'Publicaciones Biológicas', "Biological Publications", is an international research journal that publishes the results of original research in both basic and applied biological sciences. This journal is sponsored by the Graduate Studies Division of the Biological Sciences Department of the Autonomous University of Nuevo León.

All works published by 'Publicaciones Biológicas' are reviewed by members of the Editorial Council, with experts in each of the fields of the biological sciences.

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INTRODUCTION

THE SORGHUM CROP

Sorghum is a major source of food for millions of people in the semiarid tropics. In tropical areas sorghum grain is important as food and as livestock feed. The stem and foliage are used as a green crop, hay silage and pasturage. The stems are also used as fuel and building material. In temperate areas, it is a major source of cattle feed except in China, where it is primarily used for food (House, 1980).

Sorghum is used in the preparation of different types of food, and an unleavened bread is the most common food made from sorghum flour. Sometimes the dough is fermented before the bread is prepared, and the grain is boiled to make a porridge or gruel. It is also used in the preparation of biscuits. Beer is prepared from sorghum grain in many parts of Africa. Besides these products, popped and sweet sorghum which are parched, are also eaten (House, 1980).

The demand for sorghum as a staple food has been growing in recent years. Though sorghum is known for its versatile use, hardness, dependability, stability of yield and adaptability over a wide range of cultures and climates, the adverse edapho-climatic conditions prevailing in the sorghum growing areas of the world limit the crop's production (Swindale, 1980). The crop is often grown on poor soils by farmers who have little resources for control of moisture, the purchase of fertilizers, insecticides and other inputs. Therefore, there is a need for the development of cultivars more adaptable to the adverse climatic conditions of the SAT world (semiarid tropics, Figure 1.1).

ORIGINS AND DOMESTICATION OF SORGHUM

Nothing is known about when *Sorghum bicolor* was first brought into cultivation, but Murdock (1959) stated that, along with several West African Crops, it was domesticated some 7000 years ago. It might have reached India not earlier than 1500 BC and China by AD 900. Cultivated sorghums were first introduced to the Americas and Australia about 100 years ago (Peacock, 1984). Sorghum is distributed in wild forms in Africa and other countries. Mann *et al.* (1983) reviewed this subject. In sorghum, domestication is initiated by allelic changes at only two loci resulting from different selection pressures following the innovation of harvesting techniques. Wild sorghum disperse their seeds by the breakage of nodes (due to the absence of an abscission zone along the rachis, panicle or at spikelet nodes) with the subsequent scattering of the seeds. The essential step adopted in domestication was the harvest of the whole inflorescence, and the

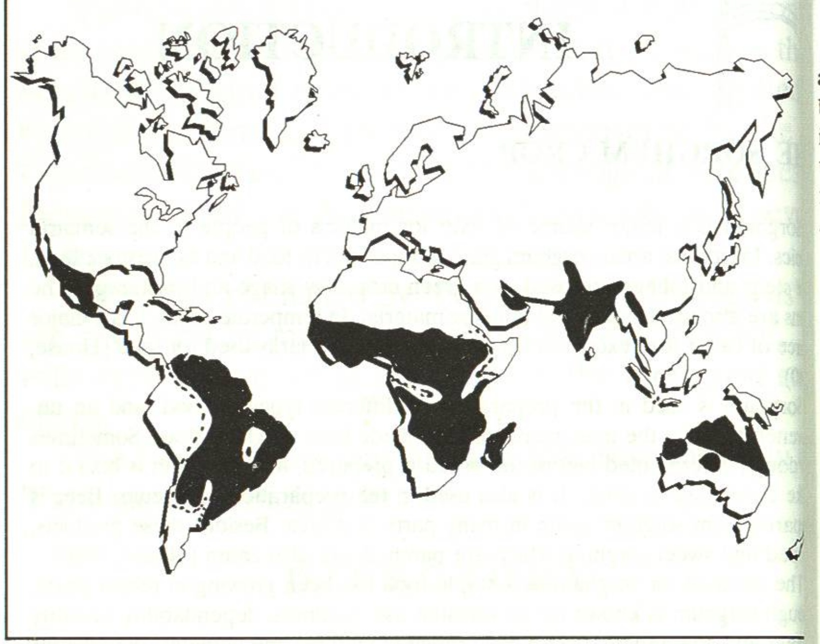

Figure 1.1 The semi-arid tropics, SAT (in black; ---indicates undemarcated boundary)

utilization of the grain for seed. Therefore, scattering is an undesirab characteristic. The types in which panicle components, rachis, panicle branch spikelet node remained intact had selective advantage for domestication. With a short time, this recessive characteristic remained fixed to complete the proce of domestication (Mann *et al.*, 1983). The domestication process continued f several thousand years. Continued artificial selection increased diversity in t crop plants.

Several authors explain the center of origin of sorghum from African countri (Vavilov, 1951; cited by Mann *et al.*, 1983), but Harlan and De Wet (1972) usi archaeological, palaeobotanical, anthropological as well as botanical evidenc believed that the center of origin of sorghum extends from near Lake Chad Africa. These areas represent the diversity and abundance of wild and wee species as well a presence of a primitive race of bicolor. Snowdon (1936; cited Mann *et al.*, 1983) believed sorghum to have separate centers of origin for diffe ent types. Mann *et al.* (1983) presented evidence that sorghum evolved and w first domesticated in northeastern Africa in the area north of the equator and ea of 10° E Longitude. The present distribution patterns of wild and cultivated rac give strong clues to demonstrate the pattern of evolution and domesticati (Mann *et al.*, 1983).

AREAS UNDER CULTIVATION

According to an FAO survey in 1978, sorghum is grown in Africa, southwest and southeast Asia, and North and South America, and on 43 million hectares in both tropical and temperate zones. It is the fourth major cereal crop of the world in production (Higgins, 1978). The cultivated sorghums have spread throughout the world, and today it is grown on 47.8 million hectares (FAO, 1982), making it fifth amongst cereals behind wheat, rice, maize and barley. The major production areas today include the great plains of North America, Sub-Saharan Africa, northeastern China, the Deccan plateau of central India, and Argentina. The potential grain yields of sorghum are similar to those of other cereals in excess of 14,000 kg/ha (Pickett and Fredericks, 1959; Fischer and Wilson, 1975). Sorghum has achieved importance primarily due to its adaptability in arid and semiarid tropics. Average yields in the developing world are near 1000 kg/ha ranging as low as 660 kg/ha in Africa to as high as 3127 kg/ha in Latin America (Peacock, 1984). The global ecological zone for sorghum extends from the humid forest zone near the equator to the deserts of the arid and semiarid tropics. The rainfall characteristics and moisture availability for SAT regions have been compiled and published by the International Crops Research Institute for the Semiarid Tropics (ICRISAT) (Virmani *et al.*, 1980). In Africa, sorghum is grown in 14 million hectares of the drought-prone countries, extending across the full width of the continent between 10° and 20° Latitudes (Motha and Sakamoto, 1979). This area is bounded on the north by the Sahara desert and sorghum is the major food crop in many of these countries. The average grain yield is only 720 kg/ha. In Asia, sorghum is grown on 20 million hectares with yields less than 660 kg/ha. In India, sorghum is the third major cereal with approximately 14 million hectares of which about 50% is cultivated after the monsoons on stored soil moisture. During the rainy season, sorghum is mostly grown as an intercrop with pigeon pea. The area under sorghum crops is on increase from the present 2.5 million hectares. The yield per hectare is 2.4 ton/ha. In Latin America, sorghum is intercropped with other cereals like pearl millet, maize and a number of legumes.

YIELD POTENTIALS AND CONSTRAINTS

Sorghum is a subsistence crop and is frequently grown by small farmers with few inputs under rainfed conditions. The risk involved in making inputs for fertilizer and pesticide are high. In these circumstances, the small farmers of SAT need cultivars which are stable and resistant to different biotic and abiotic stress factors with yields consistently higher than traditional cultivars under traditional management. There are vast differences in sorghum production in different parts of the world, the average ranging from 500 to 1000 kg/ha in tropical countries, and 1500-3000 kg/ha in temperate areas (House, 1982). These differences are due to variability in distribution of dry matter in the plant itself, responses to environments with different levels of stress, and different biotic factors like pests, diseas es, *Striga* and birds. The crop is being pushed into new environments, especially in marginal areas for maize and on acid soils. In México, where maize is the principal crop, the area under sorghum is gradually increasing for its adaptability (Maiti, unpublished). To improve sorghum production, different ways to incorporate several traits into elite breeding stocks are needed, as well as a better understanding of the plant and its environments. Commercial cultivation of F1 hybrids has contributed substantially to increase sorghum production in many parts of the world. There is a need to introduce high yielding varieties and hybrids with resistance traits in SAT areas where conditions of moisture, temperature, nutrients and other soil factors are limiting and vary considerably from place to place.

A survey was made to investigate yield reducing factors in different sorghum growing regions (Peacock, 1980; Table 1.1). Drought, crop establishment and birds appear to be the major limiting factors in sorghum crop production.

Problems differ in intensity in different environments. For example, shootfly is a major pest on sorghum in India and several African countries, but it is not a problem in the USA, where greenbug is a major insect problem. Therefore, research priorities for sorghum vary with the problems faced by a particular country. House (1982) outlined the priorities of research for the sorghum crop at ICRISAT in India. In his opinion, the main objectives of research are to develop a diverse array of agronomically stable elite varieties and hybrids in a range of maturity with good food quality grain, and with resistance to a number of important pests and diseases, and to *Striga* and drought. The priorities need to be changed with the gravity of the problems in different countries. For example, *Striga* and downy mildew, which were of less importance earlier, are now of great concern in India. The crop growing conditions in SAT are harsh and the farmers are generally poor. In order to maximize production with limited resources in this area, there is need for stability of production including resistance for important yield-limiting factors.

Table 1.1 Most serious problems limiting Sorghum production in countries of SAT (Peacock, 1980).

Countries *	A	B	W	B	O	C	E	G	H	I	K	W	L	M	N	R	P	S	D	T	d	U	V	Z	TOTAL
Drought	1	-	1	1	-	-	1	1	-	1	1	1	1	1	-	-	-	1	1	1	-	-	1	-	14
Stand establishment	-	-	1	-	-	-	-	1	-	1	-	1	1	-	-	-	-	1	1	-	-	-	1	-	8
Soil fertility	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-	1	1	-	-	-	1	-	5
Photoperiod	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1
Weeds	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	-	-	-	1	-	4
Intercropping	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1
Yield	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	1	-	3
Grain quality	-	1	-	-	-	1	-	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	4
Stability	-	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	3
Adaptability	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1	3
Earliness	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1

* Australia; Bangladesh; BotsWana; Brazil; CamerOun; China; Ethiopia; Gambia; GHana; India; Kenya; MalaWi; MaLi; Mauritania; Niger; NigeRia; Pakistan; Senegal; SuDan; Tanzania; Thailand; Uganda; Upper Volta; Zambia.

A team of multidisciplinary specialists should work together to solve these problems in recognized geographically functional regions. They need to find solutions to the specific problems that may or may not be of concern across different adaption zones. The research needs should be indicated for respective zones (House, 1982). Research priorities have been identified for various zones of adaptation for each geographically functional regions. These are defined roughly by rainfall and length of rainy season (low, intermediate, high; House, 1982):

1. Indian subcontinent
2. West Africa-low-intermediate rainfall
3. West Africa-high rainfall, long season
4. East Africa-Yemens
5. Southern Africa
6. Central Americal
7. Tropical South America
8. Far East
9. Southeast Asia USSR
10. Mediterranean
11. Oceania
12. Temperate Americas.

Several national and international organizations are involved in sorghum crop improvement research. This also involves sorghum research and training relevant to the developing world. ICRISAT is involved in research and training for semi-arid tropics of the world. INTSORMIL, and US AID program in the USA, provides funds for research both in US universities and overseas institutions. In West Africa, several regional agencies like SAFGRAD, CILLS, Institute du Sahel and ICRISAT are involved in sorghum research. There are several problems that limit sorghum crop development and productivity as a whole. Stand establishment and drought is an area of high priority. Germplasm and breeding materials need to be evaluated for resistance to disease and pests.

RESEARCH NEEDS

Cultivars tolerant to major limiting factors with stable yields and requiring few inputs will be acceptable to the poor farmers of SAT areas, therefore, the identification and development of resistant cultivars is essential (Table 1.2). There are

Table 1.2 Traits of economic importance in the sorghum improvemente program (House, 1982).

1. **Yield & Stability**	a) Genotype x management; genotype x enviroment; resistance to hazards (see 3)
	b) Yield potential
2. **Quality**	a) Traditional concepts
	b) Food preparation and taste
	c) Nutrition: high lysine, protein content
3. **Resistance**	a) Insects: stem borer, shoot fly, midge, head bugs
	b) Plant diseases: grain molds, stalk roots, downy mildew, witchweed
	c) Environmental stress: water, heat, cold, nutrition.

several factors which determine plant productivity in the arid and semi-ari tropical regions. The total production of a crop is productivity multiplied by th quality that represents the limiting factors (Elston, 1980). The productivity of th crop is the yield of plants expressed per unit of some factor that limi production. Therefore, we need to understand the ways in which several facto affect crop development. Attempts should be made to identify resistant genotype at different phenological stages of the plant. A search needs to be made to iden tify lines showing multiple resistance to major yield-reducing factors (Maiti, 1981 House (1982) stated that a major thrust of research in SAT is to help the poore of the farmers working in harsh environments with limited resources. Anothe thrust is in areas where agriculture is developing and again another in area where agriculture is highly developed. Sorghum being one of crops of sma farmers, attention should be directed on the small farmer of limited mean farming his land with few inputs and basically in rainfed conditions (Swindal 1982). Our job as scientists is not only to develop technology, but to investigat how this technology could be applied by farmers. Research needs to be directe for development of varieties, and adapted for high and/or low input situations

We should emphasize resistance to major diseases and pests and tolerance t major stress, and ensure that these factors are durable and that yield potential i retained. This involves developing screening techniques for identifying broad based genetic resistance and tolerance, incorporating them into elite breedin material and screening such material in many situations, including contrastin levels of farming.

2

SEEDS

INTRODUCTION

A healthy seed with good genetic constitution for larger yield and resistance to insects and diseases is a major target of the plant breeder. The growth and vigor of the seedlings are inherent seed traits. This article deals with seed as part of the panicle.

Seeds are borne on the panicles on raceme branches. The panicle varies in length from 4 to 25 cm and is 2 to 20 cm wide. It may be short, compact, loose or open, composed of a central axis which bears whorls of primary branches on each node. Each primary branch bears secondary branches which in turn bear spikelets (Fig.2.1, 2.2). House (1980) described a sorghum panicle as an inflorescence, which is a raceme consisting of spikelet(s). They are of two types: one sessile and the other pedicellate. The terminal spikelet is a sessile spikelet (Fig. 2.2). The number of nodes in the raceme varies with the genotype.

Sessile spikelets. The sessile spikelets differ in shape from lanceolate to ovoid, and are sometimes depressed in the center. They are green at flowering, but change into purple, black or the color of straw at seed maturity. Glumes enclosing the seed and also the ovary are intensely hairy to glabrous. They are hard and have nerves. Some genotypes posses very thin and brittle glumes, while others posses thin, papery ones. The seed is enclosed between the upper and lower glumes. The lower glume is usually flattened and spikelet-shaped, while the upper glume is more convex or boat-shaped. The seed may be enclosed by the glumes or fully exposed, which differs with the genotype (House, 1980).

There are two delicate lemmas. The lower lemma is elliptic or oblong and of the same length as the glume. The upper lemma is shorter and possesses two pistils and three stamens. In some cases, it has awns. A palea and two membranous lodicles are also present inside the floret. The feathery stigmas with short stout styles are attached to lodicles. The anthers are attached to long-thread filaments (Fig. 2.3).

Pedicellate spikelets. These are narrower than the sessile spikelets and are usually lanceolate in shape. These spikelets posses only anthers, but occasionally have a rudimentary ovary and empty glumes (Fig. 2.4).

According the IBPGR (International Bureau of Plant Genetic Resource, Rome; 1980) the description of panicle is as follows (Figs. 2.1, 2.2, 2.5).