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SORGHUM BREEDING FOR IMPROVED PROTEIN CONTENT, AMINO ACID COMPOSITION, YIELD, AND DIGESTIBILITY

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Sorghum is among the major crops of the world but it has been placed on low priority for adequate improvement programs by most countries where it has been an important crop. There are many other countries where it could be used and it has received little or no attention there. Presently, the amount of research invested is intermediate between the very large amount done on rice, wheat, and maize and the low amount on millets, the food legumes, the root and tuber crops, the vegetables, and the oil crop seeds or residues therefrom.

The "green revolution" in rice, wheat, and maize is of tremendous magnitude and is well-known. It is now time to recognize the fact that a green revolution has also started in sorghum both in terms of increased acreage and even greater productivity per acre. Since the base period of 1948-52 to the year 1968 there was a 20 percent increase in Africa in area and 18 percent increase per acre in yield. In Asia, area was increased by 17 percent and yield per area approximately 39 percent. In South America there was an increase from a very low area to an area approximately 16 percent of that in all of Africa which made a 1288 percent increase in area while the unit yield went up 80 percent. U.S. sorghum area went up 83 percent and yield per area went up 163 percent. Yields of sorghum have gone up almost twice as fast as for the other major cereals. Regarding yields under best management, almost 13,000 lbs. per acre in replicated plots were first reported at Purdue University in 1958 and ten years later were being achieved on a commercial basis under the best management practices. Now we are seeing yields of better than 15,000 to 20,000 lbs. per acre in replicated plots at Purdue and I would prognosticate the very best commercial yields would achieve that in the next 10 years. The period of impact of hybrids began in 1956.

Selection of inbred lines from the world's sorghum germplasm sources revealed lines that yield about 10,000 lbs/A and hybrids from these that now reach the peak of 15,000 lbs/A and above. Beginning in July 1966 the USAID began support of a research project entitled "Inheritance and Improvement of Protein Quality and Content in *Sorghum bicolor* (L.) Moench" at Purdue University. The primary concerns have been protein amount and amino acid composition in material with economic yield and digestibility. During this same period of time major efforts have been mounted to increase protein amount in rice, wheat, and maize and I would submit that without these efforts that the protein percentage and quality of the world's food and feed grains would have decreased much further than it has. As Bill Hoover reported, protein has already gone down over one percent in wheat in Kansas and in most of the United States. This period of very rapid increase in yield is certainly the time to have an increase in protein in the

world's major cereal crops. Sorghum has already been considered a fair source of protein since it is 1-2 percent higher than maize which is the most comparable cereal. The variability of protein has been considerable and would seem to allow for selection for 50-100 percent increase in economic yield levels. There are several sorghum lines including some of the bird resistant materials which have a strikingly low digestibility and this poses a ver important problem to the improvement program. Since there are also many high digestibility types available, presumably improved digestibility can be combined with improved yield and improved protein amount and quality.

Sorghum is presently used as the primary human food crop in Africa and Asia. In these areas it is primarily consumed as a whole grain and processed in the home. As income levels go up in these lowest income areas and in all the rest of the world sorghum becomes the first major grain available for animal feed, including poultry first priority usually and then swine, with ruminant feeding far behind in the less developed countries.

A real place has been found for sorghum in rotation as a crop to follow rice or as a short duration crop to follow wheat in many of the drier areas of the world. In order for the new genotypes to be effectively studied and subsequently produced they must be treated as part of a coordinated management package with all inputs provided at sufficient levels and with proper timing in accordance with the environmental conditions available.

An important background for the present work was the acquisition and distribution of the world collection of sorghum by the Rockefeller Foundation together with cooperators around the world. This was essential in providing the variability for the present improvement program. Presently there are two concerns about the collection. One is the adequacy of the collection in representing all naturally occurring variability. Drs. Harland and de Wet have been collecting each year in the areas of Africa not presently adequately represented. In addition they are collecting the wild and grassy types that were almost entirely absent from the world collection. This year 2,000 diverse new lines that were well documented as to source were acquired from the Camerouns and represent a major addition. In addition collections are currently being made by local research workers in Mali, Ethiopia, and Korea since their available variability was not well represented. The Kaoliang group with primary center of availability in northeast Asia is presently the most deficient group among the cultivated types. The second concern is the adequacy of sampling from the collection and this is presently under study. It is already obvious that there is much unused variability within the Guinea group and the kaoliang groups. Many other sub-groups are expected to be sampled in the near future. The range of composition in protein and the limiting amino acids found to date is as follows:

7 to 26 percent for protein

.34 to 4.51 for tryptophan (the lowest levels may involve destruction, methodology still in development stage)

.98 to 4.62 for methionine/crystine (sulfur-bearing amino acids)

3.26 to 5.51 for isoleucine

9.5 to 17.1 for leucine

.272 to .380 for isoleucine/leucine ratio (highest ratio desirable)

High levels of protein and amino acid composition have been found in all kernel types. The floury types that were sorted out by J. R. Quinby were analyzed and showed more or less a normal distribution in protein composition. In the early stages of this study of sorghum grain composition the variance was found to be relatively high among plants, genotypes, and years. The development of adequate sampling procedures of several open pollinated seeds has led us to an excellent repeatability of composition among genotypes. We have several dozen lines with a lysine level above 2.5 up to 13 percent protein that shows consistent superiority in composition and yield over check hybrids in many varying environments. We are now looking for the specifics of location inter-actions. As reported by Dr. Mertz in some of our earlier research reports the endosperm changes in sorghum seem to be the same types that occur in maize. Apparently they are governed by many genes rather than a single gene as in the case of "opaque-2." In addition to these endosperm variation, embryo can also vary significantly. The composition of the embryo is much higher than the endosperm of the same seed with protein ranging from 18-25 percent in seeds where the endosperm is approximately one-half that and lysine varies from 5.5 to 6.5 percent which is two to three times the lysine level in related endosperms. Oil content also has a significant range of approximately 1.2 to 6 percent.

A network of cooperators has been developed in approximately 60 countries around the world with well over a hundred nurseries presently growing material from this program. A mailing list for research reports from this project has evolved with almost 600 names presently included. In the interests of first testing possible broad areas of adaption, approximately 50 percent of the world collection that is day-length insensitive material has been sampled extensively and much variation provided to cooperators. In 1970, 200-300 inbred lines were sent to 103 nursery locations in 53 countries with an additional 100 high protein, high lysine lines sent to 12 locations. A major contribution to date has been providing these breeding programs with a maximum number of diverse lines with yield potential and high protein amount and quality. For the immediate future it appears that relatively high yield types with high protein can be provided. To evaluate these new varieties properly they must be tied into the proper cropping system and management. The dramatic shifts in amino acid composition seem to be present and should be able to be incorporated into improved yield and protein amounts in the near future. Selections have been made for material distributed to date and many selections have been made in each country. Usually these are incorporated into breeding programs to recombine the high yield and protein amount and quality with local resistance and adaptation. In several locations in South America, lines selected directly from our material have exceeded the performance of the best checks. One variety in Colombia was named "Marupaanste" and presently needs further checks to determine its breadth of adaptation and superiority of performance.

The one severe limitation to breadth of adaptation of this material has been between high and low elevation. Thus we are in the process of developing a high elevation network in which to incorporate selections adapted in Mexico with those that are native to Ethiopia and other high elevation locations.

Biological testing is an absolute necessity in measuring the improvement in nutritional value by compositional changes. To date, preliminary trials have been done with In-Vitro

tests which are used for predicting values in feeding tests. Some rat and poultry feeding trials have been run. In the immediate future additional biological tests will need to be run on improved protein material that have been incorporated into locally adapted lines in other countries.

Another factor that is needed is greater attention to information exchange in sorghum breeding programs in the world. Development of the present mailing list of cooperators and distribution of analyses, research, and experimental material has been a start. We need to distribute information from this location but also from other competent stations among sorghum workers and also need the distribution of methodology studies with workers of other cereal crops. A critical element in getting this work started in many countries of the world has been the assistance in planning and crop management by means of personal visits with workers concerned. One of the biggest thrills to date has been the degree to which officials have invested in expanded research programs.

Thus while sorghum is a primary human food crop in much of Africa and Asia, it is primarily a feed crop in the rest of the world. It is probably the first grain in many areas to be deleted from the human diet and used for animal feed. In South America, however, where it is usually found as a feed grain, it is quite possible to mix it with wheat and other cereals to be used for human food. Thus it is possible to use it for human food in times or places of shortages and have it for animal feed in times of plently.