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DEPARTMENT OF AGRICULTURE

DEPARTMENT OF AGRICULTURAL EXTENSION

KASETSART UNIVERSITY

THE ROCKEFELLER FOUNDATION

SORGHUM BREEDING

L. R. House

Sorghum Leader, ICRISAT, Hyderabad, India

The objective of the ICRISAT sorghum improvement program is to improve the yield and stability of varieties and hybrids in diverse phenotypic backgrounds including a range of maturities and plant heights and with good grain quality for food use. Important is the development and utilization of resistance to priority insect, disease, Striga, and drought problems.

The ultimate goal is to help generate a shift from traditional subsistance agriculture to a more technical market oriented agriculture. A new variety and its management can trigger change, but alone cannot sustain change. New varieties and their management create changes in disease and insect problems and a relevant research structure need be developed to anticipate and respond to these changes. Failing this the new variety may create new problems and fail to contribute. But also, the development of new varietal material is a continuing process. To sustain change in agricultural development requires a long term commitment to research. In addition, the engineer, the socioeconomist, the politician and government planners must also be involved to ensure the community of goods and services (including credit) that must be part of the process of creating change

The rate of the crop improvement process is enhanced by the sharing of experience and materials. I have been impressed in my experience of the value realized from sharing knowledge and the rapid mobilization of useful germplasm between scientists. I attribute much of the change that we have observed during the last 20 years to rapid germplasm exchange.

I. Determination of Objectives

To determine objectives we must ask some questions:

1) What is our target group? I understand that one of your major objectives is the feed market in Japan. At ICRISAT we frequently refer to the poorest of the poor where inputs such as fertilizer, water, and insecticides may not be feasible. We maintain a concern however, that our varieties and hybrids do respond to good management sufficiently to contribute to those who can provide inputs.

2) How do we manage our breeding nurseries and yield trials? We must endeavour to realized the objective for which a nursery or trial was organized This appears obvious, but how many times has a yield trial failed because of bird damage. I will return to this problem in greater detail, but generally one wants to maximize his selection opportunity. We have indications that variety by fertility interactions are small and find it easier to select at reasonably good fertility levels. On the other hand, interaction of variety with moisture stress is high so evaluation of the same entries in both con-

ditions is desirable. Permitting non-devastating attacks by insect pests in a nursery may provide the opportunity of discarding the susceptibles. Location, time of sowing, and use of spray may all be useful to permit a desired level of infestation leading to a desired opportunity for selection. Ultimately yield trials should be grown in farmer's field conditions.

3) What kind of a research organization do we want? Generally there are one or more stations identified to undertake developmental work and other stations identified primarily for evaluation. Final evaluation frequently is undertaken on farmer's fields. A team of scientists; breeders, entomologists, physiologists, pathologists, and others, is frequently at the main stations. Coordination is useful to planning, evaluation, and reporting of work. Another advantage of coordination is assisting in rapid mobilization of breeding stocks between stations. Coordination cannot be forced, it is a service, and agreed to by all concerned. We feel it best if the coordinator is a scientist with his own research program.

An important objective of regional research institutes such as ICRISAT is the strengthening of country programs. International centers can assist but cannot creat the sustained changes required to generate a shift to a more technical agriculture; certainly they cannot replace the need for in-country research capability. The sharing of experiences between country programs and international centers is important to both organizations. At ICRISAT we hope to develop agronomically useful material in phenotypically different backgrounds to develop sources of resistance and grain quality in agronomically useful backgrounds, to develop techniques, and to assist with training. We do not feel that we can develop final products, we recognize environments and problems for which we cannot respond. We know that resistance traits will have to be incorporated into locally used varieties in their adaptation areas. We feel the need for local research capability to respond to changing needs. Plants have no knowledge of political boundaries and we recognize the value of research anywhere to the international community. The international center can provide a coordinating service taking care to acknowledge credit.

4) The variety vs hybrid question is a frequent issue. It has been well demonstrated that hybrids are more stable and yield better than varieties particularly as growing conditions become more harsh. The major problem in using hybrids is the production and marketing of seeds. This is more related to an industrial type activity than a governmental type activity and ministries and departments of agriculture need the willingness and flexibility to study the problem and encourage new developments. Properly done, a hybrid seed industry can lay a base for developing a seed law, including certification, strengthening quality control of seed. I prefer to face the problem of seed production accepting concern that an effort must be made to get the job properly done. This is an industry and requires a market - if the area sown to sorghum in a country is too small to support a seed industry then it is likely best to restrict to use of varieties.

5) What about local varieties? It is my experience that some of the most promising selections have come from crosses between local varieties and

adapted exotic types; also good selections have come from progeny of crosses between adapted exotic types. The least contributing has been an effort to obtain contributing selections in progeny of local x local crosses. There are exceptions. A look at the situation in India is interesting. Three hybrids have been developed that are contributing - moving to the farmer. The first is CSH-1 and this is a cross between combine kafir 60 A-line and IS-84, a yellow endosperm line selected from segregating material from Texas. CSH-5 and CSH-6 both have the same pollinator parent CS-3541 (CSV-4). This elite parent was selected from a cross between IS-3541, a Zera Zera local type from the Sudan and IS-3675, a recovered yellow endosperm kafir line from Texas. The female parent of CSH-5, IS-2077A is derived from the cross MS-385A (a kafir 60) x IS-1053 (G-11, a line from Andhra Pradesh). The female parent of CSH-6, IS-2219, is from a kafir shallu introduction in the collection. In short, the three most promising hybrids in India today involve 5 original lines only one of which is from India. CS-3541 is from a local by exotic cross, except the local is from the Sudan and not from India. The role of introduction is apparent.

A problem arises in attempting to use exotic varieties to compete with locals in parts of West Africa, where moisture stress is severe. The locals have frequently come to an equilibrium situation with respect to diseases, pests, and other problems and yield favorably with respect to introductions. The introductions are frequently much more susceptible and we talk about crossing to the local as a source of resistance. At times one asks himself; why bother with exotics? Almost universally, breeders are wanting varieties 2 to 4 weeks earlier than the locals. The availability of resistance to grain mold makes this more possible as deterioration is avoided if the rains continue beyond expectation. We still must solve the problem of midge build-up on early exotics that do substantial damage to the later maturing locals - total production can in fact go down. The grain-straw ratio of locals is not good (1 to 4, 1 to 5) and this frequently limits yield - best grain yields are realized when this ratio is close to 1 to 1 or 1 to 2. The chances are good that yields can be increased above those of the local with a change in plant type. In fact, advances in yield that I am aware of have generally come from plants that are phenotypically quite different than local types (again, there are exceptions).

Frustration can be experienced in working segregating populations from crosses between early, short and late types. There are a large number of poor plants but progress can and has been made. Another route is to convert promising tall, late types by backcrossing to introduce genes for earlier maturity and reduced plant height. The problem is much reduced when both parents have the same height and maturity genes.

6) Adaptation Zones. Some people dream of varieties and hybrids with universal adaptation. It is true that local varieties frequently have rather limited environmental adaptation. Hybrids used in such areas may have much broader adaptation but they also have limits. From our point of view at ICRISAT, we find no correspondence between the adaptation of varieties at Hyderabad with the high rainfall long season or high elevation adaptation

zones in Africa and Central America. Some opportunity to undertake developmental activity is important if varieties developed in one adaptation zone are poor in others. Ultra fine environmental definition does not appear necessary for varietal and hybrid improvement.

The distribution of disease, insect, and other problems do not follow climatic adaptation zones. The availability of sources of resistance in good agronomic backgrounds may be useful out of their varietal adaptation zone - incorporation of such traits into adapted varieties would need to be done locally.

It is sometime a question of whether a farmer should sow corn or sorghum. Corn is encroaching into the vast sorghum area in the high, long season rainfall area of Africa. Sorghum is encroaching into corn areas of Central and South America. Some farmers in areas of Africa and the Americas sow corn on land where moisture availability is marginal. They would be better off if sorghum was used. The availability of good grain quality sorghums should help the process of sowing the right crop in the right place. I feel that yield trails including the best corn and the best sorghum varieties or hybrids should be conducted periodically.

II. The Crop Improvement Process

1) The maintenance of variability. It is just as important for a breeder to generate useful variation on which selection can be practiced as it is to exploit variation in the development of new lines and hybrids.

(a) The collection numbering about 17,000 entries, is in constant use for agronomic as well as resistance traits. ICRISAT is involved in collection activities and increasingly we hope to convert the best of these into agronomically more useful backgrounds.

(b) I feel it useful for the breeder to purposely select to improve types because they are phenotypically diverse. Some types are more elite than others and there is a tendency to select the most elite. This soon leads to loss of variability and an approach to a yield plateau. Conscience selection to retain an ever improving array of diverse types is a step in maintaining variability.

2) We are as much interested in stability of yield as yield per se. By stability we mean a more constant performance over locations and seasons. There is variation for this trait, for example SC-108 (a recovered gambella type), performs well over a diverse array of locations. We select for stability by multilocation evaluation. Resistance to major limiting factors and earlier maturity are also traits contributing to stability.

3) There is interest in population breeding procedures but other, more traditional procedures, contribute and may be more relevant.

(a) The pedigree breeding process rapidly exploits genetic variation resulting in good grains in a short period of time. If speed is important in meeting an objective this is a good breeding procedure. Pedigree breeding in advanced generations from crosses is common practice and contributing. This is a powerful breeding technique.

(b) Backcrossing to incorporate specific traits, particularly if they are simply inherited, into agronomically elite varieties is worthwhile and fast. Probably, this well-known breeding procedure could be used to greater advantage than is currently practiced.

(c) Population improvement is slow but a high level of variability is maintained over long periods of time. Our experience with populations at ICRISAT has taught a few lessons. We feel that the population approach has proved its worth and is a valuable breeding procedure. It is time consuming to develop a population. It takes land and is labor consuming (expensive); hence, we feel that only one station in an adaptation zone need be involved in building a population (incorporating male-sterility, random mating, and the first cycle or two of selection). The population might then be worked at several locations, possibly recombining after several cycles at each location. We have found multilocation yield trials as part of the evaluation phase of each cycle to be a burden on cooperators and now restrict multilocation trials to locations available to ICRISAT in India. Derivatives from populations advanced by pedigree breeding have been useful. In time, when population trials include more elite material we will reconsider sending them to cooperators abroad (we do send a trial or so on a limited basis now). The population program began in 1973 from existing populations.

We feel that populations should be made up of lines carefully selected for some good reason. Simply putting entries together to have a wide base does not appear to be as rewarding. We also feel that some 15 to 25 entries is sufficient and want to avoid building populations with several hundred parents. A population, then, would be formed after a breeding program had identified good material; it would not be developed to initiate a program. Different people no doubt have different ideas.

4) The role of seed exchange is important. The value of breeding stock is in the using and not the having. The more good material can be made available for use by others the faster we can make progress. Coordination facilitates rapid seed exchange. Programs should be receptive to incorporation of new introductions and not so "locked in" to their own materials and interests that an inflow of new material does not occur. To me, as breeders, we have responsibility to make good breeding stocks available and also to maintain adequate flexibility in our programs to constantly incorporate new material.

III. Breeding for Resistance

1) Priorities. Incorporation of resistance to limit problems may be essential. It is time consuming and one wonders how much effort to make. CSH-1 in India is used as a susceptible check for many problems, yet it is still the most commonly used hybrid. Certainly a first priority is the

development of something of sufficient agronomic superiority to justify incorporating resistance. On the other hand, the first pearl millet hybrids in India were so susceptible to downy mildew, ergot and smut that inoculum increased so high that even local varieties could not be grown. CSH-1 supported a build up of midge that attacked late locals. There is no way that one can indicate what balance should exist between breeding for yield and breeding for resistance - this will be location specific. However, it is clear that one cannot ignore the need to include breeding for resistance as a priority when the situation warrants.

2) The team. Greatest progress can be made if a team of relevant scientists - the breeder, physiologist, pathologist and entomologist - work together. They should operate as a team developing varietal material together. We feel this is a much more effective way to cooperate than for a pathologist to receive an array of entries from a breeder, evaluate them and send the results back to the breeder.

3) Collections. The world collection has and is providing sources of resistance to an array of yield limiting traits. Efforts are made to strengthen the level of resistance by intercrossing and to incorporate resistance found in the collection into agronomically elite material. Collection is a process in which we can all be involved and any resistance sources any of us find should be sent to Hyderabad. We are suggesting that varietal names in the local language be translated as the names frequently are significant - at times indicating resistance.

4) Opportunity for screening. The gain from selection depends very much on the screening opportunity. We have made use of different locations to screen for different traits because the expression is more reliable and better than at Hyderabad. With diseases, even in good locations for the disease, we have inoculated to obtain a more reliable and uniform infection. At Hissar, during March and April the shoot-fly, and during the monsoon the stem borer, are sufficiently severe that use of attractants and spreader rows or infestation with stem borers is not necessary.

We are interested in an opportunity to screen at different levels of severity so that we do not over-pressure early generation material, but increase severity as resistance in the plant material improves. We are realizing a lower stem borer pressure in the monsoon season than in the post monsoon season following artificial infestation at Hyderabad. The level of severity during the monsoon season at Pantnagar is between that found at Hyderabad and Hissar. We can use sowing date during the monsoon season to gain some control of shoot fly attack. Late sowing favors midge and head bugs at Dharwar. Early sowing at Dharwar favors downy mildew, later sowing charcoal rot, and still later sowing sugary disease. As we gain more experience we are able to identify locations and sowing dates to maximize the selection opportunity that we want.

Technique can be very important. Selection of plants at maturity for resistance to shoot fly is not very useful - almost no gain is made. Once we began to separate the effects of oviposition non-preference, antibiosis, and recovery resistance in the seedling stage much more progress was made - we now have entries that showed a 70% stand when the best local check had a 40% stand. Recently trichomes, microscopic hairs on the leaves, and a glossy trait have been shown to contribute to resistance and we will begin to back-cross these traits (they appear to be linked) into our elite breeding stocks.

Number of locations desired for screening is influenced by the reliability of the screening procedure. Our techniques for shoot fly and grain mold are sufficiently good that we use only 2 locations. Striga and midge are chancy - some years expression is good and in some years poor. Uniformily of Striga infestation is very difficult to realize. We therefore choose more locations (4, 5, 6 as possible) and in the case of Striga use more replications (4-6) and space a common susceptible check frequently throughout the field. The increased number of locations helps ensure that at least one or two of them will succeed each year.

5) Separating effects. One of the big problems that we have is separating one effect from another. Shoot bug can interfere with screening for grain mold, stem borers can reduce head size resulting in poor expression of charcoal rot, using chemicals to control shoot fly attack has an adverse effect on stem borers placed during the infestation process; sugary disease can interfere with midge screening. We now go to considerable expense to control the unwanted effect; for example, shoot fly eggs are removed by hand every two days in the post monsoon stem borer screening nursery. We make use of insecticides, even using more frequent applications than normally required to control stem borers in a charcoal rot screening nursery. We head bag to protect from midge to evaluate head bug damage.

6) Working with quantitative inherited traits. Most of the problems that we work with are quantitative in nature. One approach that we are taking is to try and identify resistant and susceptible cultivars from field screening. Once we have made such identification we begin to look for contributing factors. Todate we have only approximated this approach. Resistance to shoot fly was known but progress by breeding began when oviposition non-preference, antibiosis, and recovery resistance effects were separated while selecting. Subsequently trichomes and a glossy trait contributing to resistance were identified. A search among cultivars by field screening for Striga resistance has been coupled with laboratory tests. Low stimulant production (stimulant in root exudate from sorghum that germinates Striga seeds) and mechanical barriers to penetration by Striga roots have been identified. Unfortunately, low stimulant production and field resistance have not been well correlated (Correlation Coef. of 0.4). When we can identify various components of a quantitatively controlled trait we can breed to increase the expression of the components. Hopefully, we can recombine components realizing a higher level of resistance than if the trait were selected as a whole. This has certainly been the case for shoot fly where selecting for normal mature plants in a screening field resulted in almost no gain. Screening for components has been very successful. A question is raised whether we should screen for components or for the effect itself - some feel that selecting for components

may result in placing too much stress on some aspect and missing the total. If selection is for the trait all components are improved. Our experience has not been this way and we prefer to look at components when this appears possible and contributing.

7) Mode of inheritance. We are concerned about the mode of inheritance in any array of diverse types showing resistance. In the last 2 years the presence of trichomes and the failure to produce the stimulant to germinate *Striga asiatica* seeds have been identified to be controlled by single recessive genes. We think that glossy is also controlled by a single recessive factor and will confirm this, this year. Obviously such simply inherited traits can be easily used by backcrossing.

We are also interested in the magnitude of additive variance effects and the magnitude and direction of dominance. We are interested in heritabilities - all of this information helps decide breeding approach.

8) Simultaneous incorporating of multiple traits. We are planning a breeding approach where F_2 and F_3 generations will be sown slightly late in the monsoon season to increase the levels of attack by shoot fly, stem borer, head bugs, shoot bugs, downy mildew, etc. slightly above the level of severity found in farmer's fields. This will enable us to drop susceptibles. Seeds will be increased in the F_4 and families in the F_5 and F_6 will be screened for all traits of concern. We will then group materials based on scores for those 3 traits for which the score was best. Selection pressure will then be applied for these 3 traits simultaneously until good levels of resistance are realized. Then, further recombination will be undertaken. It has been suggested that it is not possible to simultaneously handle more than 3 traits because of random effects in each trait that reduce the gain by selection. Geographic distribution of problems and varietal adaptation will be considered while pooling traits. Some traits that go together are already becoming apparent - drought resistance, charcoal rot resistance, and *Striga* resistance; i.e., drought resistant lines usually are more resistant to charcoal rot and *Striga* (based on casual observation). We recognize the value of the population breeding method for simultaneous incorporation of traits. Families can be evaluated for a number of traits and the best included for recombination.

IV. Breeding for Resistance to Moisture and Temperature Stress

Efforts to breed for resistance to drought based on yield have not been good. Correlation between performance with adequate moisture and in moisture stress is poor indicating the need to evaluate breeding material in both situations. Attempts to correlate plant traits with yield in moisture stress situations has been poor. Clearly, breeding for drought resistance is going to be a problem - this is not unexpected.

Some aspects related to stand establishment and seedling drought resistance have been rewarding. Seeds of some varieties emerge from as deep as 25 cm. The value of deep sowing is that there should be adequate moisture in the soil at the time of germination to sustain seedling emergence and growth if rains fail after sowing. Tests for seedling drought stress have been carried out screening for seedling that with stand drought and those that recover when stress is released. The glossy trait contributing to resistance to shoot fly is also contributing to seedling drought tolerance.

Drought resistance in the seedling stage is not well correlated with drought resistance later in the life of the plant. Preliminary experiments are showing definite differences in the ability of seedling of some varieties to emerge through a soil crust. A line source method of irrigation is proving useful to evaluate drought resistance throughout the life of the plant. Rows are sown perpendicular to an irrigation line with about twice the normal number of sprinklers. In the future we hope to learn more about the role of soil and air temperature on plant development.

V. Grain Quality

Initially considerable emphasis was placed on high lysine. Two sources were available; the shrunken seeded types from Ethiopia (IS-11758 and IS-11167) and an opaque seeded type (P721) from Purdue University. No one has succeeded in recoverning a plump seeded high lysine segregate that is stable when the Ethiopian types are used as donor parents. It appears that the shrunken seed and high lysine are pleotropic. The opaque seed source has also been disappointing because the lysine as percent of protein is about the same as in normals under low fertility conditions. Most of the farmers that we are concerned about will be growing in low fertility conditions. Our interest in high lysine sorghums has dropped to a low priority.

We are interested in food quality and have standardized procedures to evaluate Chapatis (an unlavened bread in India), Uge, a porridge and Ugali, a dumpling used in East Africa. Considerable differences have been found in foods prepared from visually similar pearly white grain. We feel that we can identify varieties with good grain quality, reducing the problems of acceptance.

VI. The Future

Where are we going? On a global basis the investiment in sorghum is increasing - Title XII in the U.S.A. and ICRISAT are examples. A major effort is being made to improve crop stability. This is being undertaken in many ways - breeding for stability per se, developing varieties some 2 to 4 weeks earlier than the locals (in case the rains fail), and the development of resistance traits. I foresee an increased use of hybrids.

Resistance to drought is high on the priority list - we are concerned about both moisture and temperature stress. We are also concerned about problems of stand establishment. Stem borers top the list of insect problems; internationally midge is more important than shoot fly. We are also concerned about sucking bugs. Grain molds are a universal problem, charcoal rot is spreading rapidly in India and several areas of Africa. Downy mildew is increasing as a problem in India and is of major concern in the Americas. Sooty stripe is a major problem in West Africa and grey leaf spot is a problem in Africa and several American countries. Anthracnose is a problem in parts of South America and the high elevation areas of Ethiopia. _Striga hermonthica_ is a major limiting factor in parts of Africa.

We are placing emphasis on varietal improvement with a strong input into hybrids. An effort is being made to develop good food quality types to minimize acceptance problems. We are developing techniques to screen for the yield limiting factors and are concerned by simultaneous incorporation of several traits into elite varietal material. We are doing this on an international scale. These objectives will occupy much of our attention in the 1980's.

Training and an effort to build national research capability is important to our objective.

VII. Interaction with International Centers

As mentioned, a main objective of ICRISAT is to help strengthen country programs. You may ask the question "How"? Training is certainly an important aspect - generally, each country identifies candidates for the training program. Candidates can be nominated from different kinds of institutions within a country - government, university, research corporations, etc. ICRISAT is able to support a good number of trainees but some are funded by other agencies. It is necessary for trainees to be able to communicate in English.

ICRISAT has an arrangement with the Andhra Pradesh Agricultural University for degree studies (M.Sc.). Students who are accepted by the University, do their course work and receive their degree from the University but do their research at ICRISAT. There are also post-doctoral (research scholar and intern) opportunities. These vary from one to two years. There are opportunities for visiting scientists to come to the institute for periods of a few weeks to a year or more to work on special projects. All of these activities are controlled by the training department and approval to come to ICRISAT is provided by a training committee.

ICRISAT also sends a diverse array of seeds to many parts of the world. These may be seeds of entries in the world collections, from the breeding programs, or in the form of international yield trials and nurseries. They may be seeded of high yielding lines or of lines with resistance or quality traits. Seed from any of these sources can be obtained by writing a letter of request. Our only limitation in sending seed is the actual quantity available. If it is too low we will first have to make an increase - this is seldom a problem. Many of our regional trails and nurseries have been grown in Thailand.

ICRISAT is developing a Sorghum and Millets Information Service (SMIC). newsletter is now coming out - there will be three issues per year. This ewsletter will have a bibliography section on recent sorghum and millet iblications. SMIC is also developing a documentation service and already opies of articles have been made available on request.

ICRISAT has centers in other countries. These centers exist by an invitation of the host country and are funded by various donor agencies.