The IRAT Sorghum Program Highlights and Areas for Interaction with INTSORMIL

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Structure of IRAT Sorghum Program

General presentation of CIRAD/IRAT

The Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières (IRAT), was established in 1960, in order to respond to the African states' demand for assistance in food crops research. It later became CIRAD/IRAT, as a member of CIRAD (Centre de Coopération Internationale en Recherche Agronomique pour le Développement), in 1984.

CIRAD is a French state-owned organization (roughly a staff of 2000 and a turnover of US $ 184 million), devoted to agricultural research with emphasis on tropical and subtropical areas. This center, with 11 departments, has been mandated to contribute to the development of the mentioned areas through research, experiments, training and information dissemination. One of its major activities is the assistance, on request, to National Agricultural Research Systems (NARSs).

Within CIRAD, CIRAD/IRAT is the most important department, with 160 scientists. It is in charge of the improvement of food crop production in order to contribute to the success of food self sufficiency policies claimed by most of the third world countries. It is also deeply concerned by carrying out appropriate techniques to achieve the conservation and the optimum use of natural resources without which the first objective could not be reached sustainably. In addition, a long experience in its intervention area has convinced CIRAD/IRAT of the importance to extend more and more its activities at farm level.

To reach its targets, CIRAD/IRAT's activities are managed within two divisions. One is an environmental division called the Division of Natural Resources which leads various activities in the fields of soil science, remote-sensing, mapping, soil management, climate-soil-crop relationship, hydraulics, etc. The second division is devoted to crop programs, namely five major crops (rice, maize, sugarcane, sorghum and vegetable crops), and miscellaneous crops.

The IRAT Sorghum Program

IRAT has supported research on sorghum since its inception, aiming at the optimum utilization of this cereal potential. These activities encompassed the fields of plant breeding, agronomy, crop protection, and grain technology. They were mainly carried out in West and Central Africa.

At present, with nine scientist positions, the IRAT Sorghum Program is organized as shown in Table 1. The four scientists in Mali are posted in the ICRISAT/WASIP regional

Table 1. Organization of IRAT Sorghum Program.

Discipline	No. scientist positions	Locations
Breeding	3	Burkina Faso[1] Mali[2] Senegal[3]
Agronomy	2	Mali[2] - Togo[3]
Weed Science	1	Mali[2]
Entomology	1	Mali[2]
Technology	1	Montpellier
Biotechnology	1[4]	Montpellier

[1]posted in NARS
[2]posted at ICRISAT/WASIP
[3]posted in a SAFGRAD project
[4]=2 research scholars

[1] Respectively, IRAT Entomologist and IRAT Agronomist, Head of IRAT Sorghum Program, ICRISAT/WASIP, B.P. 320, Bamako, Mali.

Table 2. Major varieties of IRAT sorghum breeding programs.

	From landraces evaluation carried out in the sixties
Traditional sorghums for rainfed cultivation:	
Senegal	Ngor Gatna (IRAT 1), Congossane SH 60 (IRAT 4)
Mali	SH2D2 (IRAT 5), Tiemarifing
Burkina Faso	S 29, Gnofing, Ouedezoure
Niger	Jan Jare, Hamo Kire (IRAT 2), El Dele
Cameroon	Makalari (IRAT 55)
Dune sorghums:	
Niger	Bogoba, Babadia ja, Babadia Fara
Flood recession cropped sorghums:	
Senegal	RT 13, RT 50
	From crosses dating back to the sixties
Burkina Faso	IRAT 6, IRAT 7, IRAT 8
Mali	IRAT 74, IRAT 75, IRAT 76
Niger	C1-13-1-1, C6-4-1-3
	From crosses dating back to the seventies
Early lines (90 days)	IRAT 10 (CE 90), IRAT 202 (CE 145-66), IRAT 204 (CE 151-262)
Medium cycle lines (110 days)	IRAT 11 (L.30), IRAT 16 (CE 111-6)
Late maturing lines (130 days)	IRAT 174
Hybrids	
for rainfed cultivation	IRAT 325
for irrigated conditions	IRAT 179, IRAT 180, IRAT 181

center at Samanko, which is indeed a joint venture between ICRISAT and CIRAD/IRAT. The agronomist acts as the head of IRAT Sorghum Program. The breeders in Burkina Faso and Senegal are integrated to NARSs, (INERA and ISRA, respectively), on a bilateral basis. The agronomist in Togo is working on the SAFGRAD project.

Other activities related to sorghum although not implemented within the sorghum program which should also be considered, are: genetic resources management (Montpellier); agroclimatology and water balances (IER, Mali; Niger); and cereals mineral nutrition (IER, Mali).

The program is thus very much West Africa oriented, although expert missions can also be carried out in other regions.

Major achievements and current strategy

Plant breeding

The sorghum breeding program at IRAT dates back to the 1960's, when activities started almost simultaneously in Senegal, Mali, Burkina Faso, Niger, Benin and Madagascar. Initially it involved mass selection and pure line isolation from West and Central African local varieties. Later on, it incorporated various other breeding methodologies. These include the use of exotic varieties as sources of dwarfism genes, the creation of hybrids using a *cms* system, the creation of composites bringing together numerous parental sources, and the application of induced mutagenesis. The major varieties obtained from the selection work carried out in the sixties and seventies are presented in Table 2.

These experiences led to placing the present breeding emphasis on grain quality and yield stability, and on improving our knowledge of available genetic resources for the rationalization of hybridization strategies.

A second part, more methodological, has been carried out mainly in Burkina Faso and in Montpellier.

Varietal creation and evaluation

The IRAT Sorghum Breeding program aims at obtaining two types of fixed material for human consumption in the tropical zones:

- one related to local varieties which are generally tall, photoperiod sensitive, hardy, with low yield but high quality grain;
- one similar to high yielding sorghums that are to be found in developed countries, short stalked, photoperiod insensitive, with heavy and compact panicles, large grains, but often not appreciated for food consumption in West Africa.

Concerning the first type, we are trying to improve their yield potential, while maintaining their own particular qualities. We therefore are looking for a better balance between vegetative and reproductive parts of the plant (by means of straw shortening and tillering limitation), using breeding methods that modify local varieties for only the desired (and limited) changes. We use methods such as:

- back crossing and mutagenesis in Burkina Faso;
- recurrent selection with ms_3 male sterility gene, from a population coming from a mixture of local landraces in Mali.

Varieties obtained, though looking very much like traditional material, valorize better cropping intensification. At the same time, they do not drastically change the farmer habits, and could therefore constitute a transition towards the introduction of better yielding, but also more labor and input demanding varieties.

Concerning the second type (high yielding varieties), we are mainly looking for a better adaptation to tropical conditions. With this aim in view, we are looking at resistance to main leaf diseases and insect pests (notably panicle feeding ones), yield stability and improvement of grain quality.

Our main breeding method is that of crosses between parents with complementary qualities followed by pedigree selection of progenies showing interesting combinations of parental characters. It is used in Senegal, Mali and Burkina Faso. In Mali, recurrent selection is applied to a *caudatum* population to obtain fixed varieties with grain mold resistance (character controlled by several genes).

Our varietal creations are capable of high yields but require more labor intensive farming care than traditional varieties. They are aimed at farmers with a minimum technical background.

On a limited scale, the IRAT sorghum breeding program works on the exploitation of heterosis in order to obtain original hybrid formulas, to respond to the demand for cost efficiency of irrigated plots (which are still not many in West Africa).

A large part of the material is still in the breeding process. At present, certain lines or composites are promising and are likely to have a significant impact in the tropical rural world. In Burkina Faso, the first recurrent selection cycle was successful and improved the composite created in 1987, which became as good as variety IRAT 277. In Mali, out of 160 accessions of *guineense* and 111 accessions of caudatum that were evaluated at Samanko, 23 and 19 were selected, respectively, to create random-mating populations. Out of 232 germplasm accessions, 12 were selected for use in the pedigree breeding program to develop full-season varieties adapted to the Northern Guinean Zone.

In terms of varietal creation in Senegal, priority is given to medium cycle varieties, high yielding, with good tolerance to grain molds and good grain quality from *guinea* and *caudatum* material. In varietal evaluation tests conducted in 1989 and 1990, the best varieties under rainfed conditions were: CE 180-33, CE 196-7-2-1, CE 145-66 (IRAT 202) and F2-20. F2-20 was included in SAFGRAD Sorghum Network regional nurseries. The best variety for irrigated cropping during the rainy season was CE 151-262 (IRAT 204), and for irrigated cropping during the dry season, 75-14 (IRAT 207).

Biotechnology

The evaluation of genetic diversity was conducted with concurrent morpho-agronomic (in collaboration with INERA, Burkina Faso) and isozyme analyses, as part of an EEC funded project.

Three groups could be identified on the basis of multivariate analysis of 25 morpho-agronomic traits in a representative sample of 157 traditional *Sorghum bicolor* varieties. This

scheme verified the panicle and grain traits as classification criteria, as had already been found by Harlan and de Wet.

From the analysis for 11 enzymes of a representative sample of 348 traditional varieties, it was found that the variation observed in Africa included all the variation found in the species. Three groups, roughly corresponding to three broad geographical areas, namely Western, Eastern/Central and Southern Africa, were resolved by multivariate analyses of multi-locus associations.

A second series of analyses focused on the Guinea group. Three groups could be identified on the basis of multivariate analysis of 30 morpho-agronomic traits in a sample of 55 traditional varieties. This scheme was again close to the key developed by Harlan and de Wet. Three groups were defined by multivariate analysis for 8 enzymes of a sample of 167 traditional varieties. The agreement between the morpho-agronomic and the isoenzymatic analyses was stronger in this guinea sample than in the first sample which represented the whole species.

As a result of these investigations, a global scheme of the domestication and subsequent migrations of sorghum, and a simplified scheme of its genetic variation, could be proposed. Conceivably, this can then be used to identify trends in the breeding behavior of combinations within and between groups, and thus to formulate guidelines as to which type of cross should help in obtaining specific objectives.

At present, a genetic diversity study using RFLPs (Restriction Fragment Length Polymorphism) is in progress in Montpellier. Its objective is to assess whether additional markers will modify the relative differentiation between the groups identified so far, and further resolve differences within these groups.

Plans to undertake marker-assisted genetic analysis of grain quality traits are being considered. The grain quality data and the RFLP diversity analysis will provide a basis for selecting parents for relevant crosses. The three plant breeders located in Burkina Faso, Senegal and Mali, and the grain technologist at Montpellier will be involved.

In other respects, research has continued aiming at directly obtaining pure lines by ways of haploid production. Three approaches were explored: gynogenesis induced after an intergenera crossing or pollination with irradiated pollen, and in vitro androgenesis. None of the approaches has been completely successful so far.

Grain technology

The IRAT grain technology laboratory has been helping sorghum breeders to screen varieties suitable for first and second processing, for several years now. A sorghum grain hardness measurement test based on the evaluation of particle size after grinding (Particle Size Index Method) was set up in the laboratory. It allows the prevision of sorghum grain decortication ability from 20 g samples.

A second test was developed, at the request of breeders aware of problems linked to the acceptability of improved new varieties, to assess tô (a traditional West African stiff porridge) texture, using an INSTRON texture tester. This method can also be used as a screening tool for varieties under selection: it allowed us to sort out 20 varieties in 12 groups. It is also used in the laboratory to identify biochemical characteristics linked to tô quality.

A multiple regression analysis, based on the results of a preliminary study established the importance of starch characteristics on tô consistency. Sorghums with high amylose content, whose starch swells little and solubilizes in water at tô cooking temperature, would give firmer porridges. Some proteins can have an indirect role on tô texture, particularly through grain hardness and therefore particle size and rate of damaged starch.

In other respects, a statistical study clearly established the influence of grain physicochemical characters on tô quality. These characters are, in decreasing order of importance: vitrosity, protein content and per cent recovery at decortication.

Twenty sorghum varieties from Mali, France and from the IRAT catalog were decorticated using the TADD (Tangential Abrasive Dehulling Device). Decortication rate appears to play an important role in tô stability. Re-

search on factors affecting tô quality is being carried out jointly with the IER/SRCVO Cereals Technology Laboratory in Mali. Studies on milling (flours characterization, development of a suitable laboratory technique) are also underway.

Agronomy

Earlier work

Before the sixties, the technical bases for improved sorghum cultivation, from either local or improved varieties, were known from earlier work carried out in a range of situations in Francophone West Africa. In the sixties, experiments continued in Benin, Burkina Faso, Cameroon, Mali, Senegal and Togo, on land preparation, fertilization, sowing and weeding. For rainfed cultivation, they recommended deep plowing, so as to improve the soil physical properties, in connection with better root development for sorghum. The major role of nitrogen was established. The problem of crop succession, especially toxic effects of sorghum on the following crops (allelopathy) in sandy and clayey soil was also investigated.

During this period, research efforts were also devoted to flood recession cropped and transplanted sorghums.

Due to drought problems in the seventies, studies on water requirement were carried out, and techniques of improved irrigated sorghum cultivation were developed. Results from a study conducted for five years in Burkina Faso suggested that water-saving technology implementation at the plot level (soil-scarification, plowing, ridging, earthing-up, tied ridges and weeding, taken separately or as combinations) could play a role on sorghum production as important as breeding for drought resistance. Techniques of irrigated cropping were improved, and an interesting experiment was carried out on 8500 ha in the Sarir desert in Libya, which was a success.

Current activities and main results

Mali

The current agronomy program in Mali aims at developing sorghum based cropping systems efficiently using natural resources and maintaining soil fertility as well as long term productivity ("sustainability"). It has two components:

- Agrophysiology: study of the functioning of sorghum-legume intercrop systems and their efficiency in using nitrogen; study of sorghum yield determinism in connection with nitrogen nutrition;
- Cropping systems: improvement of cropping techniques used in sorghum-legumes intercrops (farm level); study of production evolution and soil fertility maintenance in diverse agrosystems including sorghum (long run study).

At our partners' (NARSs) request, the second component is given major emphasis.

With respect to response of sorghum cultivars to nitrogen, it was found that N fertilizer significantly increased grain yields, mainly due to an increase in number of seeds per panicle. Root:shoot ratios were also increased. Sorghum/soybean systems were found to be globally more efficient than sorghum/groundnut ones, which suffer from an early inter-specific competition. Promising results have already been gained in the fields of optimum combinations for sorghum/legumes intercropping systems, varieties, fertilization, sowing, rotations, weeding, etc. Specifically, the system consisting in alternate paired rows of sorghum and cowpea (2S:2C) proved to be particularly relevant.

As for weed control in sorghum/legume intercrops, it was found that intercropping, particularly sorghum/cowpea, depressed weed emergence between 0 and 70 DAS, because of rapid covering of the soil surface, and only two weedings were thus required in intercrops, compared to three in the sorghum sole crop. Mean fresh mass of weeds was also lower in the sorghum/cowpea system. Intercropping also reduced total labor time required for man-

ual weeding and enabled a savings of about 10% in labor charges.

A legume, as a sole crop, was the best preceding crop for sorghum, with average sorghum yield increase of 20 to 30% as compared to sorghum-sorghum rotation. Legume/sorghum intercrops had no effect on succeeding sorghum yield compared to that of sorghum as a sole crop. However, the intercrops had an important preceding effect on cotton production when no fertilizer or a mineral fertilizer was applied; a combined fertilization (organic + mineral) confounded the effects of all preceding cropping systems. When sorghum-legume intercrops succeed to themselves on the same plot, their yield advantage compared to sole crops succeeding to themselves was maintained after two years (LER between 1 and 1.4). However, these rotations of sorghum-legumes intercrops have no comparative advantage with sole crop rotations of legume on year 1 and sorghum on year 2.

Togo

Research on sorghum based intercropping systems (including groundnut, cowpea and pigeonpea) are also carried out in Northern Togo, and comparisons are being made with maize based cropping systems. Among the systems tested in on-farm trials, it was found that the sorghum/pigeon pea intercropping system with respective densities of 62,500 and 31,250 plants ha^{-1} gave the best yields, namely 74% over that of sole crops.

Crop protection

General aspects

Until recently, few activities had been devoted to this research area. Earlier work, dating back to the sixties, mainly consisted in inventories of main sorghum diseases and insect pests. Particular attention was then paid to grain molds.

With the development of WASIP in Burkina Faso and in Mali, crop protection research within the IRAT Sorghum Program took a new start. Besides some aspects that are tackled by breeding programs (such as grain molds) or agronomy programs (weeding), special programs are now devoted to parasitic plant control (particularly *Striga*), from an agronomic approach, and to insect pest control, with major emphasis on host plant resistance.

Crops parasitic plants

The program has three main research components: a bio-ecological study, a village-level survey, trials in farmers fields (on the pair *Striga hermonthica* and sorghum only, jointly with IER).

Surveys undertaken in Burkina Faso were extended to Mali (southern, northern and northwestern regions). It allowed the census of 21 parasitic species belonging to 9 genera and 4 families; 10 species are recorded in genus *Striga* alone. In the cultivated fields of these regions, the most important *Striga* species are *S. hermonthica* on millet and sorghum and *S. gesnerioides* on cowpea. In the Sudano-Guinean Zone of Mali, where the ecological conditions are more favorable to crops and where the farmers are more progressive due to cotton cultivation, *Striga* is rarely a problem. On the other hand, in the Sudanian Zone (north and northwest) the climatic conditions and the farmers' lack of resources have favored the spread of *Striga*, which is a major yield reducer in this area. Detailed investigations conducted in three villages resulted in mapping at the parcel level, with the indication of parasitic species in one of them. *Striga hermonthica* was the most harmful species.

A manual for identification of the main crop parasitic species was prepared, and computer software developed, for the analysis of data, thus aiming at diagnosing the importance of these parasites and the farming practices that favor their spreading. An experiment showed that covering the wet soil for 35 days with black polyethylene sheet in April, when temperatures were high, reduced *Striga* emergence significantly and doubled grain yield of sorghum variety 'Tiemarifing'. This method could possibly be used to obtain different levels of *Striga* infestation in experimental plots.

The integrated control tests conducted in a farmer's field heavily infested with *Striga* showed that an improved *caudatum* variety

ICSV 1063 BF was relatively less attacked by *Striga* and produced higher grain yields than Seguetana and Tiemarifing, the two local guinea varieties under test. Of the control methods tested, an early 2,4-D herbicide application (70 DAS) was the most effective in reducing numbers of emerged *Striga* plants; however, low concentration used did not completely eliminate *Striga*. The grain yields were nearly doubled with this treatment. Weeding by late hand pulling (85 DAS), preferably when the soil is dry also reduces *Striga* emergence and increases sorghum yield. Straw mulching reduces vegetative development of *Striga* but does not hamper its fructification as the two other techniques do. Integrated *Striga* management research is implemented jointly with IER/SRCVO.

Entomology

The entomology program is giving priority to two major groups of sorghum pests in West Africa, namely stem borers and head bugs. Some activities are also devoted to sorghum midge, storage pests, and insects of flood recession cropped sorghum.

The noctuid *Busseola fusca* was identified as the main stem borer at Samanko, where its incidence, however, is pretty low. It was reared on an artificial diet in the laboratory for several generations during the dry season without undergoing diapause.

Losses due to head bugs (*Eurystylus immaculatus*) were quantified. Susceptible varieties suffer from oviposition and feeding punctures an important decrease of thousand grain mass, grain density, vitrosity, germination power, decortication rate, and tô quality.

The efficiency of the cage technique to screen sorghum for head bug resistance was confirmed. Malisor 84-7's high level and stability of resistance was confirmed, and promising selections were made among progenies of a cross between this source of resistance and high yielding improved varieties.

Losses due to stored-product insects in a sample of 27 traditional sorghum granaries distributed in four villages of Mali were assessed and found to be generally very low (about 1% weight loss for a six month storage period).

Future activities envisaged are:

- *Busseola fusca*: solve rearing problems (namely elucidate diapause phenomenon and develop a suitable artificial diet) so as to be able to mass produce this insect for screening under artificial infestation at Samanko.
- *Eurystylus immaculatus*: study of its biology and population dynamics; investigation on factors (physical, physiological or chemical) in sorghum imparting resistance to head bugs; determination of the genetics of inheritance of this resistance so as to be able to advise breeders on the best breeding strategies; simplification of screening techniques for use by breeders in NARSs.
- Storage pests: develop a suitable technique for screening sorghum grain for resistance to Rhyzopertha dominica, its major storage pest in West Africa; screen local material and lines at the pre-releasing stage on a routine basis, so as to be sure not to release supersusceptible varieties.

Genetic resources

Photoperiod insensitive varieties are being produced at Montpellier. A new edition of the varietal catalog was published in 1988.

Future strategy and areas of interaction with INTSORMIL

Future strategy of IRAT Sorghum Program

At present, the IRAT Sorghum Program is concentrating its efforts on West Africa. It is unlikely that it will in the near future significantly extend to other areas (with the possible exception of the Mediterranean area, where its hybrids can be cultivated).

However, it could logically be strengthened by scientists from CIRAD/IRHO (oil department) and CIRAD/IRCT (cotton department), as, as it is likely to happen, CIRAD programs shift their emphasis from plants to cropping systems (such as cropping systems based on

sorghum, groundnut and cotton, for the sudanian zone).

Areas of common interest with INTSORMIL

The objectives and activities of the IRAT Sorghum Program and INTSORMIL are in several respects very similar, in most of the fields encompassed by both institutions, notably in their common countries of intervention (namely Mali and, to a lesser extent, Senegal), and in terms of technical thrusts, as well as training, which is becoming one of the major emphasis of the IRAT Sorghum Program. Sustainability has become a priority for both institutions.

IRAT operates within the national agricultural research organizations and conducts cooperative programs with them. It also participates in WASIP and SAFGRAD sorghum network. INTSORMIL has always coordinated and collaborated with ICRISAT regional activities located in West Africa, in order to avoid duplication of activities. ICRISAT/WASIP provides an opportunity for closer interaction.

In the field of plant breeding, the IRAT sorghum breeder posted at CNRA Bambey, Senegal, (ISRA) is involved on a more or less formal basis in a collaborative project with University of Nebraska (UNL-115). In agronomy (Mali), there is no joint project between IRAT Agronomist posted at ICRISAT/WASIP and IER scientists involved in INTSORMIL projects on nitrogen uptake and cropping systems, however, only unofficial scientific relationships do exist at the moment.

In entomology (Mali), collaboration with Texas A&M University is underway, notably to determine the mechanisms and genetics of inheritance of head bug resistance in sorghum (Projects TAM-121 and TAM-122).

In Mali again, support is provided to IER/SRCVO Cereals Technology Laboratory by both INTSORMIL and IRAT. Both institutions address problems such as factors affecting tô quality in Mali. Although coordination exists (through meetings between Texas A&M, IRAT, ICRISAT and IER scientists), the IRAT food technologist is not a collaborating scientist in Project TAM-126.

In other respects, we feel that much benefit could also be gained from coordination between Purdue University and IRAT on support of *Striga* research (although countries covered are not the same) and on biotechnology (Projects PRF-103A, PRF-107 and PRF-104B).

We strongly think that the type of collaboration that currently exists, (namely, with a NARS when an IRAT scientist working in a NARS is involved, or with ICRISAT when IRAT scientists working with ICRISAT/WASIP are involved), does not suffice and should be structured and enhanced in order to more efficiently use available funds.

If direct collaboration between IRAT and INTSORMIL could pose problems because of institutional difficulties, at least a better coordination is needed, in order to avoid duplication of activities, so as to best serve the interests of NARSs.

As a first step, a joint meeting between INTSORMIL, IER and ICRISAT/IRAT scientists and representatives could be proposed to be held soon in Mali, with the objective of discussing possible ways of cooperation on themes such as nitrogen uptake and utilization, sorghum based cropping systems, sorghum resistance to head bugs, sorghum technology and food quality.

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