry and rat trials.

d. Determine the mechanisms which permit some sorghum genotypes with a pigmented testa to have good biological value.

e. Determine the effect of the high lysine gene on biological value of sorghum lines which are high in tannin content.

f. Determine the biological value of several new opaque mutants in sorghum derived from chemical mutagen treatments in 1972.

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. Continue development of high protein and high lysine male sterile (ms_3) random mating populations at Lafayette, Puerto Rico and other cooperative locations.

b. Continue to evaluate families in the F_3, F_4, F_5, F_6 and F_7 generation made by crossing various combinations of protein level and nutritive value as determined by rat feeding.

1. Develop random mating populations containing the high lysine sorghum gene in temperate germplasm.

2. Develop random mating populations containing the hl gene in tropical germplasm obtained from crosses with four Ugandan populations developed by Hugh Doggett.

3. Develop random mating populations containing the hl gene in disease and insect resistant populations from Texas A & M and ICRISAT.

c. Develop by appropriate crossing and test crossing double mutant sorghum lines and populations which contain the hl gene for high lysine and also a gene for IS 4526 which from preliminary studies closely resembles the su_2 gene in maize.

d. Derive lines from F_3 and F_4 progeny from crosses between broadly adapted high yielding sorghum lines (study 298) and lines carrying the high lysine gene identified in the two Ethiopian sorghum lines.

e. Continue protein yield trials with 12-15 cooperators in the U.S. and overseas using a third set of 20 sorghum lines (study 398 and 498).

Additional Plans

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

a. 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 analyzing.

- Populations and segregating materials (one or two random mating high protein populations) as requested.

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

c. M.S. and Ph.D. degree programs with theses on the work related to this project will be continued at about the level of four candidates at a time.

d. 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 (six months to one year) visiting professors and others.
- Commercial company and other trainees.
- Special research problems by superior Purdue undergraduate students.
- Post-doctorates (three positions and a quarter-time position funded by this project).

2. Initiate and develop plans for a workshop to be held in Africa as soon as feasible to be followed by one in Asia.

3. Initiation of opportunities to share findings and problems with co-workers will be promoted by visits to the Texas sorghum program, Nebraska sorghum program, overseas cooperators, 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.

BUDGET 1974-75

Line item 1	= salary and wages	$126,216.00
2	= indirect costs (68.5%)	86,458.00
3	= salary related costs	8,610.00
4	= permanent equipment	4,000.00
5,6	= expendable supplies	15,216.00
7	= winter nursery	12,500.00
8	= travel	8,000.00
9	= computer services	1,000.00
10	= subcontract services	18,000.00
11	- publications	3,000.00
12	= workshops, seminars	2,000.00
	Total	285,000.00

H. APPENDICES

Supporting Evidence for Interpretation of Data.
Current Research Report Topics. (Copies of these articles appear in the 1973 Purdue-AID Sorghum Project Research Report no. 10.)

1. Survey of the world sorghum collection for opaque and sugary lines. R. Singh and J. D. Axtell.

2. Biological value of high lysine (hl) and sugary (su) mutants. R. Singh and J. D. Axtell.

3. Inheritance of high lysine and sugary lines and their amino acid compositions. R. Singh and J. D. Axtell.

4. Estimation of genetic components, heritability and genetic advance of protein, lysine and oil content in grain sorghum. S. Z. Mukuru, W. E. Nyquist and J. D. Axtell.

5. Effect of tannin content of *Sorghum bicolor* (L.) Moench grain on nutritional quality. D. P. Cummings and J. D. Axtell.

6. Relationships of pigmented testa to nutritional quality of sorghum grain. D. P. Cummings and J. D. Axtell.

7. Effects of bird resistant sorghum grain and various commercial tannins on chick performance. W. D. Armstrong, W. R. Featherston and J. C. Rogler.

8. Biochemical and nutritional studies in sorghum. R. Jambunathan and E. T. Mertz.

9. Rapid ninhydrin color test for screening high lysine mutants of maize, sorghum, barley and other cereal grains. E. T. Mertz, P. S. Misra and R. Jambunathan.

10. Nutritional quality of *Sorghum bicolor* (L.) Moench as estimated by polyphenols, crude protein, amino acid composition and rat performance. D. L. Oswalt.

11. Agronomically acceptable line selections from the world collection of grain sorghum for breeding and development programs. D. L. Oswalt and Srinivasan.

Bibliographic List and Short Abstracts of Research Reports for 1973 Representing Efforts to Disseminate the Results of the Research Project.

1. Abifarin A. O. and R. C. Pickett. 1970. Combining ability and heterosis for yield, protein, lysine and certain plant characters in 18 diverse inbreds and 56 hybrids in Sorghum bicolor (L.) Moench. African Soils - Vol. 4:1-2-3.

2. Armstrong, W. D., J. C. Rogler and W. R. Featherston. 1974. Effect of tannin extraction on the performance of chicks fed bird resistant sorghum grain diets. Poultry Science (In Press).

3. Armstrong, W. D., W. R. Featherston and J. C. Rogler. 1974. Effects of bird resistant sorghum grain and various commercial tannins on chick performance. Poultry Science (In Press).

4. Cummings, D. P. 1973. Effect of tannin content and testa of Sorghum bicolor (L.) Moench grain on nutritional quality. M. S. Thesis, Purdue University.

5. Hinze, G. O. 1973. Relationship of factors influencing protein yield and quality in Sorghum bicolor (L.) Moench. Ph. D. Thesis, Purdue University.

6. Ibrahim, H. A., J. D. Axtell, D. L. Oswalt and G. Srinivasan. 1973. Effect of tannin in grain sorghum on rat growth. Journal of An. Sci., Vol 37:281.

7. Jambunathan, R. 1973. Protein quality and nutrition research. Paper presented at the Sorghum Improvement Conference of North America, Stillwater, Oklahoma, September 27.

8. Jambunathan, R. and E. T. Mertz. 1973. Relationship between tannin levels, rat growth and distribution of proteins in sorghum. J. Agr. Food Chem., Vol. 21:4.

9. Mukuru, S. Z. 1973. Estimation of genetic components, heritability, genetic advance and interrelationships of kernel weight and volume, protein, lysine and oil content and certain other traits in four segregating populations of grain sorghum. Ph. D. Thesis, Purdue University.

10. Oswalt, D. L. 1973. Nutritional quality of Sorghum bicolor (L.) Moench as estimated by polyphenols, crude protein, amino acid composition and rat performance. Ph. D. Thesis, Purdue University.

11. Oswalt, D. L., H. A. Ibrahim and D. P. Cummings. 1973. The influence of tannins on nutritional quality of Sorghum bicolor (L.) Moench as estimated by weanling rat weight gain. Agronomy Abstracts, p. 65.

12. Schaffert, R. E., V. L. Lechtenberg, D. L. Oswalt, J. D. Axtell, R. C. Pickett and C. L. Rhykerd. 1974. Effect of tannin on *in vitro* dry matter and protein disappearance in sorghum grain. Crop Science (In Press).

13. Schaffert, R. E., D. L. Oswalt and J. D. Axtell. 1974. Effect of supplemental protein on the nutritive value of high and low tannin *Sorghum bicolor* (L.) Moench grain for the growing rat. J. An. Sci. (In Press).

14. Singh, R. and J. D. Axtell. 1973. A mutant gene (*hl*) in sorghum which improves lysine concentration in the grain. Agronomy Abstracts, p. 14.

15. Singh, R. and J. D. Axtell. 1973. High lysine mutant gene (*hl*) that improves protein quality and biological value of grain sorghum. Crop Science 13:535-539.

16. Singh, R. 1973. Effect of high lysine (*hl*) and sugary (*su*) genes on improved nutritional quality of sorghum grain. Ph. D. Thesis, Purdue University.

ABSTRACT

COMBINING ABILITY AND HETEROSIS FOR YIELD, PROTEIN, LYSINE AND CERTAIN PLANT CHARACTERS IN 18 DIVERSE INBREDS AND 56 HYBRIDS IN SORGHUM BICOLOR (L.) MOENCH. A. O. Abifarin and R. C. Pickett

Results from this experiment indicate that high yielding materials exist in this sorghum population. All the fourteen sorghum characters evaluated were shown to be more under additive genetic actions as indicated by large GCA and small SCA. This was responsible for the high narrow sense heritability obtained for many of the fourteen characters studied. Many of the characters revealed favorable correlations with yield. Protein was found to be favorably correlated with panicle exsertion, lysine with panicle length and days to half bloom. It is possible to improve yield and lysine together, but raising the protein level may not be as easy. However, protein yield could be improved if acceptable protein levels are maintained or improved by the high grain yielders. These results illustrate possible progress in yield and quality work in sorghum. The magnitude of the additive gene action indicates the feasibility of developing pure homozygous lines of high grain yield and reasonable grain quality. These lines could either be utilized as such or in a hybridization program.

African Soils - Vol. XV, 1-2-3/1970.

This research supported in part by the United States Agency for International Development through Contract AID/csd-1175 entitled "Inheritance and Improvement of Protein Quality and Content in *Sorghum bicolor* (L.) Moench."

ABSTRACT

EFFECT OF TANNIN EXTRACTION ON THE PERFORMANCE OF CHICKS FED BIRD RESISTANT SORGHUM GRAIN DIETS.
W. D. Armstrong, J. C. Rogler and W. R. Featherston.

Three experiments were conducted to determine the effects on chick performance of extracting the tannin from bird resistant sorghum grains BR 64, IS 8260 and IS 6992, as well as non-resistant sorghums RS 610 and RS 671. The procedure, involving alkaline treatment of whole grain followed by hot water washing, removed most of the tannins from bird resistant sorghums and renders then equivalent in tannin content to non-resistant sorghums. Comparisons among sorghum grains were made on an isonitrogenous basis in a sorghum-soybean meal diet at sub-optimal protein levels. Extraction of the tannins from bird resistant sorghums BS 64 and IS 8260 resulted in significantly better chick growth and feed conversion as compared with that of chicks fed the intact bird resistant sorghum diets. Performance with these treated bird resistant sorghums was approximately equal to that obtained with intact non-resistant sorghums. The extraction process did not significantly influence growth rate but did significantly improve feed conversion of the non-resistant sorghum grains. Supplementation of the sorghum IS 8260 diet with methionine resulted in a significant improvement in chick performance and an increased incidence and severity of leg abnormality as compared with the unsupplemented IS 8260 diet.

This research supported in part by the United States Agency for International Development through Contract AID/csd-1175 entitled "Inheritance and Improvement of Protein Quality and Content in *Sorghum bicolor* (L.) Moench."

Methionine supplementation of a diet containing sorghum IS 8260 after extraction of the tannin resulted in similar leg scores and only a slight improvement in performance as compared with the same diet without added methionine.

Poultry Science
(In Press 1974)

ABSTRACT

EFFECTS OF BIRD RESISTANT SORGHUM GRAIN AND VARIOUS COMMERCIAL TANNINS ON CHICK PERFORMANCE. W. D. Armstrong, W. R. Featherston and J. C. Rogler, Department of Animal Sciences, Purdue University, W. Lafayette, Indiana.

Studies were conducted to determine: (1) the effect of protein level on the performance of chicks fed bird resistant sorghum grains; (2) the influence of two levels of DL-methionine in alleviating the detrimental effects of bird resistant sorghum grains; (3) the effects of various sources of commercial tannic acid on chick performance.

Bird resistant sorghum (BR64) produced poorer chick performance than non-resistant sorghum (RS610) in sorghum-soybean meal diets containing 16 and 20% dietary protein. Addition of 0.15% DL-methionine to both sorghum grain diets resulted in significant improvements in chick performance, but the magnitude of the response was greater with the bird resistant than with the non-resistant sorghum grain diets. After methionine supplementation, the BR64 diets supported similar chick weight gains as the RS610 diets at both dietary protein levels; however, feed efficiency of chicks fed the BR64 diets remained poorer.

In additional studies, sorghum RS610 supported significantly better chick performance than either bird resistant sorghum BR64 or sorghum RS610 plus 1% isolated tannic acid. The addition of 0.15% DL-methionine to sorghum RS610 and BR64 diets resulted in significant improvements in chick weight gains with no further increase being noted when 0.30% supplemental DL-methionine was fed. Adding methionine to the RS610 plus tannic acid diet

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had little effect on chick weight gain. Supplemental methionine resulted in significant improvements in feed conversion with both the BR64 and RS610 plus tannic acid diets.

Addition of tannic acids of varying molecular weights to a non-resistant sorghum grain diet resulted in significant depressions in chick performance. The detrimental influence of the tannins did not appear to be closely associated with their molecular weights as all depressions in chick weight gain and feed conversion were roughly similar. The supplementation of 0.15% DL-methionine to diets containing each of the tannic acids had little effect on improving chick performance.

Poultry Science
(In Press 1974)

ABSTRACT

EFFECT OF TANNIN CONTENT AND TESTA OF SORGHUM BICOLOR (L.) MOENCH GRAIN ON NUTRITIONAL QUALITY. D. P. Cummings

The vanillin-hydrochloric acid (VHCl) and modified vanillin-hydrocholoric acid (MVHCl) tests were used to determine the tannin content of 175 samples of grain sorghum harvested from individual plants in a segregating F_2 population from a cross between a high tannin and a low tannin line. Three groups of bulked samples were compiled on the basis of tannin content and presence or absence of testa. Weanling rats were fed the three sorghum diets for 14 days. The MVHCl test resulted in higher CE values than the VHCl test. Different or additional related polyphenolic compounds were probably being measured. Rat performance indicated that sorghum selections having testa present can perform as well as selections without a testa.

A second experiment was conducted to determine what level of tannin causes growth depression in weanling rats. NaOH-dehulled, high tannin sorghum was mixed in varying proportions with its whole counterpart to prepare a series of iso-nitrogenous diets differing only in tannin content. Lysine was supplemented to approximately 75 percent of the rat requirement. A significant decrease in weight gain, feed efficiency and protein efficiency with increasing levels of tannin was found. The data indicated no threshold for tannin since any amount of tannin in the diet resulted in decreased rat weight gain.

M. S. Thesis 1973
Purdue University

This research was supported by the United States Agency for International Development through Contract AID/csd-1175 entitled "Inheritance and Improvement of Protein Quality and Content in Sorghum bicolor (L.) Monech."

ABSTRACT

RELATIONSHIP OF FACTORS INFLUENCING PROTEIN YIELD AND QUALITY IN SORGHUM BICOLOR (LINN.) MOENCH. G. O. Hinze.

A total of 19 lines from the world collection of sorghum were used as male parents in crosses with four cytoplasmic male sterile lines to produce a total of 76 hybrids. The males were selected for phenotypic diversity of leaf angle, leaf area, plant height, and maturity. The male sterile lines used were Redlan, Martin, Combine Kafir-60, and KS-24. All material involved in this study was grown at Lafayette, Indiana in 1969.

Analyses for combining ability effects were determined for the following characters: early vigor, days to 50% bloom, number of leaves, flag-leaf area, third-leaf area, tillering, stalk size, relative canopy, leaf angle, lodging, plant height, percent protein, percent lysine, head length, yield of grain per head, weight of 100 grains, grain yield per acre, mg protein per seed, and mg lysine per seed. Highly significant mean squares were determined for male effects for all characters. Female effects were significantly or highly significant for days to 50% bloom, plant height, head length, mg of protein per seed, and mg of lysine per seed. Significant male or female effects were considered expressions of additive gene action, which could be utilized in varietal improvement. Specific combining ability, indicated by significant mean square estimates of male x female interactions, would indicate effects best exploited in a hybrid production scheme. Significant or highly significant interaction

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This research was supported by the United States Agency for International Development through Contract AID/csd-1175 entitled "Inheritance and Improvement of Protein Quality and Content in Sorghum bicolor (L.) Moench."

levels were determined for early vigor, days to 50% bloom, leaf number, flag-and third-leaf areas, relative canopy, leaf angle, lodging, plant height, percent lysine, head length, grain yield per head, and mg protein per seed.

In this study male sterile KS-24 was found to be generally superior female parent for protein quantity and quality. Its hybrids averaged highest in yield, highest in percent lysine and mg lysine per seed, and second in percent protein and mg protein per seed. In addition, its hybrids were early in maturity and averaged 20 cm shorter in plant height than hybrids of the other three male sterile lines.

This study indicated a positive and significant correlation of mg protein per seed with seed weight, percent protein, and mg lysine per seed, and was not correlated with grain yield. A selection program utilizing mg protein per seed appeared to offer a powerful index to improve the protein selection program without reducing yield, especially if it were combined with a screening test for high levels of percent lysine.

Seed weight was correlated with plant height, but not with yield per acre. Protein content per seed remained relatively constant over yield per acre. These factors indicated no adverse effects should develop relating to yield if a selection program emphasized seed size.

Plant height was correlated with grain per head, 100 grain weight, grain yield, percent protein, and protein and lysine per seed. Unfortunately, tallness was also correlated with percent lodging and negatively correlated with percent lysine.

Correlation coefficients between parental performance and F_1

performance for six quality factors were calculated. In a few instances, these were determined to be significantly correlated. However, these correlations were deemed useful only if a full testing program was impossible, since the confidence interval established for these values is too wide to allow utilization as a reliable indicator.

Ph. D. Thesis 1973
Purdue University

ABSTRACT

EFFECT OF TANNIN IN GRAIN SORGHUM ON RAT GROWTH.
H. A. Ibrahim, J. D. Axtell, D. L. Oswalt and G. Srinivasan

Tannin compounds present in "bird-resistant" varieties of grain sorghum have been implicated in reducing the nutritional quality of the grain. Direct comparisons of isogenic lines which differ only in tannin content have not been available. In this experiment, seed of a high tannin sorghum variety was blended in varying proportions with its dehulled low tannin counterpart to provide rations of the same genotype with a range of tannin content. The catechin equivalent values (tannins) of the rations ranged from 0.10 to above 3.00. Each iso-nitrogenous ration was fed with and without lysine supplementation in two replications to twenty weanling rats for fourteen days. Rat weight gains were increased by lysine supplementation at all levels of tannin content and were significantly lower at catechin equivalent levels above 1.00. Rat weight gains were compared to *in vitro* dry matter disappearance determinations.

Journal of An. Sci. 1973
Vol. 37:281

This research supported in part by the United States Agency for International Development through Contract AIC/csd-1175 entitled "Inheritance and Improvement of Protein Quality and Content in *Sorghum bicolor* (L.) Moench."

ABSTRACT

PROTEIN QUALITY AND NUTRITION RESEARCH.
R. Jambunathan

A short summary of the procedures used at Purdue for the screening of sorghum lines from the world sorghum collection was presented. Also, the chemical analysis data of the normal and the Ethiopian high lysine sorghums and their nutritional quality were discussed. Out of 10,000 lines that were screened from the world sorghum collection, two floury lines of Ethiopian origin, IS 11167 and IS 11758 were selected which had 3.3 and 3.1% lysine (based on protein) and 15.7 and 17.2% protein respectively. Although the high lysine sorghums were dented, the starch snythesis was not blocked, as the percentage of starch in normal and high lysine sorghums was similar. When fed at 10% protein level, IS 11167 had a protein efficiency ratio (PER) of 1.78 and IS 11758 had a PER of 2.06. When fed at 94% level of the ration, rats fed IS 11758 gained an average of 3.4 gr per day, while those fed the opaque-2 corn gained 3.3 gr per day. Inherited studies indicate that the high lysine character is controlled by a single recessive gene.

Paper presented at the Sorghum Improvement Conference of North America, Stillwater, Oklahoma, September 27, 1973.

This research supported in part by the United States Agency for International Development through Contract AID/csd-1175 entitled "Inheritance and Improvement of Protein Quality and Content in *Sorghum bicolor* (L.) Moench."

ABSTRACT

RELATIONSHIP BETWEEN TANNIN LEVELS, RAT GROWTH AND DISTRIBUTION OF PROTEINS IN SORGHUM. R. Jambunathan and E. T. Mertz

The discovery that the opaque-2 gene in corn improves protein quality has stimulated considerable interest among breeders, agronomists, nutritionists and biochemists in improvement of protein quality and quantity of other cereal grains. Sorghum grain ranks fifth in acreage of crops of the world and forms the basic food in many parts of Africa and Asia. In order to improve the quality of sorghum grain, it is desirable to separate the proteins of sorghum and study the individual fractions in detail. Published literature has been very limited because of the insoluble characteristics of sorghum grain proteins. The procedure that has been employed for the fractionation of sorghum proteins by other workers is based on the classical procedure of Osborne and Mendel. Some of the problems that have been associated with this procedure have been reported by other research workers, such as low nitrogen recoveries and the inability to work with the alcohol fractions and with the glutelin fractions due to the gelling of these fractions. Thus, Osborne and Mendel's procedure and its modifications appear to be unsatisfactory in selectively extracting different classes of proteins of sorghum due to the insoluble nature of the proteins in the solvent systems employed.

We have employed the procedure of Landry and Moureaux. This procedure

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solubilizes most of the nitrogen of sorghum and yields five different soluble fractions. In the Osborne and Mendel procedure, four protein fractions are obtained: albumins, globulins, prolamines, and glutelins. In the present procedure, in addition to extracting the albumins, globulins, and prolamines, three additional fractions are obtained in place of the one glutelin fraction of Osborne and Mendel. We have fractionated the proteins of three high tannin and three low tannin sorghum samples and have compared the various fractions obtained. The possible influence of polyphenols (tannins) on the distribution and availability of sorghum proteins is discussed. A preliminary report has been published.

J. Agr. Food Chem. Vol. 21:4, 1973

ABSTRACT

ESTIMATION OF GENETIC COMPONENTS, HERITABILITY, GENETIC ADVANCE AND INTERRELATIONSHIPS OF KERNEL WEIGHT AND VOLUME, PROTEIN, LYSINE AND OIL CONTENT AND CERTAIN OTHER TRAITS IN FOUR SEGREGATING POPULATIONS OF GRAIN SORGHUM. S. Z. Mukuru.

From four crosses of grain sorghum, 45 F_2 random plant selections from each cross were advanced to the third generation. Two random plants were selected from each of 180 F_3 progeny rows and the resulting 360 F_3 selections were evaluated in the fourth generation in one replication and two locations. Each cross is referred to as a population.

The percent heterosis over midparent for kernel weight and volume was negative in all populations. On the other hand, positive percent heterosis was obtained for percent protein in only population IV, lysine as percent of protein in all populations and percent oil in populations II and IV. A wide range of variation was exhibited for several characters in many populations. Transgressive segregation occurred in both directions for several of the plant characters and also for percent protein, percent lysine of protein and catechin equivalents.

Statistically significant differences were indicated among either the F_2 subpopulations or F_3 subpopulations within F_2 subpopulations or both for several characters in all populations. No significant differences, however, were obtained for grain yield, kernel density and percent lysine of sample in any populations.

This research was supported by the United States Agency for International Development through Contract AID/csd-1175 entitled "Inheritance and Improvement of Protein Quality and Content in *Sorghum bicolor* (L.) Moench."

Several estimates of additive genetic variances for chemical and seed characters were negative and even those that were positive were always small in magnitude relative to estimated dominance genetic variances. This implied that dominance gene action was relatively more important than additive gene action for the inheritance of chemical and seed characters in the four populations studied. Estimates of heritability and the genetic progress to be expected under selection for the chemical and seed characters were not very high, but they did give sufficient evidence that substantial improvement can be made in several populations for some characters, including kernel weight and volume, percent protein, percent lysine of protein and percent oil.

Grain yield was positively correlated with panicles per plot, panicle weight and kernels per panicle in all populations. However, correlations of grain yield with kernel weight and volume were non-significant, which suggests that kernel weight and volume are not components of yield. There were no consistent and favorable correlations, to give a clue as to which of the seed or plant characters could be used as indicators of protein, lysine and oil in all the four populations. However, kernel weight or volume could reasonably be used as an indicator in selecting percent protein in population I and percent oil in population III.

Ph. D. Thesis 1973
Purdue University

ABSTRACT

NUTRITIONAL QUALITY OF SORGHUM BICOLOR (L.) MOENCH AS ESTIMATED BY POLYPHENOLS, CRUDE PROTEIN, AMINO ACID COMPOSITION AND RAT PERFORMANCE.
D. L. Oswalt

Selections from 172 samples representing potentially useful germplasm from the world collection of grain sorghums were analyzed and correlated with weanling rat weight gains to evaluate nutritional quality differences in genotypes.

Significant differences in *in vitro* dry matter disappearance percentages were found among commercial hybrids and selected genotypes which showed a positive correlation to weight gain. *In vitro* dry matter disappearance percentages were negatively correlated with catechin equivalents which were used to indicate low and high concentrations of polyphenolic compounds (tannins) associated with some pigmented caryopses.

Amino acid analyses of the grain showed lysine to be limiting for normal weanling rat growth. Supplementing rations made from grain of genotypes having low catechin equivalent concentration with lysine and with lysine, threonine, methionine and phenylalanine resulted in significantly increased 14-day rat gains. However, similar supplementation of rations made from grain of genotypes with high catechin equivalent concentrations showed no significant increases over unsupplemented ration weight gains.

Partial removal of the pericarp and testa of genotypes containing high concentrations of catechin equivalents lowered catechin equivalent concentrations and rations made from such dehulled genotypes resulted in weight

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This research supported by the United States Agency for International Development through Contract AI /csd-1175 entitled "Inheritance and Improvement of Protein Quality and Content in Sorghum bicolor (L.) Moench".

gains similar to rations made from low catechin genotypes with and without amino acid supplementation. Rat weight gains were positively correlated with lysine content of grain in rations made from genotypes containing low catechin equivalent concentrations. However, rat weight gains on rations made from genotypes high in catechin equivalent concentrations were correlated with protein content. These studies indicate that to effectively evaluate nutritional quality factors of grain sorghum, genotypes containing low and high concentrations of catechin equivalents need to be investigated as separate populations.

Ph. D. Thesis, Purdue University, 1973

ABSTRACTS

THE INFLUENCE OF TANNINS ON NUTRITIONAL QUALITY OF *SORGHUM BICOLOR* (L.) MOENCH AS ESTIMATED BY WEANLING RAT WEIGHT GAIN. D. L. Oswalt, H. A. Ibrahim and D. P. Cummings

This experiment was designed to determine the level of catechin equivalents (CE) that significantly lowered rat weight gains to permit the grouping of grain sorghum genotypes into high and low catechin (tannin) groups for biological evaluation of their nutritional quality. Isogenic lines varying only in CE were not available. Therefore, isonitrogenous rations of Redlan x IS 8165 formulated by blending dehulled (CE = 0.01) and whole (CE = 4.84) grain were fed supplemented (0.8% lysine-HCl) and unsupplemented to weanling rats for 14 days. Rat weight gains from lysine supplemented rations of 26.8 to 6.7 g correlated (r = -.936**) with CE ranging from .07 to 2.60 respectively, with percent *in vitro* dry matter disappearance (IVDMD) (r = .982**), with feed consumed (r = .933*) and g feed/g weight gain (r = .860**). The sharp decrease in weight gain and feed efficiency as CE increased was apparently due to reduced protein availability. These data support the hypothesis that tannins in some grain sorghums reduce the biological value of the grain protein in direct proportion to the amount of tannin present.

Agronomy Abstracts 1973, p.65

This research was supported by the United States Agency for International Development through Contract AID/csd-1175 entitled "Inheritance and Improvement of Protein Quality and Content in *Sorghum bicolor* (L.) Moench."

ABSTRACT

EFFECT OF TANNIN ON *IN VITRO* DRY MATTER AND PROTEIN DISAPPEARANCE IN SORGHUM GRAIN. R. E. Schaffert, V. L. Lechtenberg, D. L. Oswalt, J. D. Axtell, R. C. Pickett, and C. L. Rhykerd.

In vitro rumen fermentation techniques were used to determine the effect of tannin and added urea on *in vitro* dry matter disappearance (IVDMD) and *in vitro* protein disappearance (IVPD) in sorghum (*Sorghum bicolor* (L.) Moench) grain. IVDMD of low and high tannin genotypes after 48 hours of fermentation were 72.5 and 46.4% respectively. The addition of urea increased IVDMD to 93.4 and 79.2% for the low and high tannin genotypes. IVPD of low and high tannin genotypes was not affected by urea and averaged 88.2 and 69.6% respectively. After 96 hours of fermentation, the IVDMD of low and high tannin genotypes was 93.8 and 85.8% respectively, indicating a true difference in digestibility of about 8 percentage units.

The major factor limiting the utilization of high tannin sorghum is apparently the availability of protein. Undigestible protein and tannin complex may account for more than half of the difference in IVDMD between low and high tannin genotypes.

Crop Science
(In Press 1974)

This research was supported by the United States Agency for International Development through Contract AID/csd-1175 entitled "Inheritance and Improvement of Protein Quality and Content in *Sorghum bicolor* (L.) Moench."

ABSTRACT

EFFECT OF SUPPLEMENTAL PROTEIN ON THE NUTRITIVE VALUE OF HIGH AND LOW TANNIN SORGHUM BICOLOR (L.) MOENCH GRAIN FOR THE GROWING RAT.
R. E. Schaffert, D. L. Oswalt and J. D. Axtell

Grain sorghum diets with 0, 5, 10 and 15% soybean, seeds without hulls, solvent extracted, maximum 3% fiber, (Soybean meal) supplementation using genotypes containing less than 1.0 or more than 4.0 catechin equivalents (tannins) were fed to weanling rats. Thirteen-day weight gains of 36 g and 28 g, feed consumption of 155 g and 170 g and feed efficiency ratios of 6 and 17 were highly significant for low and high tannin genotypes, respectively. Weight gains of 7, 27, 42 and 53 g, feed consumption of 145, 169, 168 and 166 g and feed efficiency ratios of 21, 6, 4 and 3 were obtained for the four levels of soybean meal supplementation respectively. Average rat weight gains from the high tannin genotypes differed significantly from the low tannin rat gains for 0, 5, and 10% soybean meal supplemented diets, respectively, but the gain from the 15% soybean meal diets were not significantly different. Feed consumption of the high tannin diets was greater or equal to the low tannin diets. The lack of antagonistic interactions with supplemental protein for weight gain, feed efficiency and feed consumption indicated that protein from soybean meal can be supplemented without changing the relative performance of different sorghum genotypes.

J. An. Sci.
(In Press 1974)

This research was supported by the United States Agency for International Development through Contract AID/csd-1175 entitled "Inheritance and Improvement of Protein Quality and Content in Sorghum bicolor (L.) Moench".

ABSTRACT

A MUTANT GENE (hl) IN SORGHUM WHICH IMPROVES LYSINE CONCENTRATION IN THE GRAIN. Rameshwar Singh and John D. Axtell.

Seeds from over 9,000 lines in the world sorghum (*Sorghum bicolor* (L.) Moench) collection were classified for endosperm phenotype to identify floury endosperm lines and evaluate each for potential increases in lysine concentration. Sixty-two floury endosperm lines were selected. Two floury lines of Ethiopian origin, IS 11167 and IS 11758, were exceptionally high in lysine at relatively high levels of protein. The average whole grain lysine concentration of high lysine lines IS 11167 and IS 11758 was 3.34 and 3.13 (g/100 g protein) at 15.7 and 17.2% protein respectively. Inheritance studies suggest that the increased lysine concentration of each line is controlled by a single recessive gene, although it is not known whether the genes from both lines are allelic. The biological value of the high lysine lines was much higher than that of average sorghum lines. The weight gain of weanling rats was three times higher on an IS 11758 ration and twice as high on an IS 11167 ration as weight gains on rations prepared from normal sorghum lines in a 28-day isonitrogenous feeding experiment.

Agronomy Abstracts 1973, p. 14

This research was supported by the United States Agency for International Development through Contract AID/csd-1175 entitled "Inheritance and Improvement of Protein Quality and Content in *Sorghum bicolor* (L.) Moench."

ABSTRACT

HIGH LYSINE MUTANT GENE (hl) THAT IMPROVES PROTEIN QUALITY AND BIOLOGICAL VALUE OF GRAIN SORGHUM. Rameshwar Singh and John D. Axtell, Department of Agronomy, Purdue University, W. Lafayette, Indiana 47907.

Seeds from over 9,000 lines in the world sorghum (Sorghum bicolor (L.) Moench) collection were classified for endosperm phenotype to identify floury endosperm lines and evaluate each for potential increases in lysine concentration. Sixty-two floury endosperm lines were selected and analyzed for protein and lysine composition. Two floury lines of Ethiopian origin, IS 11167 and IS 11758, were exceptionally high in lysine at relatively high levels of protein.

The average whole grain lysine concentration of high lysine lines IS 11167 and IS 11758 was 3.34 and 3.13 (g/100 g protein) at 15.7 and 17.2% protein, respectively. Both lines were also high in percent oil. Carbohydrate analyses of whole grain samples of the two high lysine lines were similar to that of normal sorghum grain except for a twofold increase in sucrose concentration.

The high lysine gene altered the amino acid pattern in hl hl hl endosperm tissue relative to normal endosperm checks. The major changes were increased lysine, arginine, aspartic acid, glycine, and tryptophan concentrations and decreased amounts of glutamic acid, proline, alanine, and leucine in the hl hl hl endosperm.

Inheritance studies suggest that the increased lysine concentration of each line is controlled by a single recessive gene, although it is not

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This research supported by the United States Agency for International Development through Contract AIC/csd-1175 entitled "Inheritance and Improvement of Protein Quality and Content in Sorghum bicolor (L.) Moench."

known whether the genes from both lines are allelic. The high lysine gene(s) present in IS 11167 and IS 11758 from Ethiopia is (are) herein designated as hl. The endosperm of kernels homozygous for the hl gene is partially dented.

The biological value of the high lysine lines was much higher than that of average sorghum lines. In a 28-day isonitrogenous feeding experiment the weight gain of weanling rats was three times higher on an IS 11758 ration and twice as high on an IS 11167 ration as weight gains on rations prepared from normal sorghum lines. When fed rations without any dilution except the usual 2% vitamin and 4% mineral supplementation, rats gained 94 g on high lysine sorghum (IS 11758) and 28.5 g on our current best nutritional quality sorghum lines (IS 2319), versus 91.5 g on opaque-2 corn (*Zea mays* L.) and 30.2 g on normal corn in a 28-day feeding trial. Feed efficiency ratios for this trial were 3.0 for the high lysine sorghum, 6.8 for IS 2319, 3.4 for opaque-2 corn, and 7.4 for normal corn.

Crop Science 13:535-539,
1973.

ABSTRACT

EFFECT OF HIGH LYSINE (hl) AND SUGARY (su) GENES ON IMPROVED NUTRITIONAL QUALITY OF SORGHUM GRAIN. Rameshwar Singh.

Over 9,000 lines from the world sorghum collection were classified for endosperm phenotype with the main objective of identifying floury and sugary endosperm lines to evaluate for potential increases in nutritional quality. Sixty-two floury and 5 sugary endosperm lines were identified. Two floury lines IS 11167 and IS 11758 of Ethiopian origin were exceptionally high in lysine content at relatively high levels of protein content. All five sugary lines were relatively high in lysine and protein contents. Four sugary lines (IS 4668, 5376, 5614 and 5623) are extremely high in water soluble polysaccharides (WSP) and amylose, but are very low in starch content when compared to normal sorghum. Another "sugary" line IS 4526 is similar to normal sorghum in reducing sugars, WSP and starch content but is 62% higher in amylose content and 65% higher in sucrose.

Carbohydrate analysis of IS 4668, 5376, 5614 and 5623 resemble the sugary-1 (su_1) mutant of corn, whereas IS 4526 resembles closely the sugary-2 (su_2) corn mutant. The carbohydrate analysis of the two high lysine lines is parallel to normal sorghum line except for their nearly three-fold increase in sucrose content.

The inheritance data suggested a single recessive gene for inheritance of the high lysine character. The high lysine gene is designated as hl.

This research was supported by the United States Agency for International development through Contract AID/csd-1175 entitled "Inheritance and Improvement of Protein Quality and Content in *Sorghum bicolor* (L.) Monech."

As reported earlier, a simple recessive mode of inheritance of the sugary gene was also noted. High lysine lines (hl hl) have slightly dented kernels while sugary lines show great variation in the extent of dimpling in their kernels.

An effect of the high lysine gene is seen on the changed amino acid pattern. The major changes in high lysine kernels were increases in lysine, arginine, aspartic acid and glycine contents and decreases in the contents of glutamic acid, proline, alanine and leucine as compared to normal counterparts. Average increase in lysine content of the endosperm tissue of high lysine kernels was 83% over normal endosperm. Similar changes in the amino acid pattern of two naturally occurring high lysine lines is also noticed.

Protein, lysine and oil contents of the two high lysine lines is greatly increased as compared to normal sorghum. Average lysine content in high lysine lines IS 11167 and IS 11758 was 3.34 and 3.13% at 15.7 and 17.2% protein level respectively. When compared with normal sorghum, the 100 seed weight of IS 11758 is 10% lower while IS 11167 has 10% higher test weight. The average amount of protein per seed in high lysine lines was nearly 22% higher than normal, while per seed lysine content was almost doubled.

Protein, lysine and sulphur amino acid contents were higher in the sugary lines. However, per seed protein and lysine content of the sugary lines was not different from normal lines due to their lower test weight.

The nutritional quality of the high lysine lines was much higher than the average sorghum. When fed at a 10% protein level, gain in weight of rats was 3 times higher on IS 11758 and over twice higher on IS 11167 than normal sorghum. Protein quality of IS 11758 was nearly two and one-half times better

than normal sorghum.

When fed without any dilution except the usual 2% vitamin and 4% mineral supplementation, rats gained 94 g on high lysine sorghum (IS 11758), 28.5 g on our current best nutritional quality sorghum line (IS 2319), 19 g on another high protein normal sorghum line (IS 1484), 91.5 g on opaque-2 corn and 30.2 g on normal corn in 28 days. Though the total feed consumption of rats on high lysine sorghum rations is more than normal sorghum, the amount of feed needed per unit gain in weight is only one-third of normal sorghum feed. Feed efficiency ratios (amount of feed consumed per unit of body weight gain) for the 28-day feeding trial was 3.0 for high lysine sorghum, 6.8 for IS 2319, 8.5 for IS 1484, 3.4 for opaque-2 corn and 7.4 for normal corn.

Ph. D. Thesis 1973
Purdue University

Samples of News Releases and Other Articles Related to Significant Research of this Project follow:

For the
PRESS

FOR RELEASE AFTER 10 A.M.
FRIDAY, SEPTEMBER 28, 1973

AID-73-71
Platt
(202) 632-8636

AID-SPONSORED PURDUE SORGHUM RESEARCH FIND BRINGS NEW HOPE FOR PROTEIN-SHORT MILLIONS

A seven-year pursuit by Purdue University scientists has led to the discovery of a gene in the sorghum plant considered to be "of life-giving importance" to over 300 million protein-starved inhabitants of Africa, Asia and Latin America.

The scientists found the high-lysine gene in two strains of sorghum collected in Ethiopia after screening 9,000 varieties of the grain from all over the world. Lysine, one of the amino acids, is an essential component of protein in human nutrition. The discovery promises to nearly triple the protein quality of normal sorghum strains.

It was to increase the protein quality of sorghum that the Purdue scientists began screening plant strains from the world collection. Two Ethiopian lines were found to have a 30 to 40 percent increase in protein with about twice as much lysine and correspondingly improved amino acid balance, compared to commercially-grown sorghum.

The research was carried out under a $1.7 million contract from the Agency for International Development (AID). The new finding is expected to lead to improved sorghum varieties for human consumption in 3 to 5 years.

Announcement of the gene's discovery was made at a news conference at the State Department today (Sept. 28) where AID Administrator John A. Hannah introduced the Purdue scientists and hailed their contribution as a "breakthrough of the first magnitude."

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"When we recall that sorghum is the principal subsistence cereal for more than 300 million people--indeed the poorest people in the world's poorest countries--improving its protein quality will amount to a gift of life, especially for children," he said.

Citing recent figures which show that insufficient protein in the diet is chiefly responsible for a mortality rate up to 60 times greater for young children in the poor countries compared to that in the United States, Dr. Hannah made the following observations:

- More than two-thirds of the 800 million children in the developing countries will encounter severe sickness or disabling diseases brought on or aggravated by malnutrition.

- In many parts of Africa, almost every child under 5 suffers from some degree of protein malnutrition. Even if he survives, the malnourished child may suffer continuing physical and mental retardation.

- In Latin America, over half of all childhood deaths are related to malnutrition.

- In rural India, an estimated 80 percent of preschool children suffer from malnutritional dwarfism.

"It is against such grim statistics," Dr. Hannah asserted, "that the meaning of the Purdue discovery is of life-giving importance."

The scientists credited with the sorghum research breakthrough are Dr. John Axtell, project leader, and Dr. Rameshwar Singh, his former graduate student recently returned to India. The project, initiated in 1966 by Dr. R. C. Pickett of the Purdue faculty, has since been carried on by Dr. Axtell and his collaborators.

Sorghum is the fourth most important cereal crop in the world, surpassed only by rice, wheat and corn. In some countries, notably in Africa, sorghum is the primary source of calories for tens of millions. In the United States it is produced primarily as livestock feed.

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One of sorghum's chief characteristics is that it can be grown on land that is too dry and often too infertile to grow other cereals. It is on such land that most of the poorest people of the least developed countries depend. For this reason, the research breakthrough in the protein quality of sorghum is regarded by development assistance officials as of the highest importance.

The improved biological value of the newly discovered high-lysine lines is controlled by a single gene, so that the improved grain quality can be easily incorporated by crossbreeding into sorghum varieties grown in the less developed countries.

A similar high-quality gene--known as Opaque-2--was discovered in corn by a team of Purdue scientists nearly ten years ago. In many respects, Dr. Axtell explained, the mutant gene found in sorghum resembles that in Opaque-2 corn. "Both have a high lysine content; they are inherited as a single gene, and improve the biological value of the grain substantially," he said.

Purdue experiments also led to another major breakthrough--the discovery by Dr. Axtell and Dr. Dallas Oswalt, a co-worker, that tannin, a pigmentation chemical that gives the sorghum grain its dark color, somehow blocked the release of the protein for animal or human use.

High-tannin sorghum, which is bitter-tasting compared to the light-colored variety, is preferred by growers in Africa and elsewhere because of its bird-repellant powers. Birds, the worst enemy of sorghum, have been known to devour entire crops of the light-colored strains.

Tannin resides in an extremely thin layer under the "skin" of the kernel. Its presence is due to a single dominant gene, thereby making it easy to correct genetically. Removal of the tannin, however, would only serve to attract the hungry birds. Scientists are considering three approaches to deal with the tannin problem: (1) To control birds in other ways; (2) remove the tannin-containing "skin" of the kernel by milling; (3) search for another, genetically controlled agent that is distasteful to birds but does not tie up protein for human assimilation. Research is under way on all three approaches under the Purdue contract and other AID-funded projects.

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From an economic standpoint, the discovery of the sorghum gene is also certain to benefit livestock production around the world, according to Dr. Erven J. Long, a senior official in AID's Bureau for Technical Assistance.

Noting that the protein content of most cereals is not adequate to support livestock weight gain, he said that sorghum's improved protein quality should lessen the need for such supplements as soybean meal. "As a consequence," he added, "overall costs should be reduced and efficiency increased."

"The most important benefit, however," Dr. Long asserted, "will be the availability in sorghum-consuming areas in the less developed world of a cereal food far superior in nutritional quality than they have thus far depended on."

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news news

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WITH HIGH LYSINE SORGHUM

West Lafayette, Ind., Sept. 28. Purdue University President Arthur G. Hansen and Purdue Dean of Agriculture R. L. Kohls today commented on the discovery of high lysine sorghum by Purdue agricultural scientists. They said:

Dr. Hansen--"I want to congratulate Dr. John Axtell and his fellow scientists who have worked on the project for such a long time and have made such a very remarkable discovery. I think it illustrates the point I have been trying to make for quite some time--why we need a research university like Purdue. The contribution that it makes to the state, to the nation and to the world are inestimable, and for this reason alone its support and its encouragement are worth every penny that we are receiving in support."

Dr. Kohls--"I am extremely proud of this accomplishment of the scientists of the Indiana Agricultural Experiment Station here at Purdue. This is just one more indication of the high status of Purdue among the agricultural educational and scientific organizations of the world. All Hoosiers should share in this pride. Such discoveries as this not only make significant contributions to the solution of the world food problem, but also have direct and practical implication to Indiana farmers and consumers."

9-73

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WITH HIGH LYSINE SORGHUM

West Lafayette, Ind., Sept. 28. What happens when a new grain variety is discovered, as in the case of Purdue University's just announced high lysine sorghum?

Among other things, it, in effect, goes into the bank. It may even have come from the bank, in actuality. The bank, in this case, is the World Sorghum Collection, which represents a truly international research effort. Purdue has been a part of this research effort for nearly two decades, chiefly in the area of protein quality improvement.

Just what is this collection? Essentially, it is a genetic resource center--a bank--where seed collections including all the natural, desirable variations of grains are cultivated, recultivated and improved, and distributed to the nations of the world. Centered in India, the bank also acts as a museum so that the genetic characteristics will be forever kept available to plant breeders.

Purdue's new high lysine sorghum was the result of a seven-year research program with sorghum lines from the World Collection. The high lysine gene was found after screening more than 10,000 varieties from the collection.

Why is such a collection important?

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First, a little background on plant breeding...a new plant or grain does not simply pop from a test tube or laboratory. It represents the work of at least a decade, and usually longer.

When plant breeders wish to grow, say, a grain, with a specific characteristic--high protein content--they first select plants with the most desirable features needed--high protein, strong stalks, disease resistance, and others. These, then, become the basis for extensive breeding programs. These "best available" plants are crossbred, grown, and the best of their progeny are selected on the basis of the desired characteristics.

Then, these "most desirable" ones are grown, and their best are selected, and so on, until a highly desirable plant is achieved. Then the experimental seeds are planted, grown, harvested, and the seed saved, grown, harvested, until the seed supply is increased.

All this sounds very simple, but it isn't.

Thousands, even millions, of seedlings are rejected, because they do not measure up.

A strong-stalked plant, may, for instance, turn out to be susceptible to disease. A resistant plant may have low yields, or other shortcomings.

Then there is the growing season needed to produce all these seedlings. It takes years--a minimum of eight, if everything goes perfectly (and it usually doesn't) to get a single new variety.

But assuming one has been discovered. What then?

Researchers have one batch of seeds that grew plants that met all the requirements--good yield, disease resistance, nutritious and so forth. But what if this batch gets planted and there is a bad crop year? Decades of research are zapped!

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So, just as a bank has its data processing files, agricultural research has their genetic collections. There is a world corn collection, centered primarily in Mexico, and a world rice collection in the Philippines, for instance.

World collections serve yet another purpose, that of making the genetic material available to different nations, so that they may undertake to crossbreed with native varieties to produce better plants in their own climates. So, the bank acts as a distributing agent, making improved varieties available worldwide.

Dr. Robert C. Pickett, Purdue professor of agronomy, has been instrumental in establishing and expanding the world collection, which was begun in 1963, and the result of the collection has been some answers to the ever-pressing problems of human food needs.

The Purdue Agronomy farm, near Lafayette, is the site of the Purdue portion of the world collection, which is used in the protein quality research. A winter nursery is maintained in Puerto Rico, and currently some research is being carried on cooperatively with Brazil and more than 16 other nations.

feature news
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WITH HIGH LYSINE SORGHUM

West Lafayette, Ind., Sept. 28. Discovery of two lines of high lysine sorghum by Purdue University agricultural scientists had its roots in research at Purdue a decade ago.

Announcement of the sorghum lines, which contain twice as much lysine (improved protein quality) as average sorghum, was made today.

Dr. Edwin T. Mertz and Dr. Oliver E. Nelson Jr., Purdue staff members, working as a team for several years, began testing the amino acid pattern of several strains of corn. They found that one, called opaque-2, displayed an unusual amino acid balance. It contained more than twice as much lysine as normal corn and substantially more trypotophan.

Their discovery ten years ago encouraged plant breeders to search for genetic alterations that would improve the level and quality of protein in other important cereal grains.

Dr. Mertz, who continues to work actively on both the Agency for International Development project on opaque-2 corn and the AID sorghum project, commenting on the sorghum discovery, said:

"It is a great satisfaction indeed to have Purdue research workers identify two high lysine lines of sorghum. The potential benefits from this discovery in a world chronically short of good quality protein are tremendous.

(more)

High lysine sorghum should have a good market in this country in animal rations and could vastly improve the diets of humans in parts of Africa and Asia where this crop is consumed as a human food."

The mutant, opaque-2, had been known for about 30 years by plant breeders, but was used only as a genetic marker. Mertz and Nelson believed that if the unusual amino acid proportions could be maintained, high lysine corn would have protein with far superior feed value than ordinary corn.

In subsequent tests they demonstrated that the mutant gene could substantially improve the quality of corn protein. They found it was superior to normal corn for livestock rations and other scientists found it was twice as good as normal corn in certain human diets.

First nutrition tests at Purdue in 1964 showed that weanling rats tripled their growth when fed high lysine corn. Then weanling pigs fed the higher protein quality corn gained more than three times faster than pigs fed regular hybrid corn when corn supplied all of the protein.

Sensing the potential of the discovery for improving human nutrition, scientists tested children in Guatemala and graduate students on Purdue's campus. The studies in Guatemala showed that protein quality of the high lysine corn was as high as protein quality of milk. At Purdue, trials with the students proved that corn protein could be effectively used by adults.

After publication of the opaque-2 discovery, Rockefeller Foundation scientists in Colombia requested seed from Purdue as a means of obtaining a weapon to fight Kwaskiorkor, a protein deficiency disease of children.

Children who were admitted to hospitals received diets in which 100 per cent of the protein came from opaque-2 corn. They made satisfactory recovery. Commercial companies in Colombia now are producing a food for humans containing opaque-2 corn.

It is estimated that more than one million acres of hybrid opaque-2 corn will be planted by midwest farmers in 1974.

Scientists Develop 'Gift-of-Life' Grain

By Victor Cohn
Washington Post Staff Writer

In what federal officials yesterday called "a gift of life," a Purdue University team has learned to upgrade the protein content of sorghum—a basic food of 300 million of the world's poorest, most protein-deficient people.

By screening 10,000 varieties of this important grain, some of them known as "broomcorn," the Purdue scientists have discovered two Ethiopian strains rich in an essential, protein-making chemical that other sorghums lack.

Within three to five years, they estimated at a news conference called by the Agency for International Development, plant breeders should be able to cross-breed and start providing new super-sorghums incorporating the Ethiopian plant gene that makes the difference.

In protein-hungry Asia and Africa, sorghum is often the only grain that will flourish in arid soils. But the new varieties can also be used by U.S. growers who raise sorghum as an animal food, and could result in putting beef on cattle faster and cheaper.

In the poor countries, said outgoing AID Administrator John A. Hannah, the discovery's meaning can be measured against such statistics as child death rates up to 60 times greater than in the United States. In rural India, 80 per cent of pre-school children show malnutrition dwarfism, and those who live often suffer life-long physical and mental retardation.

The Purdue work was described by Hannah and Dr. Woods Thomas, Purdue's director of international education and research, as "a scientific achievement of the first magnitude." They likened it to advances in wheat, rice and corn breeding that produced the high yields of present U.S. crops, then the green revolution that has helped feed an ever more populated world.

Purdue's Dr. John Axtell said the new sorghums should be developed in time to help meet a new crisis in the 1980s, when many scientists believe expanded populations could so swamp food supply that wide

See FOOD, A6, Col. 6

THE WASHINGTON POST
A 6 Saturday, Sept. 29, 1973

FOOD, From A1

starvation would seem inevitable.

Axtell is project director of the Purdue team. AID, Hannah said, picked Purdue to get a $1.7 million sorghum research contract because of its scientists' work on what is called "high lysine" corn.

Sorghum too is a plant that needs lysine. It is a low-growing plant with a white to red to red-brown clump of seeds atop a slim, woody stalk.

It is the world's fourth most important cereal crop, after wheat, rice and corn.

Its trouble, Hannah said, is that "it is not a very good food—it may fill bellies but does not provide nutritive quality."

This is because all proteins are made of a series of chemicals called amino acids, of which lysine is one, and the protein in a food lacking lysine will be only incompletely absorbed in the body. Most will just be excreted.

One answer is to add other protein — peanut cake or soy meal — to forghum flour. This is expensive.

"Until AID zeroed in," Axtell said, "sorghum was one of the least researched food crops." Axtell, Dr. Dallas Oswalt and others began collecting sorghums, testing them and feeding likely ones to rats. A graduate student from India, Dr. Rameshwar Singh, discovered the two high-lysine Ethiopian varieties in this screening.

Fed to baby rats, lysine-rich sorghum increased growth nearly threefold over ordinary sorghum.

Cross-breeding to produce a number of new sorghums for different areas will be a next step. The Ethiopian varieties are already being grown for this purpose in plots in Puerto Rico. Both varieties are made lysine-rich by a single gene, or biochemical unit of heredity, simplifying the task.

Two basic kinds of sorghum must be developed, one low in the chemical tannin, like the two Ethiopian sorghums, the other high in it. Tannin makes sorghum taste bitter, but about a third of the world's sorghum growers choose it because the taste helps repeal flocks of grain-eating birds.

People in these lands therefore eat bitter sorghum or nothing. But tannin, Oswalt discovered, further blocks the release of the protein for nourishment.

What the scientists are also trying to do, therefore, is develop some bird-repelling sorghums that will lose their bitterness as they mature, or find other ways, perhaps harmless crop treatment, to repel birds.

Sorghum: "Miracle" Grain for the World Protein Shortage?

The development of hardy strains of so-called "miracle" wheat, rice, and corn by plant scientists has made possible a dramatic rise in the production of cereals in less developed countries. Now, researchers at Purdue University have come up with a discovery which they believe could transform the lowly sorghum plant into an important source of protein for millions of the people who need it most.

The Purdue scientists have identified two strains of sorghum with a much higher lysine content than most other sorghum plants, and are working to develop seed stocks for wide use. An estimated 300 million people in the world now depend on sorghum for their "principal" food, according to the Agency for International Development (AID).

Sorghum is the cereal crop on which the very poorest people in the developing countries of Africa, East Asia, and India depend. It grows in arid and stony soil where wheat and corn cannot. It is a staple in the African region of Sahel, which this summer experienced a wide-scale drought and famine. Sorghum seeds are pounded into flour, which is then mixed with water to make mush or baked into crude bread; the stalks are used as thatch or for fuel. The sorghum usually grown in the United States is not a human food crop; it is used as feed for animals. The stalks of certain strains yield a kind of molasses. Even as fodder, its poor protein value requires that it be supplemented.

Sorghum's nutritional defects stem from the small amounts of lysine found in most of the 16,000 strains grown throughout the world. Lysine is one of the amino acids necessary to protein manufacture in the body. Thus the lack of lysine in sorghum limits the overall protein value of the grain. While screening some 10,000 varieties of sorghum from all over the world, the Purdue researchers found two Ethiopian strains with a single gene which remedies the lysine deficiency. Hence the plants have triple the protein value of normal sorghum. The researchers, including John D. Axtell, Dallas L. Oswalt, and Rameshwar Singh, performed the work on a $1.7 million contract with AID. They will publish the results in the forthcoming issue of *Crop Science*.

Axtell stated at an AID-sponsored press conference on 28 September that, by cross-breeding techniques, this gene could be added to strains of sorghum already used by farmers. And, since the people who depend on sorghum are also susceptible to kwashiorkor and other malnutrition-related diseases, the increased nutritive value of their sorghum diet could lessen the incidence of those diseases. At the press conference, John A. Hannah, the outgoing AID administrator, went a step farther and called the Purdue discovery one "of life-giving importance" to the 300 million people who depend on sorghum.

Moreover, the sorghum discovery will aid the very poorest people in less developed countries, those who have allegedly been bypassed by the green revolution. In developing countries, only the richer farmers grow wheat and corn. Critics of the green revolution have maintained that the so-called "miracle" crops require substantial

capital investments—special fertilizer and the like—and thus have benefited only farmers who were well off to begin with. Sorghum, by contrast, is grown by farmers too poor to grow these more expensive crops.

At the press conference, Hannah likened the breakthrough to the discovery, also made by Purdue scientists, of high-lysine corn about 10 years ago. Oliver E. Nelson of the University of Wisconsin, a crop geneticist who worked on high-lysine corn, also told *Science* he thought the two discoveries are comparable. Nelson said, "Axtell's data looks very good to me." For people "who . . . draw the major part of their protein from sorghum it would be tremendously important."

However, these rosy predictions were dimmed somewhat by the scientists themselves during the press conference and at briefing sessions, where they admitted that many obstacles and unknowns lie in the path of delivering the high-lysine sorghum to farmers world wide. Axtell stated that, in the next 3 to 5 years, the scientists will probably be able to have farmers grow the genetically improved strains in the "most promising" areas, such as Ethiopia, where they believe these plants already grow. But the process of breeding the gene into the many other sorghum varieties used by farmers could be lengthy. Actual introduction of improved sorghum could take "7 to 10 years for the most difficult situations," Axtell admitted. "The tendency will be to overstate how quickly this will get into production."

For one thing, a plant that is healthy in the nursery might not fare so well in the field. The Purdue scientists so far have only preliminary results on how well the protein-rich sorghum really grows. "We don't have any data on the yield characteristics" of the strains, says Axtell, but from preliminary growing of them in a tropical environment, in Puerto Rico, "we have no reason to expect there will be any major problems." Another risk incurred by genetically altering plants is that other features—their appearance, taste, texture of grain, or resistance to disease—can be inadvertently altered. "The problem is not that they [the genes] can not be transferred to other varieties," explains Nelson. "The question is whether the gene will interact well with the genetic background into which it is put. . . . They may go to one variety with a favorable interaction, but in the other varieties," the result might be unfavorable. AID will continue to sponsor the work of crossbreeding, as will a number of international organizations.

Another set of unknowns involves the distribution of improved seeds to the farmers. Here, however, Axtell pointed out the advantages of marketing a genetically improved plant, instead of trying to get people to use food additives or of enriching their own food through processing. "Once you get the seeds to the farmer there is no further technical infrastructure needed to ensure that it will enhance his diet."

The work was part of AID's $9 million per year research program aimed at addressing problems in less developed countries. Erven Long, a senior AID technical officer, indicated recently that the sorghum breakthrough is but one of a series of "firsts" likely to emerge from this program. Other key results could come from research at the University of Illinois on a biodegradable DDT, and at the University to emerge from this program. Other vaccine. Other work might result in protein-enriched wheat and alternatives to herbicides as a method of weed control.—DEBORAH SHAPLEY

Briefing

Congress Views Détente with a Fishy Eye

The ambiguousness of the current U.S.–Soviet détente was pointed up by two votes in Congress on 26 September, one to authorize accelerated construction of the Trident missile submarine, the other to require a free Soviet emigration policy as the price for removing discriminatory tariffs on Soviet goods.

By a vote of 49 to 47, the Senate authorized a $1.5-billion appropriation for beginning work over the next 4 years on all ten of the Trident submarines presently proposed—a schedule opposed by Senator Thomas J. McIntyre's research and development subcommittee but not by the parent Armed Services Committee (*Science*, 20 April and 24 August). The House Ways and Means Committee voted, with no dissent, to deny "most-favored-nation" (MFN) treatment to the Soviet Union in levying tariffs unless Russian Jews and other Soviet citizens are permitted to emigrate if they choose. The Nixon Administration had lobbied against imposing this conditional MFN policy, contending that it might imperil détente. Ironically, however, on the other side of the Capitol, Administration spokesmen were emphasizing the gravity of the Soviet military threat in appealing to senators to support Trident. The Administration has given contradictory explanations of why it wants to rush ahead with Trident, but one reason is that it feels Trident will be a useful bargaining chip in strategic arms talks.

The Trident authorization is now in the bag, for both the House and Senate have approved it. The conditional MFN policy has not yet been approved by either the House or Senate, but a majority in each body has endorsed it. Since the recent harrassment of Soviet physicist Andrei D. Sakharov (*Science*, 28 September) and novelist Aleksandr Solzhenitsyn, a broad-based coalition of liberals and conservatives has been pressing hard for Congress to stand up for Soviet dissenters.—L.J.C.

Dominick Leaves EPA; Successor Not Yet Named

The Environmental Protection Agency's assistant administrator for hazardous materials, David D. Dominick, is leaving office 15 October to return to private life. Dominick, an attorney from Wyoming, was commissioner of the Department of the Interior's Federal Water Quality Administration until 1970 when that agency was absorbed as a part of the newly created EPA. At EPA, Dominick has been identified especially with efforts to eliminate or restrict the use of predator control poisons and the use of DDT and other persistent pesticides. Charles Wurster, chairman of the scientific advisory committee at the Environmental Defense Fund (the environmental law group that has led efforts to ban persistent pesticides), gives Dominick high marks for job performance and expresses the prayerful hope that his as yet unnamed successor will be equally competent and vigilant.—L.J.C.