SORGHUM BREEDING
AN INTERNATIONAL PROGRAMME OUTLINED

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In little more than ten years a massive international breeding programme has produced sorghums that crop much better under a range of local conditions, but yields are still ten times higher in some countries than others. An extensive collection of germplasm, gathered from around the world and now readily available to breeders, offers new and exciting opportunities for breeding cultivars which combine a number of desirable characters that are not incorporated in any of the existing cultivars.

World production of sorghum grain for 1981 was 72 million tonnes produced on 47.8 million hectares, averaging 1507 kg/ha (3) (compared to 56.3 million tonnes produced on 51.0 million hectares at 1103 kg/ha in 1969-71) (2). Yields of individual countries of the world where sorghum is important varied from 4025 kg/ha in the USA to 278 kg/ha in Niger (see Table 1), showing the very wide range of yields produced at present. Under optimum growing conditions, sorghum is known to yield 12t or more grain per hectare on a field basis.

Sorghum (*S. bicolor*) is important in the semi-arid tropics, where it is used for food, brewing, animal feed, construction material and fuel. It is also cultivated in several temperate countries, both north and south of the equator, where it is used primarily for animal feed. Important food uses of sorghum include: leavened and unleavened bread; bread from alkali cooked grain; porridge; boiled grain; noodles; beverages; and snacks such as pop and sweet sorghum.

Research on sorghum is undertaken locally by almost all countries where it is cultivated, but several international agencies also have important sorghum programmes. These include: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT); Collaborative Research Support Programme for Sorghum and Millets (INTSORMIL) – a programme of USAID; Institut de Recherches Agronomiques Tropicales et des Cultures Vivrieres (IRAT), centred in France but active in West Africa; and FAO. A number of private companies, particularly in the USA, Australia, and Switzerland, also undertake research on an international basis.

Table 1. Area, yield and production of the world's major sorghum producing countries (*FAO Production Year Book, 1981*)

	Area 1000 ha	*Yield kg/ha*	*Production 1000t*
Niger	982	278	273
Nigeria	6025	633	3855
Sudan	3106	901	2800
Upper Volta	1200	625	750
Mexico	1767	3562	6296
USA	5355	4025	22360
Argentina	2100	3595	7550
China	3004	2500	7510
India	16000	719	11500
Yemen A.R.	697	911	635
Australia	649	1679	1090

A scientist evaluates IS 8706, an accession in the world sorghum collection. The collection includes some 26000 accessions.

Germplasm resources

Resources of germplasm provide the essential basis for crop improvement programmes. ICRISAT has been invited by the International Board for Plant Genetic Resources (IBPGR) to take responsibility for the sorghum collection, which now numbers about 26000 accessions. ICRISAT is continually involved in collecting sorghum in new areas, especially in Africa, and has sometimes thoroughly re-collected in areas from which particularly valuable traditional varieties have come. A good example was the discovery of the zerazera varietal group from central eastern Sudan and the Gambella Region of Ethiopia. High yielding varieties and hybrids, producing good quality food in many parts of the world, now have zerazera in their parentage.

A Sorghum Descriptor List has been printed in cooperation with the IBPGR, and ICRISAT is accumulating descriptive data about each accession for storage in its computer. Important collections are grown and characterised in their regions of origin – as, for example, collections made in Ethiopia and Cameroun.

ICRISAT is establishing a cold store for the long-term preservation of seed, to avoid the need for repeatedly growing new batches of seed, and to reduce the risk of genetic drift. Substantial parts of the collection are kept in the USA National Seed Repository, Fort Collins, and at Purdue University. The collection is used extensively: for example, 37440 samples were distributed round the world from ICRISAT in 1983.

Tropical sorghums generally flower very late and grow very tall if they are grown out of the tropics, in the longer summer days of temperate zones. A major programme to produce shorter plants, insensitive to day-lengths, was initiated jointly by the USDA and Texas A & M University in 1962. This is basically a backcrossing programme where short early segregates are identified in the F_2 population in the temperate zone of Texas, backcrossed to the tropical parent in a winter nursery situated in the Puerto Rico tropics, and the backcross progeny selfed in a second generation in Puerto Rico. Generally four backcrosses are made.

This has been an extremely valuable approach contributing many breeding lines

A sorghum breeder looking at the heads of female (in his left hand) and male (right hand) parents in a production field of Hageen Dura No. 1. This hybrid sorghum was recently released in Sudan.

to most of the world's improvement programmes. One outstanding example is SC108, a recovered zerazera type; selections have been released in a number of countries and it is commonly used in crossing programmes. Several seed companies and ICRISAT also now have similar programmes for converting sorghum.

Besides sharing germplasm accessions and converted lines, there has been extensive sharing of breeding stocks. Organisations such as ICRISAT, FAO, Texas A & M University and Purdue University have arranged uniform international trials for yield, food quality and resistance to insects and diseases. This rapid distribution of germplasm and breeding lines is an increasingly important aspect of the improvement of sorghum.

Development of hybrids

The identification of cytoplasmic-genetic male sterility in sorghum, identified by STEPHENS and HOLLAND (5), paved the way for the use of F_1 hybrids on farms. The use of hybrids spread rapidly in the USA in the late 1950s and they were subsequently taken up in Europe. There has also been a rapid increase in the use of sorghum hybrids since the early 1960s in a number of Latin American countries – particularly Argentina, Mexico and Brazil.

A hybrid programme was started in India in 1958 and hybrids were released in the mid 1960s. In both Argentina and India there were 50% increases in yields during he 1970s (2). Hybrid sorghums were first ısed in China in the early 1960s and are ıow widely grown. They are also used in iouth Africa, but developments elsewhere n Africa have been sporadic. The first hybid was released in Sudan in January, 1983.

To support the production of hybrids here has been a tremendous investment in ›reeding elite parents with desirable grain :haracteristics and resistance traits. Most :rop breeding is concerned with characters :arried in the cell nucleus, but cytoplasm ›utside the nucleus plays an important role n breeding sorghum. The first cytoplasmic nale-sterility system, involving varieties of nilo as seed parents (donating cytoplasm) ınd varieties of kafir as pollen parents donating the genome), is stable, and many ›ollinator parents can be found that restore nale-fertility in the hybrid. Fortunately, it s easy to use the milo-kafir system in leveloping hybrids.

Other cytoplasmic systems have been dentified as able to diversify the system ınd avoid any serious effects on production f some severe yield-limiting trait arose that vas closely linked to the factors that control nale-sterility. An A2 system has now been leveloped in the USA. There are other ;ystems (for example, Maldani and Vizianagaram in India), but it is difficult perhaps impossible) to locate the factors :hat restore male-fertility, and so the value ›f these systems is limited.

Developing new varieties

Sorghum breeders have long used the traditional methods of selecting new varieties, or parents of hybrids, from single, three-way, or double crosses. As sorghum has perfect (complete) flowers, with both stamens and pistils, it is necessary in crossing to remove the anthers by hand before flowering.

Important components of the genetic varıce of a trait are often additive, so selecın among the progeny from such crosses ntinues to be a useful breeding techniıe. Backcrossing, employed to transfer sired traits into elite varieties, has been ost extensively used in recent years in the nversion programme and to develop ale-sterile seed parents for producing 'brids. If a hybrid from a cross to an ·line is itself male sterile, the pollinator ırent is said to be 'non-restoring'. By conıuous backcrossing a new A-line can be :veloped and the pollinator parent (B-line) its 'maintainer' (AxB produces an A-line).

Sorghum is primarily self-pollinating but ere are several simple recessive genes – ırticularly those referred to by breeders as ıale steriles 3,7' and 'antherless' – that sult in male sterility when they are ›mozygous. Population breeding was first :veloped in maize; it is primarily based on 'oss pollination, but the same procedure ın be used by introducing male sterility :nes into sorghum populations. Populaon breeding in sorghum was first used by '. J. Webster but is now part of the breedıg strategy of most large programmes (4). is advisable first to identify carefully the ırents that are to be included in a populaon, which can range from very few (less ıan ten) to several hundred.

After introducing male sterility genes, :eds of the parents are bulked and random ıated, usually for three generations at low :lection pressure, to break the linkages of :nes on the same chromosome. Various reeding procedures can then be followed, sually depending on the numbers of genrations that can be obtained per year and ıe heritability of relevant trait(s).

All the procedures are forms of recurrent :lection in which each cycle involves valuation and selection as one phase, and :combination as the other phase, in the ycle. Doggett used a mass selection proceure where a cycle was completed each eneration, whereas at ICRISAT an S2 ımily selection procedure is used that :quires four seasons – i.e., two years per ycle. Frequently non-restorers and restorrs of cytoplasmic male sterility are kept in ifferent populations so that lines derived :om the populations can be used as parents f hybrids.

The value of recurrent selection is to rovide constant recombinations of genes; :lection can then result in constant nprovements in the level of expression of rait(s) with little or no loss, in the genetic ariation on which selection is dependent.

Analysis of two populations at ICRISAT ıdicated gains in yield of 13-19% in the JS/R and 7-14% in the US/B populations fter three cycles of recurrent selection. The US populations arose from the combiıation of several populations introduced

A girl emasculating sorghum in a crossing block in Thailand. Anthers are removed by emasculation to enable cross pollination to take place.

from the USA: the 'B' and 'R' refer to maintainers or restorers of cytoplasmic male sterility (1). Yields in the third and fourth cycles were equal to those of the hybrid control, with no loss in variability. Good plants are continually selected from the population and advanced by traditional procedures (i.e., pedigree breeding). Such lines, derived from ICRISAT populations after ten years, have spread round the world, and several have been released for use by farmers in different countries.

The population breeding procedure provides a powerful means of simultaneously incorporating several traits: for example, yield and resistance to grain mould and stem borer. This procedure is gradually being used at ICRISAT as screening techniques permit.

Production stability

Stability of yield is an important concept, with two components: (i) an inherent genetic stability; and (ii) resistance to various traits that limit yield, such as stresses caused by insect, disease, weed and environmental factors. Genetic stability is determined by testing in a wide variety of locations. Following preliminary yield evaluation at one location subsequent evaluations are at two to five distinct locations and final evaluation is at up to 40 different places.

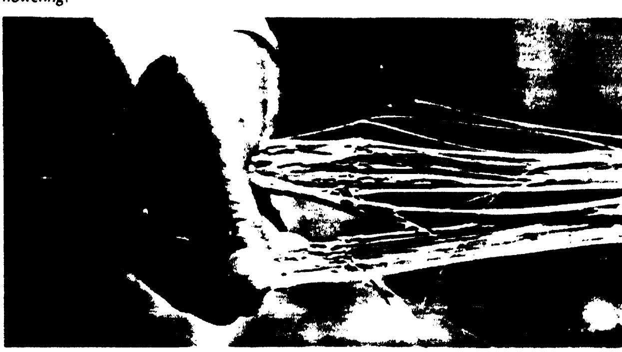
Breeding for resistance to insect, disease, weed and environmental stress varies in complexity, but the approach has common features. It is essential to have a good screening procedure and this should be simple and capable of evaluating large numbers of breeding lines. It is necessary to locate sources of resistance, searching first among the more agronomically elite breeding stocks. It may also be necessary to search the germplasm collection for resistance, or to find greater genetic diversity for the trait. Sources of resistance in unselected traditional varieties can be difficult to use because of poor adaptation, so an effort is made to develop resistance in agronomically useful varieties.

At ICRISAT, the ability to screen for resistance traits and then to incorporate them in agronomically good lines is occupying a major part of the total research effort; such work is obviously multidisciplinary and involves a team approach. Some of the important traits are listed in Table 2, but they are not equally important everywhere where sorghum is grown, so breeding strategies have to be worked out on a regional basis.

Table 2. Objectives in the improvement of sorghum for the semi-arid tropics

1. Good and stable yield
2. Response to fertilisation (good management)
3. Ability to contribute when intercropping
4. Ability to withstand weed pressure
5. Tolerance to highly acid soils
6. Resistance to moisture and temperature stress
7. Traits concerned in stand establishment; i.e., emergence through a cold or hot soil crust, and seedling vigour
8. Cold tolerance, particularly at flowering
9. Appropriate photoperiod response
10. Resistance to stemborers, midge, shootfly, head bugs and (possibly) armyworms
11. Resistance to grain moulds, stalk rots, downy mildew, a number of leaf diseases, smuts and viruses
12. Resistance to the parasitic weed *Striga*
13. Good food quality

Charcoal stalk rot, seen here, is an important yield-limiting disease of sorghum. This stalk rot is caused by a fungus and is particularly associated with drought stress about the time of flowering.



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