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Sorghum Improvement for Semi-Arid Tropics Region : Past, Current and Future Research Thrusts in Asia

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ABSTRACT

Sorghum is widely grown in the Semi-Arid Tropics (SAT) for food, feed, fodder and forage. Although India and Africa represent the major sorghum growing areas, grain yield levels are low compared to those in the developed world. An attempt is made to summarize the relevant research thrusts that have implications on improving sorghum genetically.

The cultivated taxa, *Sorghum bicolor* (L.) Moench with 2n = 20 were evolved and domesticated in North Eastern Africa. Based on spikelet characters, they are grouped into five races - *caudatum, guinea, kafir, durra* and *bicolor* and ten hybrid races. The cultivated forms probably arose from *S. verticilliflorum*. Nearly 35000 landraces collected from 87 countries are being maintained at ICRISAT Asia Center, Hyderabad, India.

Initial attempts to breed sorghum were in understanding inheritance of several morphological traits based on mendelian factors and breeding for specific adaptation. The establishment of All India Coordinated Sorghum Improvement Project in 1970, and International Crops Research Institute for the Semi-Arid Tropics with sorghum as one of its mandate crop in 1972 and the initiation of conversion program in USA in early part of 1960s demonstrated that wide adaptability and high yield can be combined and also produced materials which contributed well to several national programs in the SAT. Recurrent selection methods adopted with the help of genetic male sterile genes were not as effective as pedigree/backcross methods to achieve high yield. Discovery of genetic-cytoplasmic male sterility in 1954 enabled hybrid seed production cost effective, and it was established soon that hybrids were superior to varieties across all ranges of environments. Several high yielding hybrids were produced and released. Soon, lack of resistance to various yield constraints was recognized.

Current research portfolios involve breeding of male-sterile and restorer lines in diversified cytoplasmic background for resistance to various yield constraints with high grain fodder yield. The goal is to produce high yielding resistant cultivars. Future strategies of sorghum improvement for SAT is encoded in ICRISAT's Medium Term Plan which recognized a total of 29 production systems, five adaptation zones, and a multidisciplinary research strategy of producing high yielding resistant parents, and developing integrated pest, diseases, soil and water management methods.

Sorghums are grown throughout the world (Asia, Africa, N. C. America and Europe) and acreage (three years average) has gone up from 41 m ha in 1971–73 to 46 m ha in 1989–91 with a peak (50 m ha) reached in 1977–79. There has been marked increase in sorghum growing area in Africa from 12 m ha in 1971–73 to 17 m ha in 1989–91, while in Asia and in particular in India, there was a reduction from 16.3 m ha in 1971–73 to 14.1 m ha in 1989–91. The world' average productivity has increased from 1.2 t ha^{-1} in 1971-73 to 1.34 in 1989-91, and significantly,

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the productivity remained less than the worlds average productivity in Africa and India where sorghum grains form part of food (0.75 t ha^{-1} in India and 0.80 t ha^{-1} in Africa in 1989–91). A productivity higher than 3.3 t ha^{-1} has been achieved in China, Europe and Americas (FAO, 1973 to 1992).

Sorghums are grown for various purposes - grain as human food in India and Africa, grain as feed in Thailand, China, Australia, North and South American countries and countries in Europe. Dried stalk stems along with leaves are used as fodder to feed cattle in India and countries in Africa. Also green fodder is being used as forage to feed cattle in countries like India, Australia etc. (House, 1985). There is growing interest, of late for forage in Iran, Pakistan, China and Thailand. There are other alternate uses of sorghums (Somani and Pandrangi, 1993 and Karve, 1993). We outline, in brief the important developments in understanding *Sorghum* as a crop and the status of grain sorghum improvement research in semi–arid tropics (SAT).

ORIGIN AND DOMESTICATION

Grain improvement dates back to the domestication of wild sorghums into cultivated sorghums. Doggett (1965a) indicated that the practice of cereals domestication was introduced from Ethiopia to Egypt 3000 B. C. It is possible that domestication of sorghum began about that time. The evidence is strong that sorghums evolved and were first domesticated in North Eastern Africa, in the area North of equator and East of 10°E longitude (Mann *et al.* 1983). According to de Wet sorghum had a diverse origin and probably arose from *S. verticilliflorum*. The cultivated sorghums probably developed through disruptive selection and *durra* types were spread from Ethiopia through trade routes along the Nile to Near East, and across India to Thailand (House, 1985). Sorghum cultivation in India is mentioned in legends that date back to the first century A. D. It's sanskrit name "Yavanala" indicate that it is not a very old crop. Sorghum was introduced into China from India. It is a relatively a new crop to the Americas. It was first introduced in 1857 and used extensively for syrup making in early 1900s, (Doggett, 1965a).

SPECIES CLASSIFICATION

Sorghum has been variously classified. The most detailed classification was made by Snowden (1936, 1955). He grouped the then available sorghums into 31 cultivated species and 17 related wild species. He gave species status to 48 different types. At present his species are more convincingly considered to be races of one species. de Wet and his colleagues recognized three species in the section, *Sorghum*. They are *S. halapense* (L.) pers ($2n=40$) – a rhizomatous species, *S. propinquum* (Kunth) Hitch ($2n=20$) – a rhizomatous form, and *S. bicolor* (L.) Moench ($2n=20$) - all annual taxa as recognized by Snowden (1936, 1955). The last group contained available complex of cultivated forms (subsp. *bicolor*), a wild African complex (subsp. *drummondii* (steud.) de Wet) and weedy introgressed derivatives (subsp. *arundinaceum* (Desv.) de Wet *et al.*, Harlan) (de Wet *et al.*, 1970).

Harlan and de Wet (1972) further simplified classification readily used at present by most breeders. The cultivated taxa having 28 (out of 31) species of Snowden's series *Sativa* are partitioned into the following five basic and ten hybrid races. They are *bicolor* (*B*), *guinea* (*G*) *caudatum* (*C*), *kafir* (*K*) *and durra* (D) – all basic races, and GB, CB, KB, DB, GC, GK, GD, KC, DC, and KD – all hybrid races. The classification is based on fundamental spikelets types – shape of grain, its placement in glume, gasping of glumes, etc. Harlan (1972) provided simple description of these races.

Snowden (1936) considered sorghums to have different centers of origin, with the wild race *aethiopicum* giving rise to races *durra* and *bicolor*, *arundinaceum* to *guinea* and *verticilliflorum* to *kafirs*. de Wet and Huckaby, proposed that *durras* arose from *kafir* (House, 1985).

Caudatums arising from Ethiopia spread towards west into Chad and south into Sudan and other countries. *Durras* primarily are abundant in Yemen and other surrounding countries of India. *Kafirs* are predominant in southern Africa, and *Guineas* in western Africa, north of Sahalian belt in Africa (Mann *et al.*, 1983). *Bicolors* are predominant in central east coast of Africa, southern India and south east Asia regions (House, 1985).

LANDRACES AND STORAGE

Disruptive selection and selection by farmers led to distinct forms called landraces. ICRISAT is acting as trustee of preserving the landraces of its mandate crops including sorghum, and it collected so far (by end of 1993) 34366 accessions which are being stored and maintained at its Asia Center, Patancheru, near Hyderabad. Sorghum germplasm collection covered 87 countries–Ethiopia (contributed 13% of total accessions), Sudan (7), Cameroon (7), India (16), Lebanon (1), Russia & CIS (1), UK (0.4), Hungary (0.3), USA (6), Mexico (0.7), and Venezuela (0.5). It included cultivated forms (34021) and wild forms (345) which included tillering sudanese sorghum (*S. halapense* subspp. *halapense*) (Appa Rao, personal communication). Included in this collection are also the landraces collected and maintained previously with the help of Rockfeller Foundation by the Indian National Program prior to the establishment of ICRISAT in 1972. These are being evaluated systematically as per the descriptors (IBPGR, 1980). ICRISAT, germplasm division, apart from collection, evaluation, rejuvenation and maintainance, also supplies research samples of seed on request freely to the scientists wherever they are.

MAJOR MILESTONES IN SORGHUM RESEARCH

1. Genetics of morphological and resistant traits

Prominent among those who contributed to the genetics and breeding of sorghum in the early years were G. N. Rangaswamy Ayyangar and his colleagues and Rao Saheb Kottur and his colleagues in India (Rao, 1971), and J. R. Quinby and his colleagues in USA (House, 1985). These scientists studied inheritance of various morphological characters following mendelian segregation. Quinby and Karper (1954) have shown that height is controlled by four recessive nonlinked, brachytic dwarfing genes. Quinby *et al.* (1973) and Quinby (1924) have shown that duration of growth and floral initiation is controlled by four loci; both dominant and recessive alleles at the maturity loci. Most tropical landraces/varieties are dominant at all four loci but a recessive allele at Mal locus will cause them to be much less photoperiod sensitive and apparently less responsive to temperature variations. Other traits that received major attention were plant, glume and grain color traits. House (1985) gave details.

With the increased interest on the economic traits including resistance to various yield limiting factors, and with the development of procedures in quantitatives genetics, various workers studied the genetics of resistance to various traits and grain yield in several ways. In general, genetics of resistance to various diseases causing fungi/bacteria/virus for a given strain is simple. For example Kernel smut – three races are known, resistance to each is controlled by an incomplete dominant, Ss1, Ss2, Ss3; head smut – resistance is dominant, milo disease – single locus, susceptibility is partially dominant, anthracnose - resistance is dominant, a single locus; rust - resistance is dominant, a single locus; leaf blight – susceptibility (in sudangrass) is inherited as a single dominant (House, 1985), staygreen trait – is inherited as dominant at least with E 36–1 hybrids (Reddy and Stenhouse, 1993), downy mildew – resistance is due to alleles at more than two loci, preferably three with different interactions (Reddy *et al.*, 1992); grain mold – resistance is complex (House, 1985).

Among the diseases, grain mold and anthracnose are considered important in India (Anonymous, 1994). It was shown by Reddy *et al.* (1992) that grain mold resistant (red–grained) hybrids can be produced by crossing susceptible red–grained female parents and white-grained restorer lines. It was established that flavan–4–ols at moderate levels in red–grained females and the hardness found in white-grained restorers were not sufficient enough to cause resistance in the parental lines; but they inherited in the F 1 hybrids and complemented to result in resistant hybrids. It was shown by Reddy and Singh (1993) that a single dominant gene controls resistance to anthracnose and that the effect of cytoplasm on resistance is not significant.

The genetics of insect resistance is considered to be complex. Four insects – shoot fly (predominantly in Asia), stem borer (*Chilo* spp. in Asia and E & Southern Africa, *Busseola* spp. in West Central Africa), midge, and head bug (*Calocoris* spp.) in India, and Nigeria, Mali, etc. in

Africa) are recognized as important pests. Non-preference mechanism is the predominant one, and it is quantitatively inherited with a predominance of additive gene action (Rao *et al.*, 1974 and Sharma *et al.*, 1977). Rana *et al.* (1980) reported that F1 is almost intermediate between the two parents for shoot fly resistance. Resistance was found to be partially dominant under low to moderate shoot fly pressures but not under heavy infestation conditions. Information on stem borer mechanisms is limited. Both tolerance and antibiosis were found operating in a study by Jotwani (1976). Rana and Murty (1971) reported that resistance to stem borer is polygenically inherited. The F1 hybrids were intermediate for primary damage (leaf feeding), but better than mid parent for secondary damage (stem tunneling). While additive (A) and A x A interactions explained primary damage, the secondary damage was controlled by A and nonadditive gene interactions. Widstrom *et al.* (1972) studied the gene effects conditioning resistance to midge. Most of the crosses expressed highly additive gene effects. Sharma *et al.* (1994) at ICRISAT studied the combining ability of midge resistance and that general combining ability is predominant. Information on genetics of head bug resistance is scanty.

2. Genetics of male-sterility

Male-sterility is expressed in sorghum in many ways. Several sources of male-sterility were identified and in all the cases, it was shown that a recessive allele in homozygous condition contribute to male-sterility. These sources (c. f. Andrews, 1966; Appadurai, 1968 and Andrews and Webster, 1971) are given below.

Sterility	Character	Authority
ms_1	Anther without pollen	Ayyengar & Donnaya 1937; Stephens & Quinby 1945
ms_2	Empty pollen cells	Stephens 1937; Stephens & Quinby 1945
ms_3	Empty pollen cells	Webster 1965
ms_4	Empty pollen cell	Ayyengar 1942
ms_5	Empty pollen cells	Barabas 1962
ms_6	Micro-anthers without pollen	Barabas 1962
ms_7	Empty pollen cells	Andrews 1966

By 1970, ms_3 is widely used in population improvement programs for it is stable over a range of environments. Also, next best interms of usage ms_7 allele. At ICRISAT Center, both the alleles, ms_3 and ms_7 are being maintained in different bulks.

There is another system of male-sterility called cytoplasmic nuclear male-sterility (cms) discovered in sorghum by Stephens and his colleagues Quinby, Holland, Kramer and others (Stephens and Holland, 1954). This makes possible the commercial production of hybrid seed at low cost. Male-sterility results from an association of milo cytoplasm with sterility genes found primarily among *kafirs* but also in some varieties of other races. The genetics involved is not completely clear, but two genes *ms* C1 and *ms* C2 when recessive in the presence of milo cytoplasm result in male sterility. The parents used as pollinators in hybrid program should restore fertility to the hybrids produced when crossed to the male-sterile lines. Several types of cytoplasms were recognized depending upon the pattern of restoration/male-sterility in hybrids produced by a set of testers used as pollinators (Schertz and Pring, 1982). Most commonly known cytoplasms are A1, A2, A3, and A4. The last one again has at least three-VZM, Maldandi and G1. The work at ICRISAT identified minimum differential testers (Reddy and Rao, 1991). They are :

TAM 428 B (A 2) gives fertile F1s only on milo cytoplasms (A1),

IS 84 B (A4-maldandi) gives fertile F1s on A1 and A2 cytoplasms,

IS 5767 R (A4-maldandi) gives fertile F1s on all cytoplasms except A3;

CK60 B (A1) gives sterile F1s on all cytoplasms.

It also showed that A_1 is more stable than A_2, A_3, and A_4 (maldandi) for maintaining male sterility, A_3 than A_2 and A_4 and A_2 than A_4 (Reddy and Stenhouse, 1992).

Genetics of fertility restoration is not clear. ICRISAT work showed that frequency of recovery of restorer plants were least on A3 than A2 and A4 and A 1 indicating that more number of genes were involved in controlling fertility restoration on A 3 than the other systems (Reddy and Rao, 1992).

Several workers reported the role of temperature on male sterility and restoration (Downes *et al.*, 1971 and Li *et al.*, 1981). ICRISAT work showed that restoration is poor when temperature goes below 10°C in the nights before flowering as in postrainy season and that there is a need to screen for restoration ability of the lines especially when they are intended for postrainy season (Reddy and Stenhouse, 1994).

ICRISAT work also showed that the temperature induced female sterility in cms female lines like 296 A may be reduced by using their nonparental singlecross F 1 male-sterile lines (Reddy, 1992).

3. Environmental response characteristics

It is important to know the behaviour of genetics of sorghum response to day length and temperature. Because sorghum originated near the equator in northeastern Africa, it is sensitive to the length of the day and temperature (Miller, 1982). The species is classified as a short day type. Miller *et al.* (1968) established that sorghum has a critical photoperiod of 12 hrs. They were able to classify some cultivars into groups that had higher critical photoperiods; including a class which does not respond (insensitive). When the daylength become short (12 hr), the sorghum plant differentiates from vegetative to reproductive growth when the rain diminish in tropical areas in Africa and India. At ICRISAT it was shown that high yielding cultivars with wide adaptability (CSH 1 and ICSV 112) did not delay in flowering during rainy season even when they were exposed to day length of 17 hrs (Alagarswamy, 1994).

Information on the temperature effects is scanty. It was shown that the base temperature for germination is not constant within the species, but may vary from 4.6°C to 16.5°C. Experiences had shown that lower yields for high yielding hybrids developed in the temperate zone but grown in tropical environments (Miller, 1982). Thomas and Miller (1980) showed that lines and hybrids designated as "tropically adapted" have low germination base temperatures than the lines and hybrids designated as "temperately adapted".

4. Conversion programs

The tropical landraces do not flower in temperate countries in USA when they are grown in summer (crop) season when the day length is longer than 13 hrs. Most breeders recognize the positive correlation between height and yield and develop sorghums which are as tall as possible to withstand the hazards of production (Miller, 1982). Maximum productivity generally seen at about 1.75 – 1.80 m height and flowering at 68–70 days (Rao and Rana, 1982). A conversion program was initiated in early 60's to change tall, late or nonflowering (in USA) sorghums from tropics into short, early forms jointly by Texas Agricultural Experiment Station and USDA. This is done by substituting up to four to eight genes which control height and maturity to obtain the desired type. The scheme essentially involved backcrossing at Mayaguez, Puerto Rico of early and dwarf F3s selected from F2s grown at Texas A & M, to the landrace. This is repeated for four times before final cross made at Mayaguez involving the landrace as female to capture the landrace cytoplasm as well. This program had nearly 1279 items (Miller, 1980),and contributed to the breeding programs not only in USA but also in India and other places. BT x 622 and BT x 623 are examples which contributed to maximum to various seed parents program in several parts of the world.

At ICRISAT, a program to convert tall, late flowering zera zera (from Ethiopia – Sudan border), *kauras* and *guineenses* (from Nigeria) landraces was initiated in 1979. Later on *kauras* and *guineenses* were also included for conversion. Several short and early flowering lines were selected. Selection of early and dwarf plants is done in rainy season and backcrossing in postrainy season at ICRISAT Asia Center (IAC). The coverted zera zeras contributed immensely to various programs(ICRISAT, 1985). Next to the converted zera zeras, are the converted yellow-endosperm *kauras* interms of usage by the national breeders. The converted (short) *guineenses* were least productive and hence least preferred (ICRISAT, 1988).

5. Accelerated sorghum hybrids program and All India Coordinated Sorghum Project (AICSIP)

As a result of the efforts under the accelerated hybrid sorghum project initiated by Indian Council of Agricultural Research (ICAR) during the year 1962, which became a comprehensive Coordinated Sorghum Improvement Project, AICSIP from the beginning of the Fourth Five Year Plan period (1969–70), fourteen hybrids were released starting from CSH 1 released in 1964, CSH 2 in 1965, CSH 3 in 1970, CSH 4 in 1973, CSH 5 in 1974, CSH 6 in 1977, CSH 11 in 1986, and CSH 14 in 1992 all for rainy season. The program also released varieties for rainy season such as Swarna (1964), CSV 11 (1984), CSV 13 (1987), and CSV 15 (1993), but the varieties are not popular with farmers. However, the increased acceptance of the hybrids by farmers is indicated by the increased acreage of the area grown by hybrids over the years starting from 30% area in 1981, 56.3% in 1985, and 95–100% in 1993 in Maharashtra state alone (Rao, 1972; Rao, 1982; Vidyabhushanam, 1989, and Murty, 1994). A few hybrids e. g. CSH 7R (1977), CSH 8R (1978), CSH 12R (1986) and CSH 13R (1991–1992) and varieties e. g. CSV 7R (1974), CSV 8R (1979), Swathi (1988) and CSV 14R (1991) were released for postrainy season. CSH 7R and CSH 8R hybrids failed to make nay mark because of low fodder value and high heterotic response for harvest index leading to lodging (Rao, 1982). And other cultivars could not spread and make any effect on raising postrainy season productivity (Murty, 1994). Nevertheless the program contributed immensely for raising the rainy season sorghum productivity.

6. International Crops Research Institute for the Semi Arid Tropics (ICRISAT)

The establishment of ICRISAT in 1972 at Hyderabad (which is now being called as IAC) in India with sorghum as one of its' five mandate crops for research aimed to improve productivity and stability of sorghum for food use in SAT regions of the world. Improvement for yield potential and resistance to drought. *Striga* grain mold, downy mildew, charcoal rot, shoot fly, stem borer, midge and head bug received equal attention up to 1980. Target materials aimed were populations and varieties. Both recurrent selection methods and pedigree were followed equally. In resistance breeding programs, emphasis was given to standardizing screening techniques and identification and breeding of improved resistance sources. Up to 1975, emphasis was placed on red grain type, but slowly by the end of 1970s, white grains types breeding predominated.

During 1980s, major emphasis was given to breeding for resistance to biotic stresses (grain molds and insect pests only) in white grain background. Work on drought, downy mildew, charcoal rot and *Striga* was discontinued. Work on improvement of male-sterile lines for grain yield and grain evident food quality traits was also initiated.

Initially, several populations were introduced from USA, West Africa and East African programs and were reconstituted with selection. Later on several high yielding good grain bred-lines, and zera zera landraces (*Caudatum*) were extensively involved in breeding at IAC, and *guineenses* local landraces alongwith *caudatum* derived lines at ICRISAT W. Africa Center.

The achievements of the program are wide ranging. They are standardization of screening techniques, identification of resistant sources from landraces for various traits, and incorporating the resistance into high yielding and agronomically desirable background, and developing high yielding varieties and parental lines. Important resistant source materials developed by pedigree breeding for various purposes as examples are given below. The productivity of the improved source lines and information on agronomic desirability are given by Reddy and Rao (1992).

Materials	Charcoal rot	Shoot fly	Stem borer	Midge	Head bug	Grain mold	Downy mildew	Anthra–cnose	Striga
Source	E 36-1 BJ 111	IS 2394 IS 18369	IS 2205	DJ 6514 IS 10112	IS 17610 IS 17645	IS 9470 IS 25017	IS 18757	IS 2058 IS 7775	N 13 Framida
Improved		ICSV 705 ICSV 708	ICSV 700 ICSV 702	ICSV 197 ICSV 745	Malisor 84–7 CSM 388	SP 33311 SP 33329	ICSV 91019 SP 85013	ICSV 91027 ICSV 91023	ICSV 145 ICSV 91031

By supplying the information on the techniques and improved seed materials, and by organizing workshops and training programs, ICRISAT has done yeoman service to several national agricultural systems (NARS) in SAT areas. ICRISAT, working in partnership with NARS helped to release 28 cultivars in several countries in Asia, Africa and Latin America (ICRISAT, 1993).

7. Breeding concepts and materials

In a series of papers, N. G. P. Rao and his colleagues, prior to 1980 analysed several issues by using 'tropical' and 'temperate' sorghums crosses. Their findings (Rao and Rana, 1982) are as summarized below :

i) The tropical group is with dominant alleles for yield and plant height and the temperate group with dominant alleles for earliness. Consequently the associations between yield, plant height and maturity are strong. This asymmetric distribution of genes is also seen with resistance to shoot fly and quality traits.

ii) Selections which represented productive peaks are at heights and maturities intermediate between the two groups (e. g. 1.75 – 1.80 m for height and 68–70 days for flowering).

iii) Recovery of productive recombinants can be accomplished through emphasis on family selection rather than within family.

iv) The testcrosses performance are determined by the performance of the parents, indicating that parents for hybrid making can be selected by *per se* performance of the lines.

v) Generally, general combining ability is predominant indicating the presence of additive (A) and A x A type of gene action; hence it should be possible to develop varieties equal to hybrids in productivity. E. g. Swarna, CSV 8R, CSV 13 etc.

The breeding material so far exploited rather extensively belonged to the zera zera group. In India, it started with the conversion of IS 3541 which is a zera zera (race : *caudatum/guinea*) into CS 3541 which either directly or its derivatives became male parents for many hybrids released in India. E. g. CSH 5, CSH 9, CSH 11 etc. ICRISAT also extensively used CS 3541 and other zera zera landraces such as E 35–1, IS 12611, E 36–1, IS 3443, IS 19614 etc. (mostly *caudatum/ guinea*). This coupled with the selection criteria of high grain yield, white grain color, medium grain mass, and optimum plant height and maturity resulted in materials looking alike; this necessitated the diversification. By evaluating the hybrids obtained by crossing five representative lines from each of the landraces (*caudatum, durra, guinea, bicolor* and *kafir*) to six common (*caudatum–kafir* derived) male-sterile lines, it was shown that *guinea* restorer lines contributed to the highest grain producing hybrids across the seasons followed by *caudatum* restorer lines (Reddy and Rao, 1993). Thus, further gains can be made by making use of guinea sorghums; but to do this, the accompanying problems such as clasping of glumes to the grain in hybrids of *caudatum–kafir* male steriles and *guineas* restorers need to be corrected.

8. Adaptation and productivity enhancement

The breeding objectives differ with the end product. The end products and their uses differ from region to region. Other factors that influence breeding objectives are the yield limiting constraints which vary from region to region and from time to time.

Most of the varieties prior to 1960 in India were the result of pureline selection practiced in principle local varieties. The hybridization program was limited for improving grain yield and stalk juiciness. The emphasis was on specific adaptation in the given region.This has resulted in release of several varieties even within the state e. g. Saonar, Rankel, Aispuri, the Maldandi and Dagadi selections of Maharashtra and the Nandyal, Guntur and Anakapalli series of Andhra Pradesh (Rao, 1971). Breeders in USA also aimed to improve the lines for grain yield in the given location in short background useful for combine harvest. Also Quinby and Karper (1946) illustrated how by changing a maturity gene, Ma, grain yield could be changed substantially (Maunder, 1971).

The discovery of genetic male-sterility opened up the ready opportunity for recombination. This coupled with theoretical expectations worked out by Comstock and Robinson (1952) and Eberhart (1971) on the advantage of various mating systems and reciprocal recurrent selection methods in exploiting A, AxA and some epistatic genetic variations led many breeders to propose/take up the population improvement methods (Maunder, 1972 and Doggett, 1972) in 1960s. Several populations were developed in East Africa as a result of funding by International Development Research Council, Canada, in West Africa, again supported by external funding (Doggett, 1972), and in USA (Gardner, 1972).

Also, the pericd, 1960s was marked by the beginning of the ready accessibility of the germplasm of the developed world by the developing world. For example, the female line, CK 60A, one of the parents of CSH 1 which became the basis for transforming the Indian Sorghum Agriculture was introduced into India during early part of 1960s. It was clearly established in India and USA that hybrids have distinct superiority (by at least 48%) over the best available varieties (Maunders, 1972 and Rao, 1972). Further this work resulted in establishing clearly by 1975 that hybrids have wide adaptability in addition to high yield potential. As a result AICSIP program formulated the national policy of releasing varieties for more than one state.

In addition, the work at ICRISAT produced lines that have been found useful not only as parents in various national programs, but some programs released them directly as varieties, e. g. ICSV 112 bred at ICRISAT Asia Center was released as CSV 13 in India, as SV1 in Zimbabwe, as UANL-1-187 in Mexico, as Pinolero 1 in Nicaragua, etc.

Thus the concept of wide adaptability supported by the movements of the materials across continents was firmly established by 1985.

Very soon, however, it was realized that the ICRISAT Center bred materials did not show adaptation in drought environments in West Africa, or in high altitude areas like Ethiopia, Kenya etc. It was felt that further gains can be made by breeding into the wide adaptability the special requirements for a given stress environment. For example, ICRISAT drought resistance breeding program clearly established that drought is highly specific and that breeding for drought resistance therefore depends upon the stage of the crop at which the drought occurs, inferring that breeding in the traits that contribute to resistance to specific drought resistance can be carried out into types bred for wide adaptation to realize further productivity in the region (Reddy, 1985). This realization led to the establishment of different regional centers by ICRISAT in Africa such as ISC Center, Niamey, Niger, SADC-ICRISAT Center, Bulawayo, Zimbabwe, and ICRISAT Sorghum and Pearl millet East African Program, at Nairobi, Kenya, and Latin American Sorghum Improvement Program, El Baton, Mexico.

This work led to the release of headbug resistant variety such as Malisor 84-7 in Mali, E 35-1 for favorable environment in Burkina Faso, and several varieties/ cultivars such as UANL-1-187, ICTA C-25 Perlita and Pacifica 301 in Mexico and Pinolero 1 in Nicaragua and Agroconsa 1 and ISIAP Dorado in El Salvador in Latin Americas. Reorganization of sorghum program across SAT regions also helped many NARS to strengthen their sorghum research (ICRISAT, 1993).

CURRENT RESEARCH THRUSTS

Currently ICRISAT has research portfolio under way on sorghum improvement at IAC, Hyderabad India; West and Central African sorghum program at Bamako, Mali and at Kano, Nigeria, East & Southern Africa Sorghum Program at Nairobi, Kenya and Bulawayo, Zimbabwe. At IAC, the emphasis has been for the last four years on strategic research-development of techniques and intermediate products in partnership with NARS in Asia, suitable for utilization by the NARS Programs.

Accordingly, an ambitious program of diversifying and breeding new milo cytoplasm male-sterile lines for earliness, introgression with *durra* race, and bold and lustrous grain characters, and resistance to *Striga*, shoot fly, stem borer, midge, head bug, grain molds, downy mildew, anthracnose, leaf blight and rust is being carried out (ICRISAT, 1993). The usefulness of single-cross male-sterile F1s for use in developing 3-way cross forage hybrids is being examined. Several strategic research areas - information on stability of alternate cytoplasms, identification of differential minimum testers for various male-sterile cytoplasms, conversion of improved resistance sources into male steriles using alternative cytoplasm, development of isonuclear lines, and information on genetic methods of rectifying the low–temperature induced female sterility in 296 A, and development of restorer lines for alternative cytoplasms have been attempted. Further strategic information on the role of early seedling vigor and growth rate in biomass accumulation is being examined. Restorer program aimed to develop high-yielding shoot fly, stem borer, midge, and grain mold resistant lines is underway, and significant gains were realized in combining midge resistance and high yield.

Further, novel populations/gene pools for specific traits such as bold grain, and productive tilling are being developed. The testcrosses involving postrainy season landraces as pollinators are being examined for the fertility restoration ability under cool nights and for productivity in postrainy season. Reddy and Stenhouse (1994) found that variability for restoration was quite significant indicating the possibility of selection within the landraces and among landraces for restoration and that the frequency of hybrids with productivity was higher for landrace hybrids than bred–restorer hybrids. The feasibility of landrace hybrids for postrainy season adaptation is being examined to verify the hypothesis that landrace hybrids may find a better acceptance by the farmers unlike other released cultivars in India. Improving cultivars by introducing the desirable resistance or earliness for adaptation to the specific region is progressing well in other centers (ICRISAT 1991, ICRISAT 1992 and ICRISAT 1993b).

FUTURE RESEARCH THRUSTS

It is believed that further specificity in adaptation helps raise yield to new levels and also maintains the needed bio–diversity so vital for the sustainance of the ecosystem in the given SAT region. The action plan to achieve this goal is exemplified best by ICRISAT's recent efforts to develop research portfolio for improving sorghums for SAT. ICRISAT Medium Term Plan which becomes operational from June 1994 and lasts up to 1999 differentiated sorghum growing areas into adaptation zones in the SAT and production systems (PSs) within each adaptation zone.

1. Adaptation zones

ICRISAT recognized five adaptation zones in the SAT for the purpose of sorghum improvement based on moisture availability and temperature pattern during crop growth. Improving sorghum productivity and sustainability for each zone constitutes a projects. The projects are : 1) low rainfall sorghums (SG1), 2) medium rainfall sorghums (SG2), 3) high rainfall sorghums (SG3), 4) postrainy season sorghums (SG4), and 5) high altitude/low temperature sorghums (SG5). The projects SG1 and SG2 for rainy season, and SG4 for postrainy season are relevant for Asia.

Early maturity (< 100 days) is expected to be the key factor in low rainfall areas, medium maturity (100–150 days) in the medium rainfall areas, and late maturity (150–180 days) in the high rainfall areas. In the postrainy season, interaction of genotype with daylength, temperature and soil moisture would decide the adaptation pattern. Also prevailing low temperatures at flowering influences the extent of seed setting. The length of the growing period is 90–120 days. Similarly, low soil temperature play predominant role in germination, early seedling growth and then after in high altitude areas. The length of the growing period is 150–180 days. The constraints and their severity depends on the PSs in each adaptation zone.

2. Sorghum production systems in the SAT

ICRISAT recognized a total of 29 PSs in SAT (Appendix 1). There are 12 in Asia, six in West and Central Africa, six in Southern and Eastern Africa, and five in Latin America. Sorghum based PSs are further grouped as primary and secondary PSs. The primary PSs form the target areas for research, with the spillover of the research on the secondary PSs. The projects and, secondary PSs are as follows.

Project	Primary PSs	Secondary PSs
SG1	PS13, PS19	PS1,–5,–7,–9, –12,–14,–20,–15
SG2	PS4,–7,–9,–14, –15,–20,–21	PS5,–6,–27,–29
SG3	PS16,–22	PS–2,–3,–4,–15, –26
SG4	PS8	PS7,–9,–18
SG5	PS23,–26	PS21,–24

The importance of each project may depend on the extent of area and production, and constraints and their severity in the PSs encompassing the project. It is also influenced by the equity and gender considerations in the region covered by the project (ICRISAT, 1992b).

3. Research portfolio

ICRISAT Medium Term Plan (MTP) identified a total of 110 potential themes for the entire mandate (geographical and crops) of ICRISAT. The abiotic and biotic and abiotic themes and their severity for sorghum (single commodity) projects are given in Appendix 2. These themes were ranked across ICRISAT crops based on efficiency, quality, intentionality and sustainability. A multi–disciplinary team incharge of each project will need to carry out reaearch to bring the ongoing work to a conclusion by further breeding definitive intermediate products–male–sterile lines and restorer lines and collecting the information on their productivity in a given PS. Also, integrated pest and disease management methods and cropping systems will be assessed.

The rainy season crop is usually caught in the rains during its post flowering period and grain becomes discolored because of grain molds. Therefore it is essential to work on the diversified uses of crop surpluses and mold damaged and discarded grain. Somani and Pandrangi (1993) outlined the technologies to convert molded grains into various products such as sugars, alcohol, starch, semolina and malt products. This area needs further attention especially in taking the technology to the adoption stage.

Use of sorghum as forage is increasing (Lodhi, 1993). So far, sudangrass sorghums are being used as restorers in various forage hybrid breeding programs and no concerted efforts are made to improve them. Efforts should be made to develop fast growing high tillering restorer lines with solid sweet stems and with resistance to leaf diseases and stem borer.

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APPENDIX 1. Proposed Production Systems[1]

Asia

1. Transition zone from arid rangeland to rainfed, short – season millet / pulse / livestock. Eastern margins of the Thar desert.

2. Subtropical lowland rainy and post rainy season, rainfed, mixed cropping Central/eastern Indo-Gangetic Plain.

3. Subtropical lowland rainy and post rainy season, irrigated, wheat,–based. Western Indo– Gangetic Plain.

4. Tropical, high–rainfall rainy plus post rainy season, rainfed, soybean/wheat/chickpea. Central India.

5. Tropical, lowland, rainfed/ irrigated, rice–based. Eastern India, Myanmar, Thailand, Southeast Asia.

6. Tropical, lowland, short rainy season, rainfed, groundnut/millet. Saurastra Peninsula.

7. Tropical, intermediate rainfall, rainy season, sorghum / cotton / pigeonpea. Eastern Deccan Plateau, Central Myanmar.

8. Tropical, low–rainfall, primarily rainfed, post rainy season, sorghum / oilseed. Western Deccan Plateau.

9. Tropical, intermediate length rainy season, sorghum/oilseed / pigeonpea interspersed with locally irrigated rice. Peninsular India.

10. Tropical, upland, rainfed, rice based. Eastern India, Southeast Asia.

11. Subtropical, major groundnut and sorghum. China.

12. Subtropical, intermediate elevation, winter rain–fall and rainfed, wheat based. West Asia and North Africa.

West Africa

13. Transition zone from arid rangeland to short–season (less than 100 days), rainfed, millet/cowpea/livestock. Sahelian Zone.

14. Intermediate season (100-125 days), rainfed, millet / sorghum / cowpea / groundnut based. Sudanian Zone.

15. Intermediate season (125-150 days), rainfed, mixed, sorghum–based. Sudanian Zone.

16. Long-season (150–180 days), rainfed, mixed, maize-based. Northern Guinean Zone.

17. Humid, bimodal rainfall, mixed, root crop based. Southern Guinean and forest zones.

18. Low–lying areas prone to inundation, postrainy season, sorghum / millet / groundnut–based. Sahelian and Sudanian Zones.

Southern and Eastern Africa

19. Lowland, rainfed, short–season (less than 100 days), sorghum / millet / rangeland. Northern parts of eastern Africa, parts of the southern Africa.

20. Lowland, semi–arid,intermediate season (100–125 days), sorghum / maize/rangeland. Eastern Africa and parts of southern Africa.

21. Mid–altitude, subhumid, intermediate season (100–125 days), sorghum/maize/finger millet. Eastern and southern Africa.

22. Lowland, sub–humid, mixed, rice/maize/groundnut/pigeonpea/sorghum. Coastal areas eastern and southern Africa.

23. Highland, rainfed, long season (150–180 days), sorghum/maize/teff. Highland zones of north–eastern and eastern Africa.

24. Highland, semi – arid, rainfed, intermediate season (100–120) days, mixed maize/sorghum/wheat/barley/pastoral. Highland zones of eastern and southern Africa.

Latin America

25. Tropical, upland, rainfed, maize/sorghum inter–cropping. Central America and Hispaniola.

26. Tropical, intermediate elevation, subtropical summer rainfall, rainfed and irrigated, sorghum. Inland valleys of Mexico and Colombia, northern Argentina.

27. Tropical and subtropical coastal plains, rainfed/irrigated. Mainly Pacific coast of Central America.

28. Tropical, subhumid, rainfed, acid soil, savanna. Lianos of Colombia and Venezueala.

29. Intermediate–elevation, semi–arid, rainfed, acid soil. Northeast & central Brazil.

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1. Adopted from ICRISAT Project Planning Exercise

APPENDIX 2. Drought and biotic constraints and their severity affecting sorghum productivity

		Low rainfall			Medium rainfall							High rainfall		Post rainy	Low temp. high elev.	
		Asia PS	WA PS	E&SA PS	PS	Asia PS	PS	WA PS	PS	E & SA PS	PS	WA PS	E & SA PS	Asia PS	E&SA PS	LA PS
Themes	Rank[2]	1	13	19	4	7	9	14	15	20	21	16	22	8	23	26
Striga	18			4		3		5	5	5	5	5				
Grain/stover	22	3	4	3	3	5	5	5	5	5	5	4			5	4
Stem borer	34		4	3	4	3	3	5	5	5	3	5		4		
Grain mold	35		3			3	4	3	4		4	5	5		3	
Low temp.	44														5	
Head bugs	46		3			3	4	4	5	3		5				
Anthracnose	48				3			4	5	3	5	5			4	
Midge	49		3			5	4	5	4		4	4				
Acid soil	61											4			4	
Drought	65	3	5	5			3	5	4	5	3			4		
Leaf blight	66									3	5				4	3
Foliar diseases	72								3			3				4
Shoot fly	76						4		3			4		5		
Forage	86		3					4								3
Sooty stripe	100							4	4		4	4				
Long smut	101		5	3				5	4			3				
Store pests	102		4	3				4	3	4	4	3			3	
Ergot	104								4		3	4				

1. Severity scale on 1 to 5 where 1 = least severity, 5 = most severity
   Analysis based on ICRISAT Project Planning Exercise, 1994
2. From ICRISAT (192b)

A : WP : mypap. doc