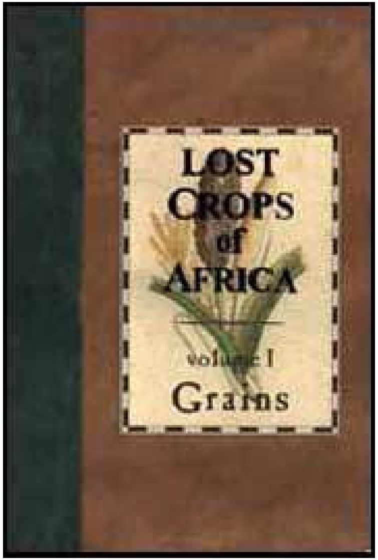

Lost Crops of Africa: Volume 1 - Grains (BOSTID, 1996, 372 p.)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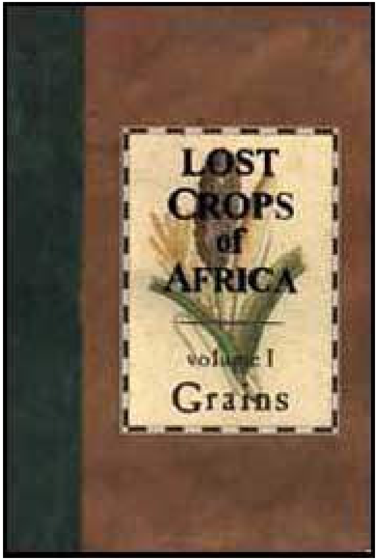

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National Research Council

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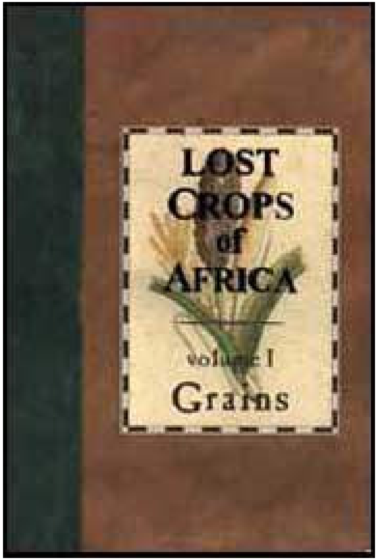


2. Finger Millet

Finger millet (Eleusine coracana) is hardly "lost." Indeed, it is one of the few special species that currently support the world's food supplies. This African native probably originated in the highlands of Uganda and Ethiopia, where farmers have been growing it for thousands of years. In parts of eastern and southern Africa as well as in India, it became a staple upon which millions depend. And its annual world production is at least 4.5 million tons of grain, of which Africa produces perhaps 2 million tons.

For all its importance, however, finger millet is grossly neglected both scientifically and internationally. Compared to the research lavished on wheat, rice, and maize, for instance, it receives almost none. Most of the world has never heard of it, and even many countries that grow it have left it to languish in the limbo of a "poor person's crop," a "famine food," or, even worse, a "birdseed."

Further, in recent years this neglected crop has started an ominous slide that could propel it to oblivion even in Africa. In fact, it has declined so rapidly in southern Africa, Burundi, Rwanda, and Zaire, for instance, that some people predict that in a few years it will be hard to find - even where until recently it was the predominant cereal. In those areas it clings to existence only in plots that are grown for use on feast days and other occasions demanding prestige fare.

The world's attitude towards finger millet must be reversed. Of all major cereals, this crop is one of the most nutritious. Indeed, some varieties appear to have high levels of methionine, an amino acid lacking in the diets of hundreds of millions of the poor who live on starchy foods such as cassava and plantain. Outsiders have long marveled at how people in Uganda and southern Sudan could develop such strapping physiques and work as hard as they do on just one meal a day. Finger millet seems to be the main reason.

This crop has many other advantages as well. Its grain tastes better than most; Africans who know it usually prefer finger millet over all others. The plant is also productive and thrives in a variety of environments and conditions. Moreover, its seeds can be stored for years without insect damage, which makes them lifesavers for famineprone areas.

Given all these qualities, it is perhaps hard to understand why finger millet is being rejected.

But the reason is simple. People are giving it up in favor of maize, sorghum, and especially cassava because producing finger millet takes a lot of work.

The truth is that finger millet, as produced at present, demands a dedication to drudgery that, given a choice, few people are willing to invest. Part of the terrible toil is in weeding the fields, part in handling the harvest, and part in processing the grain.

PROSPECTS

Even though finger millet is declining in the heartland where 30 years ago it was the major crop of the land, all is not lost. Indeed, if immediate attention is given, the impediments causing the decline will probably be eliminated. In fact, there are already signs that the slide may be bottoming out. Prices paid for finger millet have risen dramatically in some places, and the crop is enjoying something of a resurgence - and a highly profitable one at that. In

Kenya, for instance, the grain currently sells at more than twice the price of sorghum and maize. In Zimbabwe, too, the government offers an attractive producer price, which has tended to slow the decline. And Uganda's most recent statistics indicate that finger millet still occupies 50 percent of its cereal area.

Africa

If this crop is given proper attention, it has the following possibilities within Africa.

Humid Areas Excellent prospects. Certain varieties are adapted to heat, humidity, and tropical conditions. (Finger millet was once the principal staple for people in southern Sudan and northern Uganda, for instance.) Given research, recognition, and sympathetic policies, production could expand dramatically.

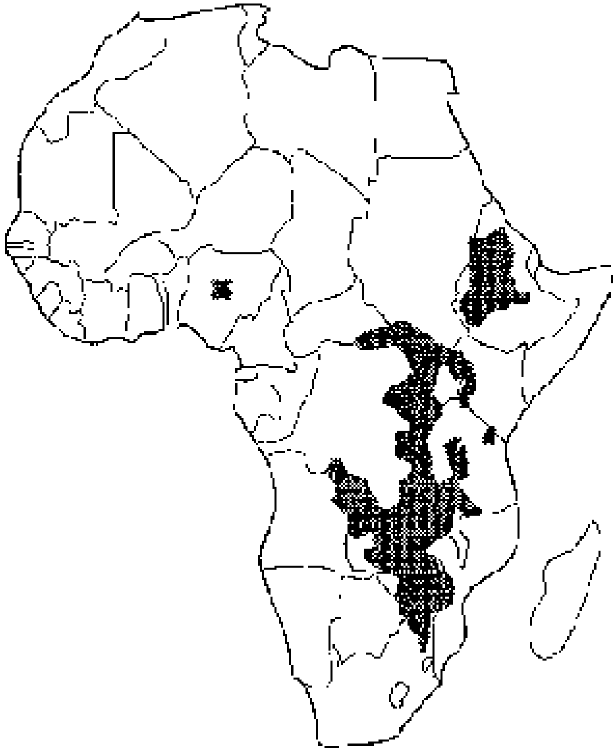


FIGURE: Finger millet is grown throughout eastern and southern Africa, but especially in the subhumid uplands of Uganda, Kenya, Tanzania, Malawi, Zaire, Zambia, and Zimbabwe. The crop originated somewhere in the area that today is Uganda.

Dry Areas Fair prospects. Finger millet is not as drought tolerant as pearl millet or even sorghum, but it could play a much greater role in savanna areas that get at least moderate rainfall.

Upland Areas Excellent prospects. Certain finger millet landraces are fully adapted to highland conditions. In Africa the crop is usually grown at altitudes between 1,000 and 2,000 m and in Nepal it is grown at altitudes up to at least 2,400 m.

Other Regions

Finger millet is certainly not being abandoned in Asia. Indeed, India's national yields have increased 50 percent since 1955.4 Moreover,

Most of the increase occurred between 1955 and 1975 and resulted from genetic improvement of India's traditional landraces. Subsequent increases were due to crosses between those and new strains introduced from Africa. in Nepal, the finger millet area is expanding at the rate of 8 percent per year.

This high-methionine grain might also be beneficial for use in weaning foods and in many other cereal products in parts of the world (Latin America and North America, for instance) where it is now largely ignored.

USES

This is a versatile grain that can probably be used in dozens of types of foods, including many that are quite unlike its traditional ones. Its several major uses include the following:

· Porridge. The small grains - which are usually brown but occasionally white - are commonly boiled into a thick porridge.
· Bread. Some finger millet is ground into flour and used for bread and various other baked products. All are relished for

their flavor and aroma.

· Malt. Malted finger millet (the sprouted seeds) is produced as a food in a few places. It is nutritious, easily digested, and is recommended particularly for infants and the elderly.

· Beverages. Much finger millet in Africa is used to make beer. Its amylase enzymes readily convert starch to sugar. Indeed, finger millet has much more of this "saccharifying" power than does sorghum or maize; only barley, the world's premier beer grain, surpasses it. In Ethiopia, finger millet is also used to make arake, a powerful distilled liquor.

· Fodder. Finger millet straw makes good fodder - better than that from pearl millet, wheat, or sorghum. It contains up to 61 percent total digestible nutrients.

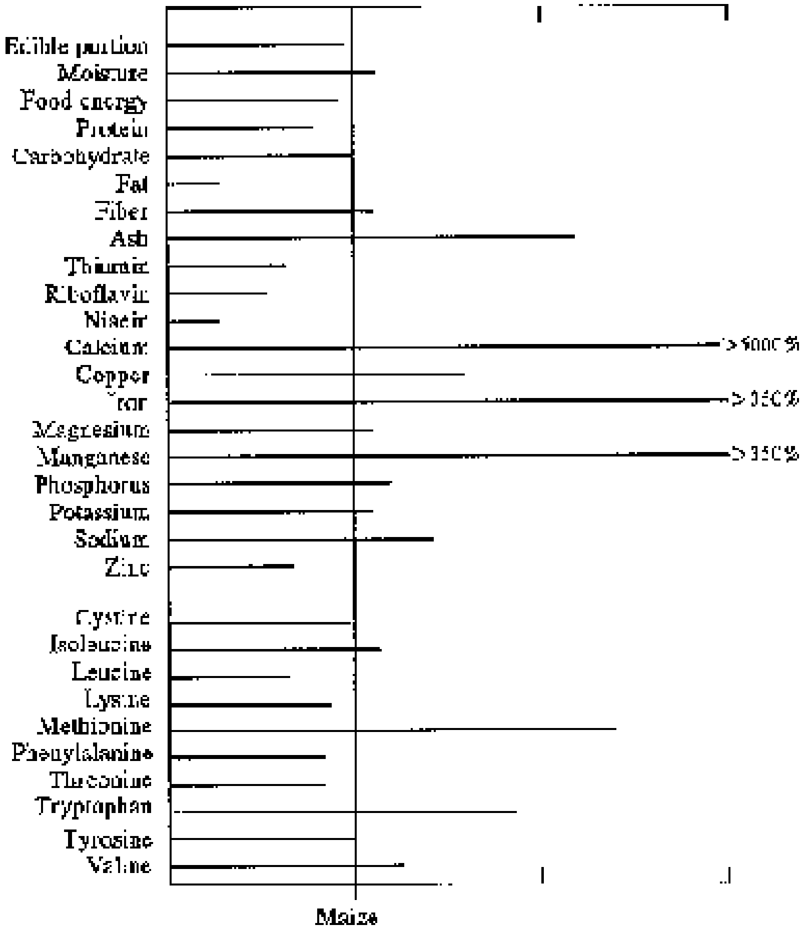
· Popped Products. Finger millet can be popped. It is widely enjoyed in this tasty form in India.

NUTRITIONAL PROMISE

Main Components	Essential Amino Acids

Edible portion (g)	95	Cystine	1.7
Moisture (g)	12	Isoleucine	4.0
Food energy (Kc)	334	Leucine	7.8
Protein (g)	7.3	Lysine	2.5
Carbohydrates (g)	74	Methionine	5.0
Fats (g)	1.3	Phenylalanine	4.1
Fiber (g)	3.2	Threonine	3.1
Ash (g)	2.6	Tryptophan	1.3
Vitamin A (RE)	6	Tyrosine	4.1
Thiamin (mg)	0.24	Valine	6.4
Riboflavin (mg)	0.11		
Niacin (mg)	1.0		
Vitamin C (mg)	1		
Calcium (mg)	358		

Chloride (mg)	84		
Copper (mg)	0.5		
Iodine (fig)	10		
Iron (mg)	9.9		
Magnesium (mg)	140		
Manganese (mg)	1.9		
Molybdenum (fig)	2		
Phosphorus (mg)	250		
Potassium (mg)	314		
Sodium (mg)	49		
Zinc (mg)	1.5		


Edible portion
Moisture
Food energy
Protein
Carbohydrate
Fat
Fiber
Ash
Thiamin
Riboflavin
Niacin
Calcium
Copper
Iron
Magnesium
Manganese
Phosphorus
Potassium
Sodium
Zinc
Cystine
Isoleucine
Leucine
Lysine
Methionine
Phenylalanine
Threonine
Tryptophan
Tyrosine
Valine
Maize

FIGURE

No single set of numbers can adequately convey the nutritional promise of a grain as variable as finger millet. The numbers in these pages should be taken with caution. The dozen or so measurements that have been reported generally agree on most of the different nutrients. However, protein contents ranging from 6 to 14 percent have been claimed. The levels of fat (1-1.4 percent) and food energy (323-350 Kc) that are normally given are fairly consistent and are about the same as in maize. However, in some samples they seem to be much higher. The situation regarding iron is somewhat similar. Most analyses give the figure as about 5 mg per 100 g. But there have been two reports of iron exceeding 17 ma.

Figures reported for the essential amino acids are generally consistent, but 3 percent methionine is commonly referred to in the literature. Possibly, this was based on degerminated flour. Even that figure is outstanding for a cereal grain.

In this chart, we have compared whole-grain finger millet with the standard figures for maize. These are perhaps not fair comparisons, but they do accurately reflect the differences between the forms in which each food is normally eaten.

NUTRITION

The grain's protein content (7.4 percent) is comparable to that of rice (7.5 percent). However, it shows considerable variation, and at least one Indian cultivar contains as much as 14 percent protein.

The main protein fraction (eleusinin) has high biological value, with good amounts of tryptophan, cystine, methionine, and total aromatic amino acids. All of these are crucial to human health and growth and are deficient in most cereals. For this reason alone, finger millet is an important preventative against malnutrition. The methionine level - ranging around 5 percent of protein - is of special benefit, notably for those who depend on plant foods for their protein.

Finger millet is also a rich source of minerals. Some samples contain 0.33 percent calcium, 5-30 times more than in most cereals. The phosphorus and iron content can also be high.

AGRONOMY

In Asia, finger millet is planted in rows and managed much like other cereals. But in Africa it is usually handled differently. Unlike maize, sorghum, or pearl millet - all of which are planted at individual stands in a rough seedbed - finger millet is traditionally planted in Africa by broadcasting its tiny seeds. This demands a very fine seedbed and means that the farmers must work hard and long, both to prepare the land and to weed the young plants.
Two crops a year are possible with early-maturing types.

HARVESTING AND HANDLING

In most of Africa the crop is harvested by hand. Individual heads are cut off with a knife, leaving a few centimeters of stalk attached. These are piled in heaps for a few days, which fosters a fermentation whose heat and hydrolysis makes the seeds easier to thresh.

Finger millet seeds are so small that weevils cannot squeeze inside. In fact, its unthreshed heads resist storage pests so well they can be stored for 10 years or more without insect damage. (It is said that if kept dry the seed may remain in good condition for up to 50 years!)

Yields are variable but (compared to those of other grains in the area) are generally good. In Uganda, for example, a threshed yield of 1,800 kg per hectare is regarded as average. In India, on reasonable dryland sites, yields may run to about 1,000 kg per hectare, and on irrigated sites a normal average is more than 2,000 kg per hectare. Yields of 5,000-6,000 kg per hectare have been obtained under ideal irrigated conditions. Similar yields have been obtained in Nepal even under rainfed conditions.

LIMITATIONS

As has been noted, the small size of the seeds is a serious drawback. It makes the crop difficult to handle at all stages. Weeding is a particular problem. In Africa the dominant weed, a wild relative of the crop, looks so much like finger millet in its early stages that only skilled observers and close scrutiny can tell them apart. The problem is compounded by the practice of broadcasting seed. To weed the resulting jumbled stands, people must inspect every plant, even going through on hands and knees.

Finger millet is subject to bird predators - notably to the notorious quelea (see Appendix A).

By and large' the plant suffers little from diseases and insects, but a ferocious fungal disease called "blast" can devastate whole fields.

Finger millet is almost entirely self-pollinating and crosses between different strains can be made only with difficulty. Until recently, genetic improvement was limited to pedigree-based

selection. However, in Uganda a few plants with male sterility have now been discovered. These should ease the way to breeding methods in which different lines can be crossed without trouble.
Because the seeds are so small, it takes skill and much effort to convert finger millet into flour - particularly by hand. Even hammer mills have difficulty. They must be fitted with very fine screens and run at high speed. Recently, however, a special mill for millet has been devised.

NEXT STEPS

If finger millet is ever to be rescued, now is the time. The key is to find ways to present its plight and promise to the public and politicians and to develop its markets. A few motivated individuals could do much here. Among helpful actions might be a pan-African finger millet conference, where researchers and others could compare methods used to grow it, prepare it, and sell it in the various nations. This meeting would provide the opportunity to exchange experiences and to begin the process of preparing papers, pamphlets, recipes, and perhaps a monograph. Another might be the establishment of a "fingermillet action program" to share seeds and research results in the future. There might even be established a pan-African finger millet "SWAT" team to provide advice and stimulus to the countries where finger millet is now declining toward economic extinction.

Rescuing this crop may be easier than now seems probable. Lifestyles and eating habits may have changed, but in much of Africa people still appreciate finger millet. Subsistence farmers like finger millet also. Every seed sown can return between 200 and 500 seeds (other grain crops seldom go above 100 even under ideal conditions). And this crop has many uses. To those whose very lives and livelihoods depend on what they grow, its flexibility is vital.

Beyond Africa, finger millet should also be given a higher research priority. It is a good way to help the rural poor in parts of Asia. Much of the spectacular rise of wheat occurred in areas where irrigation could be used. Overcoming finger millet's yield constraints would, more importantly, benefit rainfed agriculture.

Processing Finger Millet

Milling

Mechanical milling is of course well known; for wheat, rice, and maize, it is a major industry. But for finger millet, this primary step in the commercial processing of a food grain is essentially unknown. Machinery for rubbing the bran (embryo) off finger millet has never been available, perhaps through a lack of interest but mainly because the grain is exceptionally difficult to mill by machine. Finger millet, therefore, is usually eaten as a whole-grain flour, and the presence of oil in the embryo means that its shelf life is short and its commercial use limited.

Finger millet seed is a challenge to mill because it is very small and because its seed coat is bound tightly to the edible part (endosperm) inside. Moreover, the grain is so soft and friable that conventional milling equipment cannot remove the outside without crushing the inside. However, farmers have long known that moistening finger millet (for about 30 minutes) toughens the bran and reduces its grip enough that it can be mechanically separated without crushing the rest.

A machine for doing this has now been developed in India. This so-called "mini millet mill" consists of a water mixer, a plate grinder, and various sifter attachments. It is a versatile device in which debranning and sizing the endosperm (into either flour or semolina) take place in a single operation. It yields fairly white products. It can also be used to process wheat, maize, sorghum, and pearl millet and will even remove the outer husk from finger millet seeds if the clearance between the grinder plates is reduced.

This machine, and others like it, could initiate a new era for finger millet as a processed grain of commerce. The flour would then have a good shelf life and could be trucked to the cities and sold in stores as are wheat, rice, and maize. Commercial horizons would open up that have never before been contemplated.

Malting

Finger millet could be the key to providing cheap and nutritious foods for solving, at last, the malnutrition that each year kills millions of babies throughout the warmer parts of the world. As is described elsewhere (notably in appendixes C and D), the process of germinating finger millet activates enzymes that break down the complex structures of starches into sugars and other simple carbohydrates that are easy to digest. The enzymes are of course there to benefit the seeds in which they occur - to mobilize food for the growing seedling; but long ago people found that they could use them also to break up starches from other sources. This process (usually called malting) became the first step in making beer and liquor out of starchy foods such as potatoes, maize, rice, or sorghum.

What has been overlooked to a large extent is that malting can be used for more than just brewing. Indeed, it is probably the key to making cheap, digestible, liquid foods with little effort and no extra cooking fuel. These foods are particularly promising for children facing the life-threatening dietary switch from mother's milk to solid foods.

Adding a tiny amount of malted grain turns a bowl of hot starchy porridge into a watery liquid. The resulting food matches the viscosity of a bottled baby food, such as those sold in American supermarkets. A child who is too small or too weak to get down solids can then get a full meal - and get it out of the food its mother is preparing for the rest of the family.

The germinated grain acts as a catalyst to liquefy any of the world's major starchy foods: wheat, rice, maize, sorghum, millet, potatoes, cassava (manioc), yams, and the rest. Moreover, it does more than turn those staples into liquid form: it predigests the starches, making the food easy for a body to absorb, and (by releasing sugars) it renders even the blandest staples palatable.

The malted grain is readily available, cheap, and safe to eat. It should develop healthy bodies and fully functioning brains in the millions of children whose health and happiness is now jeopardized by malnutrition.

Of all the world's cereal grains, finger millet is second only to barley in its ability to hydrolyze starches ("malting power"). And it has the inestimable value of growing in the latitudes where malnutrition is rife. (Barley is strictly a temperate-zone resource.)

But for all its potential to benefit the malnourished, not much attention has been paid to malting internationally. Only in India and Nepal have malt-based children's foods been intensively studied. In both countries, food scientists have created malted-grain products that can overcome malnutrition. And in almost every product, malted finger millet was the prime ingredient.

The fact that malting is a cheap and widely understood process that can be easily accomplished in the home or village and requires no fuel or special equipment is a major benefit. This means that top-quality weaning foods can be made by the poor, who cannot afford to buy commercial baby-food concoctions.

Research Needs

Research is needed on all aspects of this plant, which now is little known to scientists in general. ICRISAT is conducting research on it, but more effort is needed. Research operations might include those discussed below.

Trials in New Areas Entrepreneurs in the United States as well as in Australia and other countries that specialize in cereal breeding could probably do much to benefit this crop. It is already grown in a small way in the United States. It grows well, but so far is used only for birdseed. Nonetheless, it might support a small specialty grain industry for local and national food uses. And enlisting the country's outstanding cereal-science capabilities could perhaps transform this crop's potential worldwide.

Farming Methods As far as Africa is concerned, finger millet's greatest immediate needs lie not so much in plant breeding as in farming practices. Reducing the current drudgery involved with its production would bring the biggest and quickest benefits.

Surprisingly, techniques for making finger-millet production less laborious can probably be employed rapidly and widely. For instance, planting the seed in rows would dramatically slash the need for weeding. One or two hoeings (or perhaps a layer of mulch) would eliminate most of the weeds with little further effort. To make this practical, however, a device is needed that can deliver small seed with precision. It would have to be easy to make and simple to use. Such devices do indeed exist (see Appendix A) but have not yet been introduced to finger millet farmers.

Examples of other types of farming practices worth exploring are the following:

· Minimum tillage seeding.
· Wide rows for water capture.
· Control of birds.
· Intercropping or undersowing with legumes. (The foliage from leguminous shrubs or ground cover may be especially helpful by supplying nitrogen to the crop.)
· Sowing or transplanting with other crops. (In Nepal, for instance, it is often planted with maize.)
· Weeding using animal power and other labor-saving techniques.
· Developing ox-drawn implements for planting, cultivating,

harvesting, and threshing finger millet.

Erosion Control In some parts of southern and eastern Africa finger millet has been abandoned because it "causes" severe soil erosion. In these areas, farmers typically clear forest from a hillside, burn it, and sow finger millet in the ashes. The tiny plants hold soil poorly, and it easily washes away. For such sites there is a need for alternative methods of erosion control. One example might be vetiver (see Appendix A). Another is mulching with stubble from the previous crop.

On the other hand, other parts of Africa actually employ finger millet for erosion control. In fact, when broadcast - or even line sown - across the slope it is good for reducing erosion.

Data from Zambia, for example, show that the plant prevents erosion more effectively than legumes do. Farmers in Nepal also report that finger millet "holds the soil."

Plant Breeding In its genetic development as a crop, finger millet is about where wheat was in the 1890s. Many landrace types are known but have not been systematically evaluated, codified, or analyzed, Thus it is likely that the best-yielding, best-tasting, and best-handling types have not been isolated or created out of the massive gene pool. Since the 1890s, average yields of wheat have risen from about 500 kg per hectare to more than 4,000 kg per hectare; finger millet's could rise similarly and much more quickly.

Various finger-millet landraces possess genes for blast resistance, robust growth, early vigor, large panicle size, high finger number and branching, and high-density grain. Similarly, there are water-efficient types with high carbon dioxide fixation and low leaf area that could be outstanding new crops for semiarid conditions. Long-glume types with high seed weight are especially promising for increasing seed size. All of these, and more, are genetic raw materials that could transform this crop.

The grain is already nutritious, but it might be improved even more. As noted, types containing up to 14 percent protein are known. Also, it is a high-methionine protein and, of all the essential amino acids, is the most difficult to find in grain-based foods. Thus these finger millets could be a "super cereal" in nutritional terms.

White-seeded forms that make good unleavened bread and bakery products are also known, and they too are undeveloped. Today's crop in Africa is overwhelmingly the coarse, rusty-red form that is mainly useful for porridge and brewing beer.

Hybrids between Indian and African varieties seem promising as well. These high-yielding "Indaf" types are popular in India. Similar hybridization and selection for improved Indaf varieties for African conditions is now being started.

Hybridization, however, is difficult and mutation breeding is another approach worth exploring.

Some of finger millet's relatives have interesting traits that might be transferable. Among wild Eleusine species are perennials that might lend some of their enduring characteristics to finger millet. Others have genes for tolerance of heat, cold, drought, and waterlogging, as well as resistance to salinity and an ability to mobilize phosphorus and utilize nitrogen efficiently. Less dramatic but more immediately practical plant-breeding needs are the fine-tuning of today's varieties. The most important objectives are resistance to blast, helminthosporium (another fungus), striga (parasitic witchweed), lodging, stressful soil and moisture conditions, and grain that can be more easily dehulled and ground.

Other objectives might include fast seedling growth to compete better with weeds, shade- tolerant types for relay and intercropping, and types with anthocyanin pigmentation in the leaves (possibly obtainable through induced mutation), which could be spotted easily in the fields and would make weeding a much easier task. Post Production Research Reducing the labor to dehull and to grind grain is obviously a vital need. Less urgent needs include: (1) improvement of malting quality (important both for brewing and for making high-methionine weaning foods); and (2) new methods of processing, such as parboiling, milling, and puffing (see Appendix B).

Ragi

Finger millet crossed the Indian Ocean more than 1,000 years ago and since then has become extremely important in South Asia. In India, where it is generally called "ragi," this native African grain is now grown on more than 2 million hectares.

In its new home, scientists and farmers have created numerous ragi races. There are, for instance, plants that are purple; seedheads that are short, long, "open," "curved," or "fisty"; seeds that range from almost black to orange-red; and there is also a popular type whose seeds are pure white. Some ragi varieties are dwarfs (less than 50 cm), some tiller profusely, some are slow to mature and are grown mainly under irrigation, while others mature quickly and lend themselves to dryland production.

Ragi is considered one of India's best dryland crops, and most of it is produced without supplemental water. The plant is both adaptable and resilient: it survives on lateritic soils, it withstands some salinity, and it has few serious diseases or pests. Ragi also yields well at elevations above those suitable for most other tropical cereals. In the Himalaya foothills, for example, it is cultivated up to slightly over 2,000 m above sea level.

Despite its importance in the Himalayas, about 75 percent of the ragi area lies in South India, particularly in Karnataka, Tamil Nadu, and Andhra Pradesh. In parts of this vast region farmers can get two crops a year; in Tamil Nadu and Andhra Pradesh three are not unknown. Wherever the rains at sowing time are uncertain, the farmers often transplant ragi like rice. In fact, the two crops are commonly grown in a "relay" that is good for both. For instance, in May a farmer may start out by sowing ragi seeds in the nursery; in June, he (or she) transplants the seedlings to the field and replants the nursery with rice seeds; in August, the ragi crop is harvested and the rice seedlings are put out into the just vacated fields. This process is efficient, highly productive, and a good insurance against the vagaries of the weather.

Ragi yields as much as 5,000 kg of grain per hectare. Because the seed can be stored for decades (some say 50 years), it is highly valued as a reserve against famines.

However, ragi is much more than just a famine food. In certain regions it is an everyday staple. It is, for instance, a principal cereal of the farming classes in Karnataka, Tamil Nadu, and Andhra Pradesh, as well as in the Himalaya hill tracts (including those of Nepal). The grain is mainly processed into flour, from which is made a variety of cakes, puddings, porridges, and other tasty foods. Some, however, is malted and turned into beer as well as into easily digested foods for infants and invalids.

As in its African homeland' ragi enjoys a reputation for being both nutritious and sustaining, and Indian studies lend scientific support to this view. Certain grain types, particularly the white ones, can match the most nutritious local cereals, at least in protein content.

SPECIES INFORMATION

Botanical Name Eleusine coracana (L.) Gaertner

Common Names

Afrikaans (and Dutch): vogel gierst
Arabic: tailabon
Bantu: bule
English: finger millet, African millet; koracan

French: petit mil, eleusine cultivee, coracan, koracan
German: Fingerhirse
Swahili: wimbi, ulezi
Ethiopia: dagussa (Amharic/Sodo), tokuso (Amharic), barankiya (Oromo)
India: ragi
Kenya: wimbi (kiswahili), mugimbi (Kikuyu)
Malawi: mawere, lipoko, usanje, khakwe, mulimbi, lupodo, males), mawe
Nepal: koddo
The Sudan: tailabon (Arabic), ceyut (Bari) Tanzania: mwimbi, mbege
Uganda: bulo
Zambia: kambale, lupoko, mawele, majolothi, amale, bule
Zimbabwe: rapoko, zviyo, njera, rukweza, mazhovole, uphoko, poho

Description

Finger millet is a tufted annual growing 40-130 cm tall, taking between 2.5 and 6 months to mature. It has narrow, grasslike leaves and many tillers and branches. The head consists of a group of digitately arranged spikes.

It is a tetraploid.

Distribution

Finger millet derives from the wild diploid Eleusine africana. There is archaeological evidence that before maize was introduced it was a staple crop of the southern Africa region. Today it is found throughout eastern and southern Africa and is the principal cereal grain in Uganda, where it is planted on more than 0.4 million hectares (especially in northern and western regions), as well as in northeastern Zambia. It is also an important backup "famine food" as far south as Mozambique.

Finger millet does not appear to have been adopted in ancient

Egypt, and it is said to have reached Europe only about the beginning of the Christian era. However, it arrived in India much earlier, probably more than 3,000 years ago, and now it is an important staple food in some places, particularly in the hill country in the north and the south.

Cultivated Varieties

Numerous cultivars have been recognized in India and Africa, consisting of highland and lowland forms, dryland and irrigation types, grain and beer types, and early- and late- maturing cultivars. By and large, there are highland races and lowland races - each adapted to its own climate.

Environmental Requirements

Daylength Finger millet is a short-day plant, a 12-hour photoperiod being optimum for the best-known types. It has been successfully grown in the United States as far north as

Davis, California (with considerable problems of photoperiod sensitivity), and it is widely grown in the Himalayas (30°N latitude); however, it is mainly produced within 20°N and 20°S latitude. Daylength-neutral types probably exist.

Rainfall It requires a moderate rainfall (500-1,000 mm), well distributed during the growing season with an absence of prolonged droughts. Dry weather is required for drying the grain at harvest. In drier areas with unreliable rainfall' sorghum and pearl millet are better suited. In wetter climates, rice or maize is preferable.

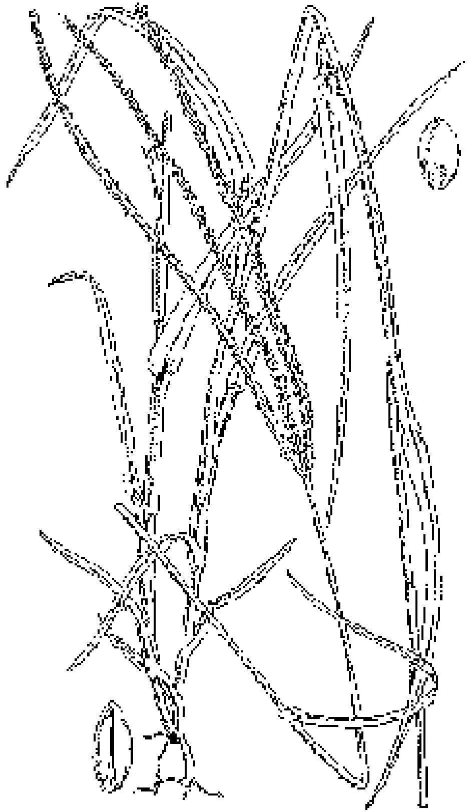
Altitude Most of the world's finger millet is grown at intermediate elevations, between 500 and 2,400 m. Its actual altitude limits are unknown.

Low Temperature The crop tolerates a cooler climate than other millets. For an African native, this crop is surprisingly well adapted to the temperate zones.

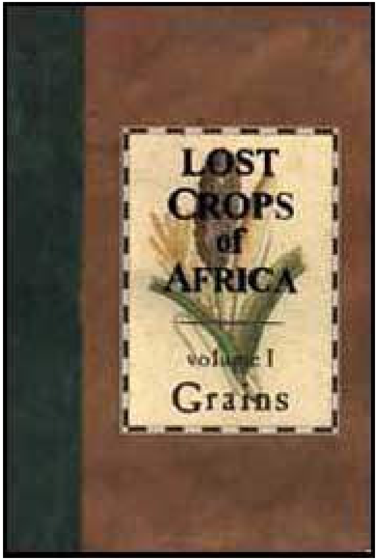
High Temperature Finger millet thrives under hot conditions. It can grow where temperatures are as high as 35°C. In Uganda, the crop grows best where the average maximum temperature exceeds 27°C and the average minimum does not fall below 18°C.

Soil Type The crop is grown on a variety of soils. It is frequently produced on reddish-brown lateritic soils with good drainage but reasonable water-holding capacity. It can tolerate some waterlogging. It seems to have more ability to utilize rock phosphate than other cereals do.

FIGURE



FIGURE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3. Fonio (Acha)

Fonio (Digitaria exilis and Digitaria iburua) is probably the oldest African cereal. For thousands of years West Africans have cultivated it across the dry savannas. Indeed, it was once their major food. Even though few other people have ever heard of it, this crop still remains important in areas scattered from Cape Verde to Lake Chad. In certain regions of Mali, Burkina Faso, Guinea, and Nigeria, for instance, it is either the staple or a major part of the diet. Each year West African farmers devote approximately 300,000 hectares to cultivating fonio, and the crop supplies food to 3 -4 million people.

Despite its ancient heritage and widespread importance, knowledge of fonio's evolution, origin, distribution, and genetic diversity remains scant even within West Africa itself. The crop has received but a fraction of the attention accorded to sorghum, pearl millet, and maize, and a mere trifle considering its importance in the rural economy and its potential for increasing the food supply. (In fact, despite its value to millions only 19 brief scientific articles have been published on fonio over the past 20 years.)

Part of the reason for this neglect is that the plant has been misunderstood by scientists and other decision makers. In English, it has usually been referred to as "hungry rice," a misleading term originated by Europeans who knew little of the crop or the lives of those who used it.(1) (1) Information from J. Harlan. In Nigeria it is usually called "acha."

Unbeknownst to these outsiders, the locals were harvesting fonio not because they were hungry, but because they liked the taste. Indeed, they considered the grain exotic, and in some places they reserved it particularly for chiefs, royalty, and special occasions. It also formed part of the traditional bride price. Moreover, it is still held in such esteem that some communities continue to use it in ancestor worship.

Not only does this crop deserve much greater recognition, it could have a big future. It is one of the world's best-tasting cereals. In recent times, some people have made side-by-side comparisons of dishes made with fonio and common rice and have greatly preferred the fonio.

Fonio is also one of the most nutritious of all grains. Its seed is rich in methionine and cystine, amino acids vital to human health and deficient in today's major cereals: wheat, rice, maize, sorghum, barley, and rye. This combination of nutrition and taste could be of outstanding future importance. Most valuable of all, however, is fonio's potential for reducing human misery during "hungry times."

Certain fonio varieties mature so quickly that they are ready to harvest long before all other grains. For a few critical months of most years these become a "grain of life." They are perhaps the world's fastest maturing cereal, producing grain just 6 or 8 weeks after they are planted. Without these special fonio types, the annual hungry season would be much more severe for West Africa. They provide food early in the growing season, when the main crops are still too immature to harvest and the previous year's production has been eaten.

Other fonio varieties mature more slowly - typically in 165-180 days. By planting a range of quick and slow types farmers can have grain available almost continually. They can also increase their chances of getting enough food to live on under even the most changeable and unreliable growing conditions.

Of the two species' white fonio (Digitaria exilis) is the most widely used. It can be found in farmers' fields from Senegal to Chad. It is grown particularly on the upland plateau of central Nigeria (where it is generally known as "acha") as well as in neighboring regions.

The other species, black fonio (Digitaria iburua), is restricted to the Jos-Bauchi Plateau of Nigeria as well as to northern regions of Togo and Benin. Its restricted distribution should not be taken as a measure of relative inferiority: black fonio may eventually have as much or even greater potential than its now better-known relative.

PROSPECTS

Unlike finger millet, African rice, sorghum, and other native grains, fonio is not in serious decline. Indeed, it is well positioned for improved production. First, it is still widely cultivated and is well known. Second. it is highly esteemed. (In Nigeria's Plateau State, for example, the present 20,000-ton production is only a quarter of the projected state demand. Third, it tolerates remarkably poor soil and will grow where little else succeeds. These are good underpinnings for fonio's future advancement.

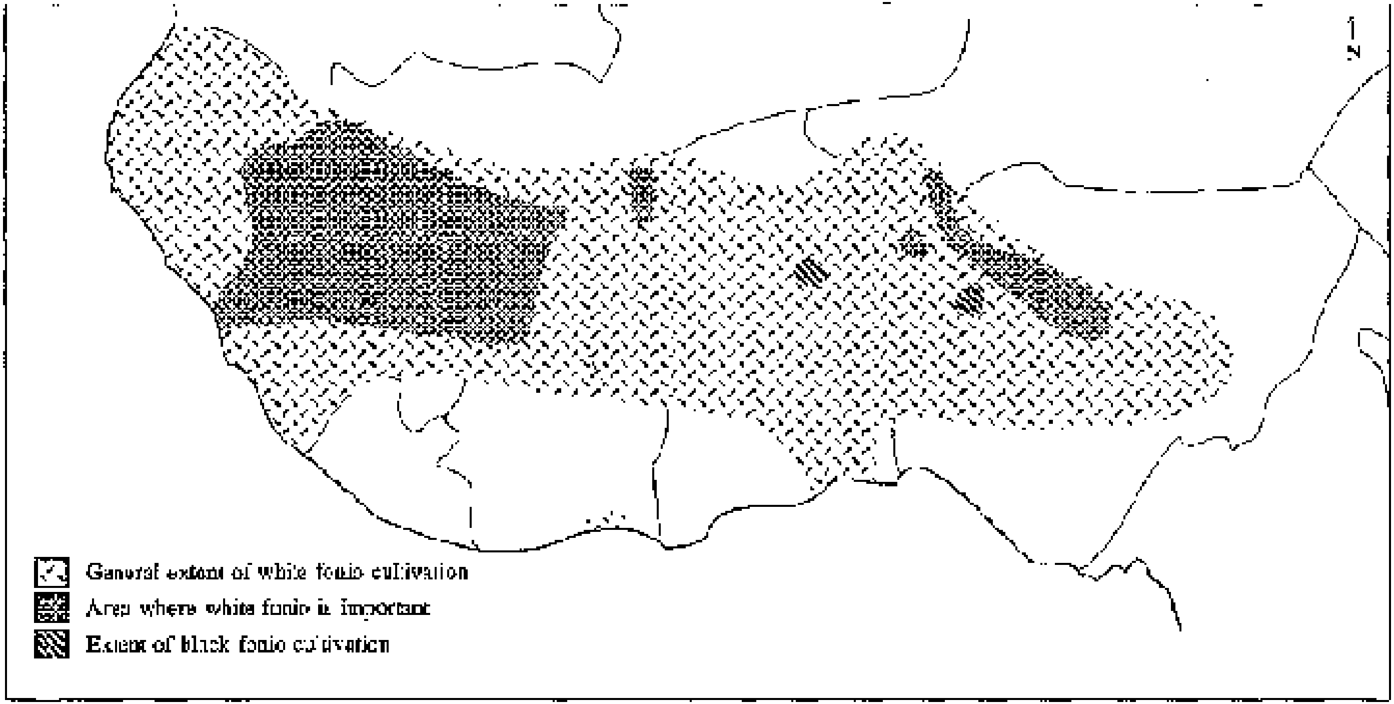


FIGURE: For a crop that is so little known to science, fonio is surprisingly widely grown. It is employed across a huge sweep of West Africa, from the Atlantic coast almost to the boundary with Central Africa.

Africa

Humid Areas Low prospects. Fonio is mainly a plant of the savannas and is probably ill adapted to lowland humid zones. It seems likely to succumb to various fungal and bacterial diseases. However, white fonio does grow around the Gola Forest in southeastern Sierra Leone, and black fonio is reportedly cultivated in Zaire and some other equatorial locations. These special varieties (occasionally misnamed as Digitaria nigeria) are possibly adapted to hot and humid conditions.

Dry Areas High prospects. People in many dry areas of West Africa like fonio. They know that it originated locally, and they have long-established traditions for cultivating, storing, processing, and preserving it. During thousands of years of selection and use, they have located types well adapted to their needs and conditions. Although the plant is not as drought resistant as pearl millet, the fast-maturing types are highly suited to areas where rains are brief and unreliable.

Upland Areas Excellent prospects. Fonio is the staple of many people in the Plateau State of Nigeria and the Fouta Djallon plateau of Guinea, both areas with altitudes of about 1,000 m.

Other Regions

This plant should not be moved out of its native zones. In more equable parts of the world it might become a serious weed.

USES

Fonio grain is used in a variety of ways. For instance, it is made into porridge and couscous, ground and mixed with other flours to make breads, popped, and brewed for beer. It has been described as a good substitute for semolina - the wheat product used to make spaghetti and other pastas.

In the Hausa region of Nigeria and Benin, people prepare a couscous (wusu-wusu) out of both types of fonio. In northern

Togo, the Lambas brew a famous beer (tchapalo) from white fonio. In southern Togo, the Akposso and Akebou peoples prepare fonio with beans in a dish that is reserved for special occasions.

Fonio grain is digested efficiently by cattle, sheep, goats, donkeys, and other ruminant livestock. It is a valuable feed for monogastric animals, notably pigs and poultry, because of its high methionine content.

The straw and chaff are also fed to animals. Both make excellent fodder and are often sold in markets for this purpose. Indeed, the crop is sometimes grown solely for hay.

The straw is commonly chopped and mixed with clay for building houses or walls. It is also burned to provide heat for cooking or ash for potash.

NUTRITION

In gross nutritional composition, fonio differs little from wheat. In one white fonio sample' the husked grain contained 8 percent protein and I percent fat. In a sample of black fonio, a protein content of 11.8 percent was recorded.

The difference lies in the amino acids it contains. In the white fonio analysis, for example, the protein contained 7.3 percent methionine plus cystine. The amino acid profile compared to that of whole-egg protein showed that except for the low score of 46 percent for lysine, the other scores were high: 72 for isoleucine; 90-100 for valine, tryptophan, threonine, and phenylalanine; 127 for leucine; 175 for total sulfur; and 189 percent for methionine.

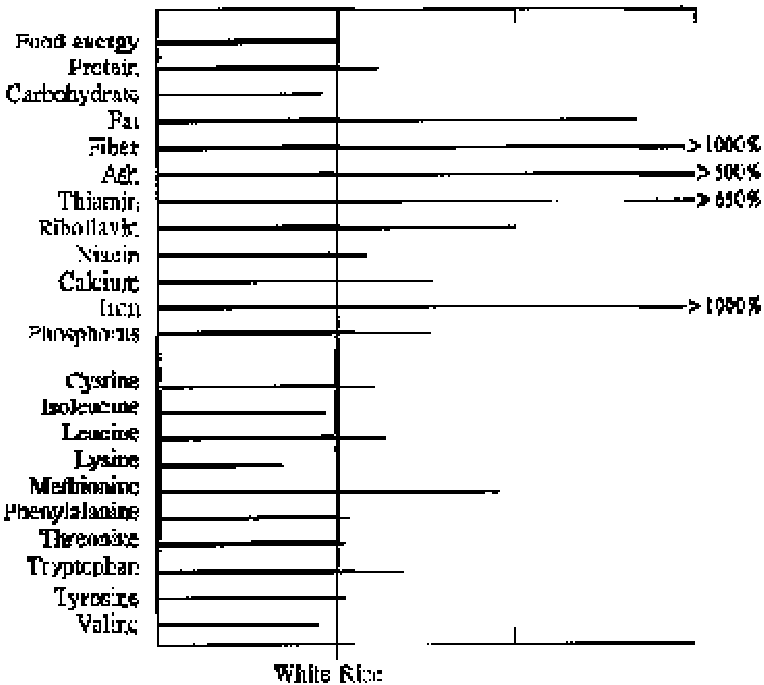
This last figure means that fonio protein contains almost twice as much methionine as egg protein contains. Thus, fonio has important potential not only as survival food, but as a complement for standard diets.

NUTRITIONAL PROMISE

Main Components		Essential Amino Acids	
Moisture	10	Cystine	2.5
Food energy(Kc)	367	Isoleucine	4.0
Protein(g)	9.0	Leucine	10.5
Carbohydrate(g)	75	Lysine	2.5
Fat(g)	1.8	Methionine	4.5
Fiber(g)	3.3	Phenylalanine	5.7
Ash(g)	3.4	Threonine	3.7
Thiamin(mg)	0.47	Tryptophan	1.6
Riboflavin(mg)	0.10	Tyrosine	3.5
Niacin(mg)	1.9	Valine	5.5
Calcium (mg)	44		
Iron (mg)	8.5		
Phosphorus (mg)	[illegible]		

Phosphorus (mg)	177		

COMPARATIVE QUALITY



FIGURE

AGRONOMY

Fonio is usually grown on poor, sandy, or ironstone soils that are considered too infertile for pearl millet, sorghum, or other cereals. In Guinea's Fouta Djallon region, where fonio is common, the soils are acidic clays with high aluminum content - a combination toxic to most food crops. It is generally grown just like upland rice, and the two are frequently produced by the same farmers. Normally, the seed is broadcast and covered by a light hoeing. It germinates in 3-4 days and grows very rapidly. This quick establishment and the heavy seeding rate (usually 10-20 kg of seed per hectare) ensures that the fields seldom need weeding. In a few cases the crop is transplanted from seedbeds to give it an even better chance at surviving the harsh conditions.

In Sierra Leone, and probably elsewhere, fonio is often grown following, or even instead of, wetland rice. This is done particularly when the season proves too dry for good paddy production and the farmers decide to give up on the rice. Fonio thus serves as an insurance against total crop failure.

In certain areas, fonio may sometimes be planted together with sorghum or pearl millet. Indeed, it is frequently the staple, while the other two are considered reserves. Commonly, farmers in Guinea sow multiple varieties of fonio and then later fill in any gaps with fastmaturing varieties of guinea millet (Brachiaria deflexa).

HARVESTING AND HANDLING

Fonio grain is handled in traditional ways. The plants are usually cut with a knife or sickle, tied into sheaves, dried, and stored under cover. Good yields are normally 600-800 kg per hectare, but more than 1,000 kg per hectare has been recorded. In marginal areas, yields may drop to below 500 kg and on extremely poor soils may be merely 150-200 kg per hectare.

Traditionally, the grain is threshed by beating or trampling, and it is dehulled in a mortar. This is difficult and time-consuming.

The seed stores well.

LIMITATIONS

Because of the lack of attention, fonio is still agronomically primitive. It suffers from small seeds, low yields, and some seed shattering.

The plant responds to fertilizers, but most types are so spindly that fertilization makes them top-heavy and they may blow over (lodge).

Birds may badly damage the crop in some areas; bird-scaring is usually necessary in those locations. The plants are also susceptible to smut and other fungal diseases.

It has been reported that fonio causes soil deterioration, but this appears to be a misperception. It is often sown on worn-out soils, sometimes even after cassava (the ultimate crop for degraded lands elsewhere). It is this association with poor soils that has given rise to the rumor, but the soils were in fact impoverished long before the fonio was put in.

Some groups dislike black fonio because, compared with the white form, it is more difficult to dehusk with the traditional pestle.

The seed loses its viability after two years.

Because of its small seed size, the harvest is very difficult to winnow. Sand tends to remain with the seed and produces gritty foods. It is therefore necessary to thresh fonio on a hard surface rather than on bare ground. Also, just before cooking, the grains are usually washed to rid them of any remaining sand.

Fonio: It's Not Just a Famine Food

Late in 1990, 1 interviewed a farmer with a largish plot of fonio. It was just a few kilometers from Bo town, in central Sierra Leone. What especially intrigued me was that this was not, as I at first supposed, a poverty-stricken woman's attempt to grow a little food for household subsistence. It was instead a commercial venture, aimed at the Bo market. There, fonio sells (cup for cup) at a better price than rice. By selling her crop she would be able to buy a larger amount of rice. To me, this was a striking confirmation of the commercial potential of this almost entirely neglected crop. To the people who know it, fonio is treasured more highly than rice!

Paul Richards

NEXT STEPS

Clearly, fonio is important, has many agronomic and nutritional virtues, and could have an impressive future. This crop deserves much greater attention. Modern knowledge of cereal-crop improvement and dedicated investigations are likely (at modest cost) to make large advances and improvements. Yields can almost certainly be raised dramatically, farming methods made less laborious, and markets developed - all without affecting the plant's resilience and reliability. These results, and more, are likely to come about quickly once fonio becomes as important to the world's scientists as it is to West Africa's farmers.

Promotion General activities to raise awareness of this crop's value and potential include a monograph, a newsletter, a "friends of fonio" society, a fonio cookbook, a series of fonio cook-offs, and fonio conferences. These could be complemented by publicity, seed distributions, and experiments to test fonio's farm qualities and cultivation limits.

It should not be too difficult to generate excitement for this "lost gourmet food of the great ancestors." It might prove a good basis for recreating traditional cuisines. Even export as a highly nutritious specialty grain is a possibility.

Scientific Underpinnings Despite its importance, fonio is a crop less than halfway to its potential. There have been few, if any, attempts to optimize, on a scientific basis, the process of growing it. Its taxonomy, cultivation, nutritional value, and time to harvest are only partially documented. Varieties have neither been compared, nor their seed even collected, on a systematic basis. Little or no research has been done on postharvest deterioration, storage, or preservation methods.

Germplasm Collection An early priority should be to collect germplasm. Varieties are particularly numerous in the Fouta Djallon Plateau in Guinea and around the upper basins of the Senegal and Niger Rivers. Among these will certainly be found some outstanding types. This alone seems likely to lead to better cultivars that will bring marked advances in fonio production. The collection should also be screened to determine if yield is limited by viruses. If so, the creation of virus-free seed might also boost yields dramatically.

Seed Size The smallness of the grain offers a special challenge to cereal scientists: can the seeds be enlarged - perhaps through selection, hybridization, or other genetic manipulation?

Yield The cause of the low yields needs investigation. Is it because of the sites, diseases and pests, poor plant architecture, inefficient root structure, lodging, poor tillering, bolting, or daylength restrictions? What are optimum conditions for maximum yields? Can fonio's productivity approach that of the better-known cereals?

Grain Quality Cereal chemists should analyze the grains. What kinds of proteins are present? What are the amino-acid profiles of the different proteins? Nutritionists should evaluate the biological effectiveness of both the grains and the products made from them. There are probably happy surprises waiting to be discovered. In particular, protein fractionation is likely to turn up fractions with methionine and cystine levels even greater than fonio's already amazingly high average.

The exceptional content of sulfur amino acids (methionine plus cystine) should make fonio an excellent complement to legumes. Feeding studies to verify this are in order. The combination could be nutritionally outstanding.

Cytogenetics As a challenge to geneticists, fonio has a special fascination. It has no obvious wild ancestor. That it appears to be a hexaploid (2n=6x=54) may help account for this. Does it, in fact, contain three diploid genomes of different origin? What are its likely ancestors, and might they be used to increase its seed size and yield?

Plant Architecture Lodging is a serious drawback, especially when the soil is fertile. This may be overcome by dwarfing the plant or endowing stronger stems by plant breeding. How "free-tillering" are the various types?

Other Uses Certain other Digitaria species are cultivated exclusively as fodder, whereas some are notable for their soil-binding properties and ability to produce an excellent turf. Is fonio also useful for such purposes? Could it, too, become a valuable all-purpose plant for many regions? Could improved fonio be "naturalized" in the northern Sahel to increase the availability of wild grain to nomadic groups'?

Sociocultural Factors How is the crop currently cultivated, distributed, and processed? What roles are played by social and cultural factors such as the division of labor, traditional beliefs, and people's expectations? (Fonio, after all, is seldom if ever grown under optimum conditions.) Its promotion will succeed best in West Africa if its development is placed within such local constraints.

Processing The processing and cooking of this crop is extremely arduous. Unless this can be relieved, fonio will probably never reach its potential.

SPECIES INFORMATION

Botanical Names Digitaria exilis Stapf and Digitaria iburua Stapf Black fonio has been known to science only since 1911, when a botanist recognized that what was growing in fields with pearl millet in the Zaria region of northern Nigeria was a species new to science.

Synonyms Paspalum exile Kippist; Panicum exile (Kippist) A. Chev.; Syntherisma exilis (Kippist) Newbold; Syntherisma iburua (Stapf) Newbold (for Digitaria iburua)

Common Names

English: hungry rice, hungry millet, hungry koos, fonio, fundi millet French: fonio, petit mil (a name also used for other crops)

Fulani: serm, foinye, fonyo, fundenyo
Bambara: fini
Nigeria: ache (Digitaria exilis, Hausa); iburu (Digitaria iburua, Hausa); aburo
Senegal: eboniaye, efoleb, findi, fundi The Gambia: findo (Mandinka)
Togo: (Digitaria iburua); afio-warun (Lamba); ipoga (Somba, Sampkarba); fonio ga (black fonio); ova (Akposso)
Mali: fani, fend, founde
Burkina Faso: fond
Guinea: pence, kpendo, founie, pounie Benin: podgi
Ivory Coast: pom, pohin

Description

As noted, there are actually two species of fonio. Both are erect, free-tillering annuals. White fonio (Digitaria exilis) is usually 3-75 cm tall. Its finger-shaped panicle has 2-5 slender racemes up to 15 cm long. Black fonio (Digitaria iburua) is taller and may reach 1.4 m. It has 2-11 subdigitate racemes up to 13 cm long.

Although both species belong to the same genus, crossbreeding them seems unlikely to yield fertile hybrids, as they come from different parts of the same genus.

The grains of both species range from "extraordinarily" white to fawn yellow or purplish. Black fonio's spikelets are reddish or dark brown. Both species are more-or-less nonshattering.

Fonio as Fast Food

As noted elsewhere (especially in Appendix C), a lack of processed products is holding back Africa's native grains. One grass-roots organization is doing something about this: it is turning fonio into a convenience food.

In southern Mali, fonio is mainly grown by women on their individual plots. Perhaps not unexpectedly, then, it is a women's group that has chosen to foster the grain's greater use. The group aims to raise fonio consumption by producing a precooked flour.

The project, backed by the Malian Association for the Promotion of the Young (AMPJ), is staffed and run entirely by women. Their goal is a fast-cooking fonio that will challenge parboiled rice and pre-packaged pasta (both of which are usually imported) in the Bamako markets.

The new "instant" fonio comes in 1-kg plastic bags and is ready for use. It requires no pounding or cleaning. It can be used to prepare all of the traditional fonio dishes. It is simple to store and handle. It is clean and free of hulls and dirt. And it requires less than 15 minutes to cook. For the user, then, it offers an enormous saving in both effort and time.

The project is currently a small one, designed to handle 6 tons of raw fonio per year. It uses local materials, traditional techniques, and household equipment: mortars, tubs, calabashes, steaming pots, sieves, matting, kitchen scales, and small utensils. The women sieve, crush, wash, and steam-cook the fonio; then they dry and seal the product in the airtight bags. The most delicate operation is a series of three washes to separate sand from the fine fonio grains.

The women have organized themselves into small working groups, formed for (1) the supply of raw materials, (2) production and packaging, and (3) marketing.

Fonio is considered a prestige food in local culinary customs. Yet, on the Bamako market this precooked product currently sells at a very competitive price: between 500 and 550 CFA Francs per kg. (By comparison, couscous sells at 650-750 CFA Francs.)

This small and homespun operation exemplifies what could and should be done with native grains throughout Africa. It is good for everyone: diversifying the diet of city folks, reducing food imports, and, above all, benefitting the local farmers by giving them a value-added product.

Distribution

Fonio is grown as a cereal throughout the savanna zone from Senegal to Cameroon. It is one of the chief foods in Guinea-Bissau, and it is also intensively cultivated and is the staple of many people in northern Nigeria. Fonio is not grown for food outside West Africa.

Cultivated Varieties

There are no formal cultivars as such, but there are a number of recognized landraces, mainly based on the speed of maturity.

Environmental Requirements

Daylength Flowering is apparently insensitive to daylength.

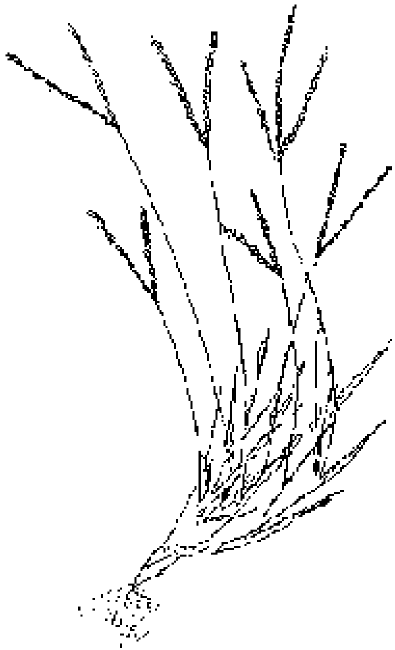
Rainfall Fonio is extremely tolerant of high rainfall, but not - on the whole - of excessive dryness. The limits of cultivation (depending on seasonal distribution of rainfall) are from about 250 mm up to at least 1,500 mm. The plant is mostly grown where rainfall exceeds 400 mm. By and large, the precocious varieties are cultivated in dry conditions and late varieties in wet conditions.

Altitude Although fonio is grown at sea level in, for instance, Sierra Leone, the Gambia, and Guinea-Bissau, its cultivation frequently is above 600 m elevation.

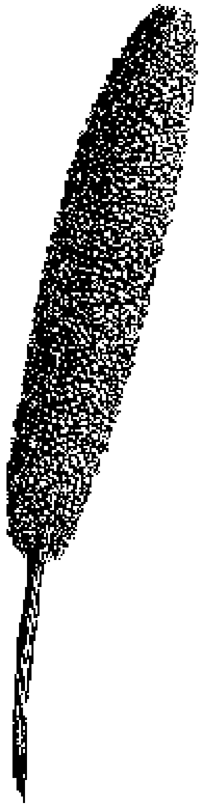
Low Temperature Unreported.

High Temperature Unreported.

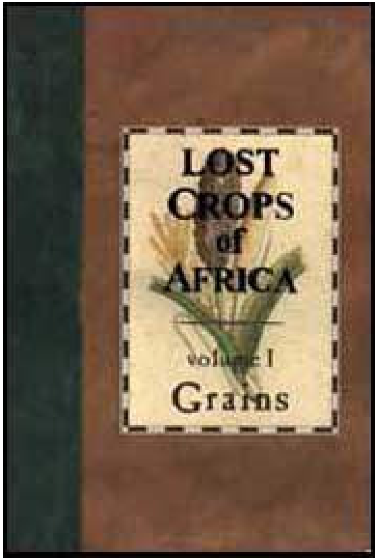
Soil Type It is grown mainly on sandy, infertile soils. It can, however, grow on many poor, shallow, and even rocky soils. Most varieties do poorly on heavy soils. However, by working with a range of varieties, one can generally adapt the crop to almost all terrains and exposures; for example, to fertile or unproductive conditions: sandy, limy, gravelly, or pebbly soils; slopes; plateaus; valleys; or riverbanks.



FIGURE



FIGURE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4. Pearl Millet

Of all the world's cereals, pearl millet (Pennisetum glaucum) is the sixth most important.

Descended from a wild West African grass, it was domesticated more than 4,000 years ago, probably in what is now the heart of the Sahara Desert. Long ago it spread from its homeland to East Africa and thence to India. Both places adopted it eagerly and it became a staple.

Today, pearl millet is so important that it is planted on some 14 million hectares in Africa and 14 million hectares in Asia. Global production of its grain probably exceeds 10 million tons a year, to which India contributes nearly half. At least 500 million people depend on pearl millet for their lives.

Despite its importance, however, pearl millet can be considered a "lost" crop because its untapped potential is still vast. Currently, this grain is an "orphan" among the significant cereals. It is poorly supported by both science and politics. In fact, few people outside of India and parts of Africa have ever heard of it. As a result, it lags behind sorghum and far behind the other major grains in its genetic development. For instance, its average yields are barely 600 kg per hectare and it is almost entirely a subsistence crop; perhaps for this last reason alone pearl millet has attracted little research or industrial support.

Indeed, largely due to neglect, pearl millet is actually slipping backwards. Production in West Africa during the last two decades has increased by only 0.7 percent a year - the lowest growth rate of any food crop in the region and far less than the population's growth rate. Furthermore, even this meager increase has been mainly due to expanding the area cultivated rather than to boosting yields. Elsewhere in Africa the decline has been even more dramatic. Just 50 years ago, pearl millet was of almost incalculable value to millions of rural people in eastern and southern Africa. But over the decades, more and more farmers - especially in southern Africa - have abandoned it and switched to maize.

There are several reasons for this. For one thing, international research efforts have made maize more productive than pearl millet; for another, government incentives have given maize an added financial advantage; and for a third, easier processing has made maize more convenient to use. The momentum for change has now gone so far that maize is often pushed into pearl millet areas to which it is poorly suited and where it cannot perform reliably.

Now, however, a new era may be dawning. Pearl millet is supremely adapted to heat and aridity and, for all its current decline, seems likely to spring back as the world gets hotter and drier. Perhaps the best of all "life-support" grains, pearl millet thrives where habitats are harsh. Of all the major cereals, it is the one most able to tolerate extremes of heat and drought. It yields reliably in regions too hot and too dry to consistently support good yields of maize (or even sorghum). These happen to be the regions most desperately in need of help.

It is there that the famines of recent decades have brought mass devastation and death. It is there that expanding deserts are destroying the productivity of perhaps 25 million hectares every year. And it is there that agricultural development could have its greatest humanitarian benefits.

These reasons alone should be sufficient to make pearl millet the target of a global initiative.

But this crop has even more promise. Rising climatic temperatures are starting to concern almost all countries. And water is shaping up as the most limiting resource for dozens of the world's nations - including some of the most advanced. Agriculture is usually a country's biggest user of water, so that crops that sip, rather than gulp, moisture are likely to be in ever greater demand. Thus, even for economies that until now never heard of it, pearl millet could quickly become a vital resource.

Agronomically, there is no reason why pearl millet could not (like sorghum) become used worldwide. Indeed, recent research in the United States is showing that its prospects are much higher than most people now think. Already, the crop is showing promise for the heartland of America. It might also become widely used in the hotter and drier parts of Latin America, Central Asia, and the Middle East. It could have a bright future in dry areas of Australia and other countries as well.

FIGURE: Pearl-millet-growing areas in Africa. There are an estimated 14 million hectares of millet in this zone, making it the third most widely grown crop in sub-Saharan Africa. The plant was probably domesticated some 4,000-5,000 years ago along the southern margins of the central highlands of the Sahara. It has since become widely distributed across the semiarid tropics of Africa and Asia. Today, approximately one-third of the world's millet is grown in Africa, about 70 percent of it in West Africa. Africa's major pearlmillet producing countries include Nigeria, Niger, Burkina Faso, Chad, Mali, Mauritania, and Senegal in the west; Sudan and Uganda in the east. In southern Africa, the commercialization of agriculture has resulted in maize partially or completely displacing this traditional food crop. (ICRISAT, 1987; each dot represents 20,000 hectares)

Pearl millet is easy to grow. It suffers less from diseases than sorghum, maize, or other grains. Also, it has fewer insect pests.

The widespread impression that pearl millet grain is essentially an animal feed, unpalatable to all but the desperately hungry, is wrong. The grain is actually a superior foodstuff, containing at least 9 percent protein and a good balance of amino acids. It has more oil than maize and is a "high-energy" cereal. It has neither the tannins nor the other compounds that reduce digestibility in sorghum.

Pearl millet is also a versatile foodstuff. It is used mainly as a whole, cracked, or ground flour; a dough; or a grain like rice. These are made into unfermented breads (roti), fermented foods (kisra and gallettes), thin and thick porridges (toh), steam-cooked dishes (couscous); nonalcoholic beverages, and snacks.

Grain from certain cultivars is roasted whole and consumed directly. The staple food of the mountainous regions in Niger is millet flour mixed with dried dates and dried goat cheese.

This nutritious mixture is taken on long journeys across the Sahara and eaten mixed with water - no cooking required.

Grain from other types is used to make traditional beer. In Nigeria, it is fermented, like maize or sorghum, to produce ogi - a traditional weaning food that is still common.

In future, pearl millet may be used in many more types of foods. The fact that it can be made into products resembling those normally produced from wheat or rice should make it acceptable to many more people.

With new technology, there seem to be possibilities of using it even to make raised breads (see Appendix C).

All this is not to say that pearl millet is perfect. Indeed, the crop has several serious problems. For one, the raw grain is difficult to process. Many consumers decorticate (dehull) the grain before grinding it into various particle sizes for use in different products. Dehulling by traditional hand pounding produces low yields of flour (around 75 percent) and the product has poor storage stability.

Despite these impediments, this plant's promise is so great that we have devoted the following two chapters to its various types. The next chapter highlights its promise for subsistence farmers -

the millions in Africa and Asia to whom pearl millet means life itself.

The subsequent chapter highlights commercial pearl millets - the types that are increasingly grown by farmers who produce a surplus to sell.

Bajra

About 3,000 years ago pearl millet crossed the Indian Ocean and became a vital contributor to South Asia's food supplies. Today it is India's fourth most important cereal, surpassed only by rice, wheat, and sorghum. Bajra, as it is called, is currently grown on almost 10 percent of India's food-grain area, and it yields about 5 percent of the country's cereal food.

Rajasthan, Maharashtra, Gujarat, and Uttar Pradesh account for nearly 80 percent of the 14 million hectares planted and 70 percent of the 5 million tons of pearl millet grain produced each year.

India's farmers grow some pearl millet under irrigation during the hot, dry months and routinely reap harvests as high as 3 or 4 tons per hectare. But most grow it in the arid areas, particularly where the rainfall is just insufficient for sorghum or maize. Here, the soils are usually depleted in fertility and there is no irrigation. Some plots receive as little as 150 mm of rainfall per year. But pearl millet survives and produces food.

FIGURE: Baira-growing areas in the Subcontinent. (ICRISAT, 1987; each dot represents 20,000 hectares)

Indians commonly grind pearl millet and make the flour into cakes or unleavened bread (chapati). Some goes into porridges, which may be thin or thick. Much is cooked like rice.

The grain is sometimes parched and eaten, the product (known as akohi, bhunja, lahi, or phula) being similar to popcorn. In some regions, the green ears are also roasted and eaten like a vegetable.

Although small quantities of the grains are used for feeding cattle and poultry, the plant is more often fed to animals as a green fodder. It is well suited for this purpose because it is quickgrowing, tillers very freely, lends itself to multiple cutting, and usually has thin and succulent stems.

All in all, pearl millet is not a neglected crop in India. Authorities realize that it stabilizes the nation's food basket. Improved strains, suited to various regions, have been created and released for cultivation. Indeed, its potential is being increasingly exploited, especially as the swelling population requires increased cultivation of marginal land.

Let Them Eat Millet Bread

Millet once played a greater role in the world of cereals for many rural people in eastern and southern Africa, but it has declined in importance over the last 30-50 years because of a preference for maize.

The decline has been compounded by increased research on maize leading to greater productivity of the crop and by the incentives given to maize production through government policies. Maize has been grown, as a result, in dry conditions to which it is not adapted and it has failed too often in these conditions. Governments have come to realize this as well as the farmers themselves.

So it is now necessary to reestablish the importance of millet and sorghum in these drier areas and to do so we must make the production of these crops attractive enough so that they can compete with maize, not only in the worst and most severe droughts but in at least a majority of years. Here is work for the scientists in millet.

But in the long run, even in Africa, maize is not the problem at all. The problem is wheat, or more correctly, bread. Politicians are going to give the people bread. They have been saying this for a long, long time, and they mean it. Technocrats may decry this trend, particularly in tropical areas where wheat cannot be grown satisfactorily, but I can assure you that the protestations will be to little avail. They may slow the process down but they will not stop it.

The people of the cities want bread, and the elected officials will ensure that they get it. The people are already exposed to bread and they will ask for it, they will insist upon it, and they will get it.

In many tropical countries it will be very expensive to satisfy this demand unless millet can become bread. And this, too, the politicians recognize and they will support this demand whether efforts can be made to decrease the cost of giving people the food that they demand. So here is something else for the millet scientists to do. Don't ask me how you do it. You know far better than I do. I am just telling you it's got to be done.

From an address by L.D. Swindale
Former Director-General, ICRISAT

NUTRITION

Pearl millet's average composition is given in the tables on the following pages. Some highlights are summarized below.

Carbohydrates usually make up about 70 percent of the dry grain, and they consist almost exclusively of starch. The starch itself is composed of about two-thirds amylopectin (the insoluble component that forms a paste in water at room temperature) and one-third amylose (the soluble component that forms a gel in aqueous solution).

Measurements made on several hundred types have shown that the protein ranges from 9 to 21 percent, with a mean of 16 percent. However, the varieties now used in farm practice have an average of about 11 or 12 percent. Of the different protein types, prolamine constitutes 40 percent and globulins 20 percent; the presence of an albumin has been also reported, but no gluten. The protein's biological value and digestibility coefficient have been measured as 83 percent and 89 percent, respectively. The protein efficiency ratio has been found to be 1.43, which is even better than that of wheat (1.2).

The grain has about 5 percent fat, roughly twice the amount found in the standard cereals. It is composed of about 75 percent unsaturated and 24 percent saturated fatty acids.

The vitamin values of pearl millet grain are generally somewhat lower than those of maize, although the level of vitamin A is quite good. The carotene value is also good - for a cereal.

Of the grain's edible portion, ash comprises about 3 percent, an amount somewhat higher than in wheat, rice, or maize. The various mineral constituents, accordingly, tend to occur in greater quantities as well. Compared with maize, phosphorus (average 339 ma) is half again as much, iron (average 9.8 ma) is more than three times, and calcium (average 37 ma) is more than five times as much. Traces of barium, chromium, cobalt, copper, lead, manganese, molybdenum, nickel, silver, strontium, tin, titanium, vanadium, zinc, and iodine have also been noted.

In feeding teals, pearl millet has proved nutritionally superior to rice and wheat. A review of research in India states that a diet based on pearl millet and pulses is somewhat better at promoting human growth than a similar diet based on wheat. In one trial, for instance, researchers made up vegetarian diets typical of those eaten by the poor. When pearl millet partially or completely replaced rice, the nutritive value increased appreciably.

Studies conducted on children showed that all the subjects fed diets based on pearl millet maintained positive balance with respect to nitrogen, calcium, and phosphorus. The protein's apparent digestibility was about 53 percent, an amount close to that for finger millet and sorghum proteins, but less than that of rice protein (65 percent). It was also found that pearl millet could replace 25 percent of the rice in a child's diet without reducing the amount of nitrogen, calcium, or phosphorus its body absorbed.

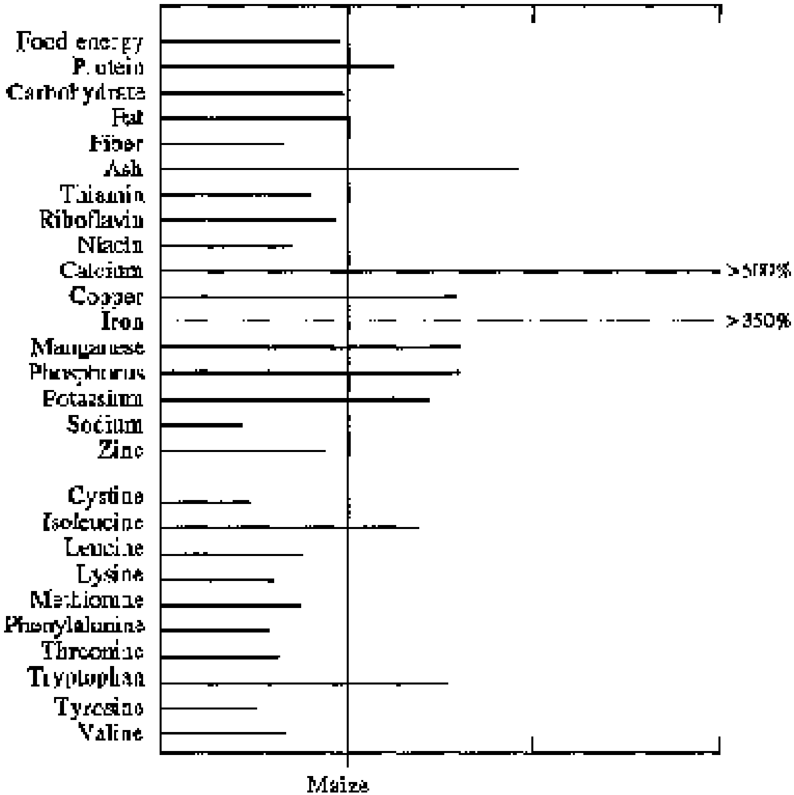
NUTRITIONAL PROMISE

Main Components		**Essential Amino Acids**	
Moisture (g)	10	Cystine	1.8
Food energy (Kc)	353	Isoleucine	3.9
Protein (g)	11.8	Leucine	9.5
Carbohydrate (g)	70	Lysine	3.2
Fat (g)	4.8	Methionine	1.8

Fiber (g)	1.9	Phenylalanine	4.1
Ash (g)	2.3	Threonine	3.3
Vitamin A (RE)	22	Tryptophan	1.4
Thiamin (mg)	0.31	Tyrosine	3.0
Riboflavin (mg)	0.19	Valine	4.9
Niacin (mg)	2.6		
Calcium (mg)	37		
Chloride (mg)	43		
Copper (mg)	0.5		
Iron (mg)(a)	9.8		
Magnesium (mg)	114		
Manganese (mg)	0.8		
Molybdenum (pa)	190		
Phosphorus (mg)	339		
Potassium (mg)	418		

Potassium (mg)	[illegible]		
Sodium (mg)	15		
Zinc (mg)	2.0		

(a)Values range from 1.0-20.7 ma.



FIGURE

The pearl millet grain is nutritious. It has no husk, no tannin, contains 5-7 percent oil' and has higher protein and energy levels than maize or sorghum. The unsaturated fatty acids making up the oil are oleic (20-31 percent), linoleic (40-52 percent), and linolenic (2-5 percent). The saturated fatty acids are palmitic (18-25 percent) and stearic (28 percent).

In general, pearl millet has a higher protein content than other cereals grown under similar conditions. In 180 pearl millet lines tested in 1972, protein contents ranged from 9 to 21 percent with a mean of 16 percent. It has an excellent amino acid profile and, depending on the variety and perhaps on the growing conditions, the levels of the various amino acids making up the protein can vary by as much as a factor of two. In general, however, the reported values show higher tryptophan, threonine, and valine and lower leucine, but otherwise similar essential amino acids in pearl millet compared with grain sorghum. What is uncertain, however, is the digestibility of pearl millet protein. It is possible that the actual amount of digestible protein is less than that of other major grains.

SPECIES INFORMATION

Botanical Name Pennisetum glaucum (L.) R. Br.

Synonyms Pennisetum typhoides (Burm.f.) Stapf and Hubbard, P. americanum (L.) Leeke, P. spicatum Roem and Schult.

Common Names

Angola: massango
Arabic: duhun, dukhon
English: pearl millet, bulrush millet, cattail millet, candle millet
Ethiopia: bultuk (Oromo), dagusa (Amharic)
French: mil du Soudan, petite mil, mil
India: bajra, bajri, cumbu, sajje
Kenya: mi/mawele, mwere (Kikuyu) Mali: sanyo, nyo, gawri
Malawi: machewere (Ngoni), muzundi (Yao), uchewere, nyauti

(Tumbuka)
Niger: hegni (Djerma), gaouri (Peul), hatch) (Haussa) Nigeria: gero (Hausa), dauro, maiwa, emeye (Yoruba Shona: mhunga, mhungu
Sotho: nyalothi Sudan: dukhon Swahili: uwele, mawele Swati: ntweka
Zambia: mawele, nyauti, uchewele (Nyanja), bubele, kapelembe, isansa, mpyoli (Bemba)
Zimbabwe: mhunga (Chewa), u/inyawuthi (Ndebele) Zulu: amabele, unyaluthi, unyawoti, unyawothi

Description

Pearl millet is an erect annual, usually between 50 cm and 4 m tall. Tillering and branching are not uncommon and are sometimes profuse. The straw is coarse and pithy.

The numerous flowers are tucked tightly around a cylindrical spike (rachis) that can range in length from 15 to 140 cm. This inflorescence is usually greenish yellow, and it may be cylindrical throughout its length or may taper at one or both ends.

The flowers can be either cross-pollinated or self-pollinated. The female part (stigma) emerges before the male part is ready to shed its pollen.

As a result, cross-pollination normally occurs. However, where the timing overlaps, some self-pollination can occur.

Grain begins developing as soon as fertilization occurs and is fully developed 20-30 days later. The whole process, from fertilization to ripening, takes only about 40 days.

The seeds range in color from white to brown, blue, or almost purple. Most are slate gray.

They are generally tear shaped and smaller than those of wheat.

The average weight is about 8 ma. Some thresh free from glumes, while others require husking.

The seeds are quick to germinate. If conditions are favorable, they sprout in about 5 days.

Freshly harvested seed may not germinate immediately; however, a dormancy of several weeks after harvesting has been reported.

Pearl millet is a diploid (2n=14).

Distribution

The two vast areas of West and East Africa where pearl millet is prominent have already been mentioned.

Soon after its domestication, the crop became widely distributed across the semiarid tropics of both Africa (15 million hectares) and Asia (14 million hectares). Pearl millet first became known in Europe about 1566 when plants were raised in Belgium from seed said to have been received from India. This form, sometimes known as Pennisetum spicatum, is still grown in Spain and North Africa. Pearl millet was introduced into the United States at least as long ago as the 1850s.

Double Dip

Pearl millet's extremely deep roots can reach down into soil layers untapped by other plants. Tests in the southeastern United States have revealed that it can pull up nutrients from residues that have accumulated below the root zones of the previous farm crops.

This finding, should it prove more widely true, has profound implications. Much of the fertilizer now put on crops leaches past their roots where it is not only lost but becomes a pollutant. Having an annual crop that can scavenge the lower layers gives farmers a second shot at the (expensive) fertilizer as well as a tool for cleaning the environment. They might even make a profit from it by selling the pearl millet.

Cultivated Varieties

There are vast numbers of types, differentiated by features such as the following:

· Quick maturity (about 80 days), medium maturity (100 days or so), or slow maturity (180 days or more)
· Height
· Amount of tillering
· Stem thickness and branching
· Leaf size and hairiness
· Seedhead size, shape, and "tightness"
· Number, length, rigidity, brittleness, and hairiness of bristles
· Size, shape, and color of grain
· The degree to which the glume adheres to the grain.

For pearl millet, the bulk of the systematic breeding has been done in India, but substantial contributions have also come from several African countries, France, and the United States.

Most yield improvements have resulted from incorporating genes from African varieties into

Indian breeder stocks. However, a breakthrough came in the late 1950s when plants carrying cytoplasmic male sterility were discovered. This genetic trait made hybrids a practical possibility. Today, singlecross pearl-millet hybrids, using male-sterile seed parents, are the basis of vigorous private and semi-public seed industries, especially in India.

Environmental Requirements

Daylength Pearl millet is usually a short-day plant (see next chapter), but some varieties are daylength neutral.

Rainfall Although the crop is grown where rainfall ranges from 200 to 1,500 mm, most occurs in areas receiving 250-700 mm. The lowest rainfall areas rely mainly on early- maturing cultivars. Although very drought resistant, pearl millet requires its rainfall to be evenly distributed during the growing season. (Unlike sorghum, it cannot retreat into dormancy during droughts.) On the other hand, too much rain at flowering can also cause a crop failure.

Altitude Pearl millet is seldom found above 1,200 m in Africa, but occurs at much higher altitudes elsewhere (for instance, in western North America).

Low Temperature The plant is generally sensitive to low temperatures at the seedling stage and at flowering.

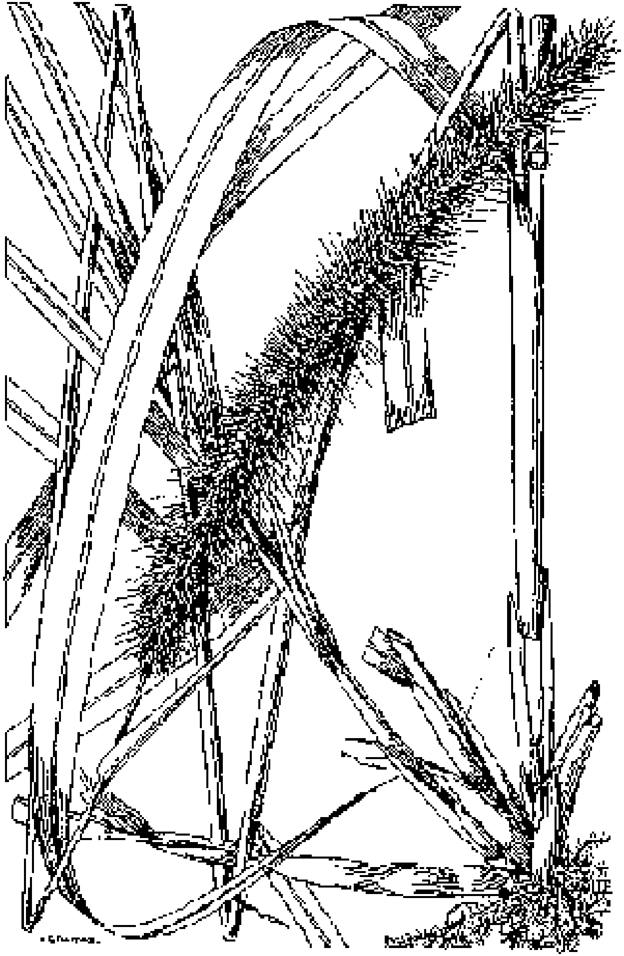
High Temperature High daytime temperatures are needed for the grain to mature. In Africa's pearl millet zone, temperatures are typically above 30°C.

Soil Type Like most plants, pearl millet does best in light, welldrained loams. It performs poorly in clay soils and cannot tolerate waterlogging. It is tolerant of subsoils that are acid (even those as low as pH 4-5) and high in aluminum content.

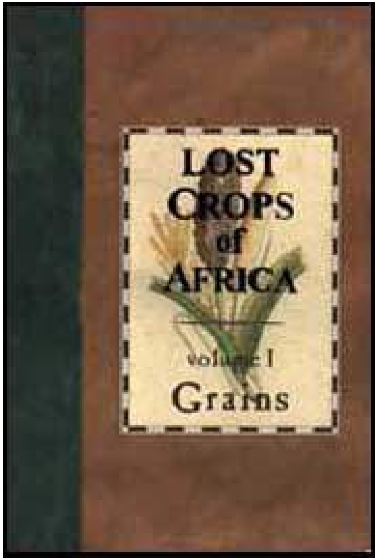
Related Species

Pearl millet has many relatives. A number are quite troublesome. In much of Africa, for instance, wild Pennisetum species manage to get their pollen in, and this cross-pollination quickly reduces the crop's productive capacity. The hybrid swarms of weedy "half-breeds" (called shibras in West Africa) are common contaminants in the farmer's crop. Whereas the cultivated races have broad-tipped persistent spikelets and large, mostly protruding grains, the wild species have narrower, pointed spikelets. Also, their grains are smaller, entirely enclosed by husks, and prone to fall out (shatter). Luckily, the weedy species did not accompany the crop to India.

Although hybridization and introgression between the crop plants and the wild relatives is a problem for farmers, it can be a blessing for plant breeders, giving rise to new forms both of the crop and of the weed.



FIGURE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5. Pearl Millet: Subsistence Types

Pearl millet is the staple of what is perhaps the harshest of the world's major farming areas: the arid and semiarid region stretching over 7,000 km from Senegal to Somalia (almost one-sixth of the way around the globe at that latitude). There, on the hot, dry, sandy soils, farmers produce some 40 percent of the world's pearl millet grain.

How to help these farmers - who live in the often drought-devastated zone on the edge of the world's biggest desert and who have no access to irrigation, fertilizer, pesticides, or other purchased inputs - is perhaps the greatest agricultural challenge facing the world. The answer may lie in their age-old staple, pearl millet.

Indeed, there is probably no better cereal to relieve the underlying threat of starvation in the

Sahel, the Sudan, Somalia, and the other dry lands surrounding the Sahara. Millions entrust their lives to this single species every day, and, of all the peoples on the planet, they are the ones most needing help. Yet, at the moment, pearl millet suffers from neglect and misunderstanding - in part because the crop grows in some of the poorest countries and regions and in some of the least hospitable habitats for humans (including research workers). People have thus unjustly stigmatized it as a poor crop, fit only for interim support while something better is located.

This chapter's purpose is to counter that misguided notion.

SUBSISTENCE MILLETS

Most pearl millets grown in Africa are necessarily oriented toward survival under harsh conditions rather than high yields.

For want of a better name, we have called them "subsistence types."

To any outsider used to the robust look of wheat, rice, or maize, subsistence pearl millets may seem puny, unproductive, and downright unworthy of consideration. To an agronomist or cereal breeder, they look particularly terrible. The plants perform poorly even when they are unstressed. They are tall and top-heavy; they are generally photosensitive; they exhibit low rates of fertilizer response; they have low harvest indexes; and they are localized in adaptation so that even the best of them cannot be easily moved around for use in other places. Above all, they are low yielding - averaging only around 500 kg per hectare.

In reality, though, subsistence pearl millets are some of the most remarkable food plants to be found anywhere. In the area of West Africa where pearl millet is paramount, the droughts can be fierce, the heat searing, and the rainstorms terrible. The sandstorms are even worse.

Early in the growing season, the ever-present winds increase in intensity and often swirl the soil so powerfully that it literally sandblasts the tender seedlings. Then, heated by the Sahara sun, the new-blown sand may "cook" the seedlings before they can grow tall enough to shade and cool the land around their roots. Finally, as the soil dries out, its surface often hardens into a crust so impenetrable that any surviving seeds cannot break through.

Because of conditions like these, crop failure is omnipresent and Sahelian farmers must repeat their sowings, often several times. But of all food crops, subsistence pearl millets tend to survive best - they sometimes survive even in bare Sahara sand dunes.

They are cereals for "base-line food security" and give the farmer the best chance of staying alive.

By and large, subsistence pearl millets can:

· Germinate at high soil temperatures;
· Germinate in crusted soil;
· Tolerate some sand blasting in the seedling stage;

· Yield grain at low levels of soil fertility;
· Resist downy mildew;
· Tolerate stem borer and head caterpillar; and
· Hold up reasonably well against the parasitic weed striga.

Few of the scientists' varieties could be relied upon to produce food under conditions of such uncompromising hostility.

Some of the "faults" perceived by outsiders are actually of great local importance, as the following examples show.

"The fact is, that after 40 years of [pearl] millet breeding. only one improved' line - CIVT - consistently surpasses (but not by much) local cultivars. Breeders' varieties routinely underperform local cultivars, even in on-station trials."

Farming on the Fringe

Pearl millet is the last cereal crop of arable farming on the edge of the desert - beyond it there is only pasturing and open grazing. There is not a more drought-tolerant cereal crop to relieve the threat of starvation. When it fails, nothing else can be substituted. Thus, millions are forced to entrust lives to this plant. It is not an easy bargain to make.

Most of Africa's pearl millet is grown where the danger of drought is ever present; where the landscape abruptly changes between the wet and dry seasons; where the rains are sometimes limited to only a month or two or three; and where utter aridity prevails the rest of the time.

It seems a cruel irony that the most destitute of people are forced to depend upon foods that they must produce for themselves in the harshest lands. But pearl millet has "rusticite," a

French term implying that it will produce something no matter what. Droughts, floods, locusts, diseases, and other hazards may hurt, but the plant produces food nonetheless. All other grains, on the other hand, are more vulnerable and more subject to complete collapse.

It is remarkable that any crop can cope with the sites where pearl millet is grown. Local cloudbursts can dump the year's precipitation in a few hours. On crusted and hard soils, such deluges result in massive rushing runoff, heavy erosion, and the nearly complete loss of desperately needed moisture. Earlyseason rains are preceded by severe dust storms that damage, bury, and desiccate tender emerging seedlings. Scorching heat can kill an entire crop before it becomes established.

Because of problems like these, the threat of crop failure is omnipresent. Farmers must repeat their sowings, often two or three times. Most sow more area - and in widely separated sites - than they anticipate getting a harvest from. During the planting period they may scatter seeds continually wherever their herds trample the soil, and thereby give the seeds a chance to survive. To farmers elsewhere, tossing a few seeds in cow tracks may seem futile, but to those of the Sahel it can mean life itself.

Late Maturation

Elsewhere in the world, plant breeders have tried to speed up their cereals - to make them mature quickly so that more than one crop can be grown per year; so that weeds, pests, and diseases have less chance of causing destruction; and so that food can be produced where growing seasons are short. This is one reason why subsistence pearl millets look bad: many tend to mature very slowly.

The long growing season certainly leads to problems. Since flowering generally takes place after the rains end, even a brief early drought can hit the plants before there is any chance of forming seed and thereby bringing on total crop failure.

However, to Sahelian farmers the delay is all important. They want the grains to ripen after the rains have ceased. Although agronomically inefficient, it eliminates many drying and storage problems. (The grains can be easily dried, and they do not grow molds.) It probably also reduces problems caused by grain diseases and insects, both of which need moisture to thrive.

For the same reason, some subsistence pearl millets are "openheaded." This, too, is inefficient, and plant breeders elsewhere try to replace loose seedheads with compact ones.

For the farmer in much of Africa, however, the open form eliminates many of the drying and storage problems encountered with tight-headed varieties.

The long vegetative growth phase is probably also a major adaptive advantage in this region where the soils are lacking in both moisture and fertility: it gives the roots a chance to explore larger soil volumes. For one thing, this probably contributes to the plant's drought tolerance. For another, it probably helps the plant amass the nutrients necessary to grow a good head of grain. This may take considerable time, because roots grow slowly and because in those depleted soils the release of any remaining mineral nutrients is itself often slow.

A related, subtle feature is that the traditional crop varieties usually mature at the same time.

This means that only one generation of birds, insects, and diseases gets a chance to attack the flowers and seeds. Adding a mixture of types that mature successively is a disaster: it provides a "rolling nursery" that builds up multiple generations of pests and diseases that then wipe out all late-maturing types.

Daylength Sensitivity

Many of the world's wild plants (as well as most traditional landraces) are sensitive to the length of day. Modern plant breeders try to eliminate this restrictive trait so the plants they produce can be grown in different latitudes and seasons. But, for the subsistence pearl millets of West Africa, daylength sensitivity is what ensures that grain will be ready to harvest just at the right time in the dry season. It is the length of day that triggers the plant to flower, not the age of the plants. The yield may be poor if the season has been difficult, but the plant will at least flower and mature whatever grain it can.

By-Products

Traditional rustic varieties tend to be big, tall, leafy plants that perform best when spaced far apart. While these varieties produce massive amounts of greenery (6-12 tons per hectare even under the prevailing circumstances), the harvest index is often less than 20 percent.

This means that less than 20 percent of the plant (above ground) is grain and more than 80 percent is stalk and leaves, as compared to 30 percent or more for improved high-yield-potential varieties.

But farmers who must produce almost every necessity right on their own land look at these cereals in totality. To them, there is no such thing as excessive stalk. For anyone who cannot buy fencing, roofing, or fuel, stalks are as valuable as grains. And for those who have a cow or some goats, the leaves are what keep the animals alive during the dry season.

Consumer Preferences

To a subsistence pearl-millet farmer, the kernel characteristics - shape, color, processing qualities, and endosperm texture - can be more important than the absolute yield. A grain is almost worthless if it doesn't have the right (and often very subtle) properties for the type of foods the family eats. Subsistence growers choose among the varieties mainly on grounds of suitability for preparing such dishes as:

· Toh. The principal food, served at least once a day in the northern Sahel, toh is a stiff porridge prepared by adding pearl millet to boiling water while stirring.
· Koko. This is prepared by mixing pearl millet flour with water into a fine paste, which is then put aside in a warm place for a day or two to ferment. The resulting sourdough is then dropped into boiling water to form a thin porridge of creamy consistency.
· Marsa. This favorite snack of Ghanaians is a deep-fried pancake, prepared from the leavened batter of pearl-millet flour.

Genetic Diversity

Pearl millets grown under truly marginal conditions are usually heterogeneous enough to ensure stable production over seasons with widely differing weather patterns. In a sense, the African farmers for centuries have been performing "population breeding," a technique that is only now becoming popular in science. With this technique, a cluster of genotypes acts as a "cohort" able (collectively) to make the best of varying conditions. The genetically different plants in the "swarm" help create a successful harvest, no matter what hazards the season may bring. Should one type be depressed by weather, pests, disease, or mismanagement, others carry the brunt.

Advancing the qualities of a plant along a broad genetic front helps ensure a reliable - although not maximum - yield. And when your life depends on what you can grow, reliability is the most fundamental need.

WHAT TO DO?

Supporting greater production of subsistence pearl millets is one of the world's most humane endeavors. But improving the plants in this case is probably of secondary importance. Given the already remarkable qualities of these time-tested survival crops, given the infertile soils and harsh climates, and given the resources at the farmer's disposal, it would be difficult to come up with a better plant than he has already.

More important is research to make the farming methods easier, more reliable, and more effective; research to make storing and handling the harvest better and safer; and research to ease the daily drudgery of processing the raw grain into edible forms.

This book is of course designed to highlight promising plants rather than farming, storage, or processing methods. However, during the course of this study we came across some innovative ideas that may help boost the performance and reliability of subsistence pearl millets. We mention them here briefly. In the appendixes can be found ideas on potential breakthroughs in pest control, grain storage, milling, and other pertinent aspects.

The Dual Track

In this report we have given equal weight to species for both subsistence and commercial production. This is certainly an uncommon approach: in recent years polarization and even rancor have prevailed between the proponents of each viewpoint. However, in a broad sense, subsistence and commercial farming, although separate, are parallel and equally worthy - a fact not widely recognized by the public and one that sometimes befuddles even the best-intentioned scientific minds.

Subsistence farming is vital to the lives of millions, of course, and strengthening it is perhaps the most humanitarian contribution that can be made to African agriculture. But it is often operationally impossible to reach the neediest in the way they want. To create a new variety - even of a well-understood crop such as wheat - can easily take a decade of dedication and perhaps a million in money. It is therefore clearly impractical to reach, individually, the thousands of subsistence regions, each with its likes and dislikes, needs and desires, climates and conditions.

Although technical farming is not inimical to traditional farming, it is often much criticized by those most motivated to helping the neediest farmers. Everybody wants to help the most poverty stricken, of course. However, there is probably not a single subsistence farmer who doesn't dream of producing a surplus for sale. And that surplus is much more than a way to pay for a daughter's dowry or a transistor radio; it is, after all, the way out of poverty.

For this reason, then, those who are developing modern cultivars and hybrids for use in even the poorest nations are not wrongheaded or misguided. Subsistence farmers may be in the overwhelming majority, but the other farmers are the ones who, producing more than they can eat, feed the nonfarming public - the city dwellers, businessmen, doctors, teachers, tourists, and, yes, even the visiting researchers. Nor is there any reason to deny subsistence farmers a route to prosperity by withholding from them the means for producing commercially desirable varieties. Any nation, to survive and prosper, must help its farmers feed more than themselves.

Commercial farming has different requirements and goals from subsistence farming, but it poses no threat. This can be seen in many parts of the world. Throughout the Middle East, for example, farmers grow rustic and advanced wheats side by side - one for family use, the other for market day. Also, in the highlands of Peru, Indians commonly grow traditional potatoes for themselves and modern potatoes for the cities.

Some have pointed out that the Green Revolution wheats in India and Pakistan were grown largely for sale. They conclude (rightly or wrongly) that commerce was the main motivation and that no quantum leap in food production can occur in Africa until similar commercial opportunities are available. Thus, despite the current polarized approaches, subsistence farming and commercial farming in the Third World are inextricably linked. Improvements in one can benefit the other.

Traditional Farmers Are Superb, But ...

Subsistence farmers are to be admired and even emulated. Their techniques have been honed in the uncompromising harshness of an unforgiving climate as well as in the ever- present knowledge that failure means hunger or even death. However, no one should get carried away with the romantic notion that peasants always know best.

In the 1860s, when the United States proposed putting an agricultural university in every state, there was much opposition and many claims that American farmers needed no technical help - that professors in universities could not possibly teach the people of the soil how to farm better. But it proved otherwise - the so-called "land grant colleges" provided the engine of basic knowledge that has driven U.S. agriculture to its current heights.

It was through those universities and similar research facilities that the life cycles of many farm pests were worked out, the effects of fertilizer demonstrated, crop genetics illuminated, soil types and soil micronutrients identified, and myriad other basic facts underlying any farming operation brought to light. With this knowledge, even the most stubborn traditionalists were able to coax more from their land, with less effort and more consistency.

All in all, there are many ways in which a basic biological understanding can benefit the subsistence farmers of the hungry nations. Even the best of those farmers can, in this way, be helped to grow their crops more easily, more reliably, and with higher returns.

In the past, scientific findings were applied mostly to commercial agriculture, but that was because larger scale farmers are usually easier to reach and more susceptible to change.

Knowledge is not detrimental to subsistence farming, and the polarization that now pervades rhetoric and thinking worldwide is deplorable.

REDUCING VULNERABILITY TO CLIMATE

Helping farmers to deal with the uncertainties of the early rains - not to mention the droughts, sandstorms, and high soil temperatures - are perhaps the most valuable interventions that can be made. These would provide more secure environments early in the planting season and would do much to reduce a farmer's vulnerability to total crop failure before the crop is even started. Following are six possibilities.

Tillering

The pearl millets grown in the Sahel tend to be nontillering - each seed puts up only a single stem. This adds a major vulnerability because if that stem dies in a drought or sandstorm, for example, the plant is lost.

But certain pearl millets put up as many as five heads - not all of them at once. In this case, then, the destruction of a stem still leaves the plant alive and with a chance to rebound.

Other things being equal, adding some tillering types would dramatically reduce the severity of crop losses in the bad years and it would reduce the need to replant damaged fields. And in the good years when the rains are plentiful and timely, two or three (or perhaps more) stems would all emerge and survive, thereby doubling or tripling the yield.

Deep Planting

In the United States, researchers are studying how different types of pearl millet perform while in the seedling stage. They have found that the seedlings show large differences in the length and in the speed with which they lengthen.

By selecting types that produce tall seedlings and rapid elongation they have been able to plant the crop as deep as 10 cm 14 to 130 mm and 6 to 40 mm, respectively.

This gives the newly germinated and highly vulnerable seedling a better chance at surviving: it can reach deeper moisture; it is less likely to be killed if the soil surface dries out; and, if it is a fast grower, it can perhaps get through to the air before the soil crusts over.

Although the tests were done in germinators and greenhouses in the United States, they successfully identified lines possessing improved stand-establishment capabilities of high potential value for the subsistence farmers facing the elements a world away.

Water Harvesting

There are many possible ways to help concentrate moisture at the base of seedlings. A companion report identifies a considerable number.

That these are likely to have significant value is suggested by a recent paper on the use of soil imprinting and tied ridges. Both techniques produce little "basins" around the plants where water collects.

In the trials (conducted in an area of West Africa where annual rainfall is 600-900 mm), tied ridges captured 85-100 percent of the rainfall received on the site during the season. Normal ridging or flat planting captured only 55-80 percent - the rest was lost as runoff. Tied ridging also reduced the soil's surface bulk density, maintained soil fertility (by reducing losses of soil nutrients), and improved the soil's water-holding capacity. In the case of the pearl millet crop, tied ridging increased the depth of rooting, the root density, the vegetative growth, and the yields - and it did it in both wet and dry years.

Transplanting

The use of nurseries is one of the oldest strategies to avoid water stress in the seedling stage. For centuries, Asians have transplanted rice seedlings and West Africans have transplanted sorghum seedlings. Now farmers in parts of Asia are transplanting maize in the same way. Direct sowing is of course much easier, but wherever catastrophic failure is a probability, transplanting provides added security.

In this process, the seeds are planted not in the fields, but in small irrigated nurseries; they are taken to the fields only after the rains have commenced in earnest. This technique seems particularly promising with subsistence pearl millet (not to mention other crops in this book) because the crop must be established during the least favorable season, the time available is often short, the water supply limited, and the weather unpredictable. On top of all that, the farmer feels pressure to plant early because the family needs food and because the growing season is all too brief.

Transplanting not only overcomes the hazards of the unreliable early rains, but compared with a seeded crop, the transplanted crop is in the field for a much shorter time. It also needs far less water for an equivalent yield, and its resistance to the elements is greater. Growing the seedlings in a nursery also allows the farmer to cull diseased plants and thereby reduce the intensity of infection.

Although transplanting is so far associated mainly with other crops, there seems to be no reason why it couldn't prove most beneficial with subsistence pearl millets. Indeed, in a few parts of India and Africa this is already practiced, and with considerable success.

Mulching

As we have noted, burning-hot soil is one of the major hazards to the newly planted subsistence millets. Anything that could cool the surface of the land would help. Apparently, little or no innovation has yet been applied to this problem, although some tests using shade have resulted in a tenfold increase in survival and yield.

Windbreaks

The "sand-blasting" effect can surely be overcome by various kinds of barriers around (or at least on the windward sides of) the fields. One suggestion is the use of vetiver (Vetiveria zizanioides) hedges. This tall, extremely rugged grass would probably be unaffected by the blasting sand as its stems are enclosed in tough sheaths. When the time for planting crops arrives - even at the end of the driest of seasons - this perennial should still be standing stiff and straight and able to battle the wind.

IMPROVING CROP MANAGEMENT

Ideas on helping subsistence farmers handle their crops with less work or higher returns can be found in various books, journals, research-station reports, and PVO newsletters, for example. We have included a few ideas in the appendixes to this volume. It is thus not our intention here to belabor such fairly well-recognized issues as the use of fertilizers, optimum levels of tillage, optimum crop population size, and the use of less-laborious cultivation practices such as hoes, plows, and draft animals.

There are, however, some promising lines of research that fit in with the spirit of innovation that lies at the heart of this book. Following are three examples.

Cropping Systems

Subsistence pearl millets are essential components of traditional agricultural systems. They are usually intercropped with cereals such as sorghum and maize or with legumes such as cowpea or peanut. To most farmers, the combined production is more important than the yield from either crop by itself. This mixed cropping is difficult for today's researchers to deal with, but there are some interesting developments. One is dwarfing.

To reduce the size of a cereal plant is a common strategy (see next chapter). It provides a compact plant that is more resilient, easier to handle, and higher yielding. In the case of subsistence pearl millets, however, dwarfing is done not for such a yield advantage.

Researchers have found that simply reducing the plant height can contribute greatly to the associated cowpea and other low-growing legumes.

The millet no longer shades its shorter companion, which, with the increased photosynthesis, results in better yields. Initial results in Niger are quite encouraging. Farmers there have adopted dwarf millets eagerly.

Building Tilth

The soil under subsistence pearl millet is usually coarse textured, containing at least 65 percent sand. Such porous sites are not only poor in fertility, they are very poor at holding water. Any rain that does fall tends to drain away below the reach of the roots. Ways to keep it in the root zone would bring marked benefits, both in the crop's yield and its reliability.

It has been found, for example, that leaving crop residues in the field dramatically raises pearl millet yields in West Africa's deteriorating semiarid areas. In three recent trials, grain yields rose by 300, 450, and 550 percent, respectively. The residues not only increased the sandy soil's moisture-holding capacity, they also lowered soil temperatures and boosted fertility.

Biological Fertilization

The areas where subsistence pearl millet is prevalent are usually so remote and so poverty stricken that despite the soil's barrenness commercial fertilizer can seldom, if ever, be used.

But all plants, even those as robust as subsistence pearl millets, need food in the form of nitrogen, phosphorus, potassium, and a few so-called "micronutrients." How to provide plant foods under subsistence conditions is one of the greatest of all agronomic challenges - not just for Africa and not just for pearl millet.

In certain places, deposits of rock phosphate have been located. This almost insoluble phosphorus-containing mineral has seldom been tapped for fertilizer in the past. But it is potentially a major source of phosphate for regions in extremity. Unlike standard soluble fertilizers, it doesn't provide an instant jolt of good nutrition, but it is nonetheless a most valuable source of a prime nutrient that plants need to remain healthy, robust, and high yielding. Certain parts of West Africa have deposits of rock phosphate that could be tapped for this purpose.

For providing nitrogen to a subsistence farmer's crops, probably nothing is more practical than biological sources. Nitrogen can be obtained in this way by:

· Incorporating crop residues or animal manures into the soil;
· Using leguminous food plants (such as cowpea or peanuts) in crop rotations;
· Intercropping with herbaceous soil-building legumes such as stylosanthes or macroptilium; or
· Incorporating nitrogen-fixing tree species such as Acacia albida into the fields.

With pearl millet there is also the potential to get nitrogen directly from a beneficial microorganism that can live on its roots. Such nitrogenfixing symbioses between a plant and a microbe are characteristic of many legumes, but of only a few grasses. Pearl millet is one of those few. It benefits from a nitrogen-fixing bacterium called azospirillum. Recent trials in Maharashtra, India, have shown that when pearl millet plants were inoculated with azospirillum, the yield of both grain and fodder was significantly increased.

Pearl Millet Helps Namibia

Namibia's farming lands are among the driest and most unpredictable to be found. Perhaps for that reason, its farmers rely on mahangu (pearl millet) to provide the basic foods to keep their families fed. In the north of the country, where two-thirds of the population live, it is the staple.

In the past, Namibia's farmers could hope to obtain only about 300 kg of grain per hectare - a pitifully small amount. Indeed, production was so low that the country had to import maize to feed its people.

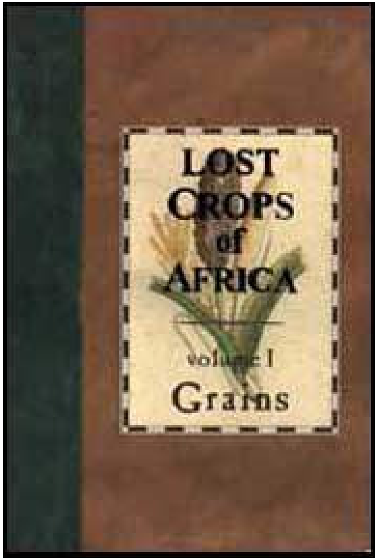
In 1986, however, the country asked ICRISAT for help, and 50 highly productive varieties were brought in and planted out for testing. In March 1987, at the new nation's first "Farmers' Field Day," approximately 100 farmers came to see the results. The variety Okashana 1 proved particularly impressive even though the rainfall that season had been only 170 mm (but well distributed).

Namibia then requested 200 kg of Okashana 1 seed for multiplication, large-scale testing, and demonstration to farmers. At the March 1988 Farmers' Field Day, 250 visitors showed up to buy Okashana seed. A year later, more than 500 farmers came, and they bought about 4 tons of the seed.

Since this new variety's arrival, Namibia's farmers have reaped bumper harvests. Even using traditional cultivation practices, they doubled their yields. But those who employed better methods obtained yields of 2.4 tons per hectare, about eight times the traditional amount.

Okashana 1 results from intensive plant breeding at ICRISAT, but it still retains its rustic resilience and is especially suited to subsistence farmers' needs. Among its characteristics are high grain yield, large seed size, early maturity, resistance to downy mildew, and ability to mature grain even when end-of-season droughts rob the plants of moisture.

According to Wolfgang Lechner, of the Mahanene Research Station at Oshkati, more than half of Namibia's pearl-millet farmers now grow the new variety. "Okashana 1 gives a light-colored flour that is highly acceptable," Lechner explains. "With this and the increased yields, within a couple of years the country may not have to rely on maize imports any more. That will save us a lot of valuable foreign exchange."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6. Pearl Millet: Commercial Types

Although it is one of the best means for sustaining life in the most desolate and difficult parts of the farming world, pearl millet also grows well under pampered conditions - under irrigation and in equable climes, for example. Because this fact is not widely known, most people dismiss pearl millet as a crop for good lands, pointing out that its low yield, low harvest index, and generally low fertilizer response mean that it cannot match the better known cereals under high-tech management.

However, it is far too early to dismiss pearl millet as a crop for regions that now grow modern maize and wheat and rice. The plant, as we have said earlier, has remarkable qualities, and some of its environmental resilience happens to be of the type that Latin America, North

America, Australia, Europe, and others may soon need desperately. Moreover, pearl millet is no longer a rustic relic. Hybrids and other advanced forms are coming available for worldwide use. The old impressions no longer hold.

In fact, a new vision of this ancient crop's potential is becoming clearer from research in the United States, where pearl millet is already exciting increasing interest.

Indeed, fast-maturing types that ripen grain in as few as 90 days after planting and can be harvested by giant combines are now viewed as important resources for a vast belt spanning the nation from the Carolinas to Colorado.

This recognition is starting a new era in pearl millet production. For almost the first time the crop is being seriously investigated with sophisticated methods in the world's finest research facilities. Malesterile forms, dwarfs, hybrids, and even some very unusual hybrids that produce fertile seed, have all recently been created. So far (at least in the United States), the emphasis has been on producing pearl millet as a feed grain - and with excellent reason: in U.S. Department of Agriculture trials, beef cattle, young pigs, and poultry fed pearl millet grain have grown as well as (or better than) those eating maize (see box).

More and more, however, America's pearl millet proponents are realizing that they have in their hands a potential new food grain for the nation and for the world.

There are good reasons for that assumption. Despite the current widespread notion that pearl millet is a second-rate cereal, the plant actually has a high potential growth rate - higher even than sorghum. Like maize and sorghum, it has the super-efficient C4 photosynthesis. Some types mature very fast and can produce two or even three generations a year if conditions permit. And there are other advantages as well. Pearl millet is, for example, "a plant-breeder's dream" and can be developed quickly into numerous and widely different forms. It is a crosspollinating species on which several different breeding methods can be successfully employed. And, by a strange twist of genetic luck, it can also be easily inbred.

In terms of large-scale commercial production, therefore, this crop is poised for revolutionary advances. It stands at about the point maize did in the 1930s. Hybrids are known but are not in widespread use; yields are only a fraction of what they might be; and although the basic understanding of the crop's physiology and genetics is still rudimentary, it is beginning to become clear. Seizing the opportunity now could propel pearl millet (like maize since the 1930s) to far higher levels of productivity by using the best of modern techniques. Indeed, pearl millet might well result in a similar leap in food production in many new areas.

Reasons for thinking this are not hard to find. The world's drylands are faced with an increasingly serious food crisis. Already this is becoming clear in the Middle East. For example, in 1989 Syria's parliamentary speaker announced at a meeting called to discuss Arab development and population problems that, unless the Arab world produces more food, one-third of its people will face starvation. In such places the world's most drought- and heat-tolerant cereal obviously has vital promise.

All in all, then, this plant's adaptability to both good and bad conditions makes it a potentially outstanding food crop for vast areas of a "greenhouse-afflicted', world where climates may change wildly from decade to decade or even from year to year, and where more and more people must obtain food from hot, dry soils.

The chances for boosting pearl millet's productivity and usefulness are good, but the improvements may not come rapidly. To make the crop a modern and globally useful food resource, varieties with large, dense, spherical, light- colored kernels that taste good are needed. In addition, improved dehulling characteristics are vital if pearl millet is going to be employed in human foods on a truly wide scale.

Eventually, all of these and more seem likely to come about, as can be seen from the following promising lines of development.

HIGH-GRAIN TYPES

The worldwide cereal-breeding advances of the last 100 years have increased rice, wheat, and maize yields dramatically, but, contrary to popular perception, the plants still produce about the same amount of growth (that is, their overall dry matter is largely unchanged).

Yields have risen because the plants were reconfigured to reduce the proportion of stems and leaves and increase the proportion of seeds. Usually, this meant reducing the plant height, but sometimes it also meant increasing the number of seedheads per plant.

Such rearranged plants have been the key to the remarkable jump in cereal yields that have occurred in most parts of the world. They respond well to good management; they make it possible to use fertilizer and other inputs profitably; and they create an upward spiral of yield and income that goes far beyond food production alone. For example, they help farmers to rest part of their land to restore its physical condition and fertility.

As of now, however, Africa's pearl millets are not of the rearranged type. After centuries of trying to stretch their heads above the rampant weeds, they are too tall for maximum grain production. In creating excess stalk, they are consuming energy and moisture that could be used to develop more grain.

Also, they cannot fully enjoy the benefits of fertilizer because it makes the plants top-heavy so that rain or wind can easily topple them into the dirt. Paradoxically, more fertilizer can mean less yield.

This was the situation of Mexico's wheats before the 1950s when genes from Japanese dwarf varieties helped create short, strongstemmed plants that could hold their heavy heads up during lashing winds and pounding storms. Strengthening the plant's architecture allowed fertilizer to work to the fullest benefit and was a prime component of the wheats that generated the Green Revolution.

A similar transformation is now occurring with pearl millet. Strongstemmed dwarf types are being put to use for the first time. Such types have already been developed in the United

States, for example. Yields of 4,480 kg per hectare have been achieved on research stations, and demonstration plots on farms in 1991 yielded 3,024 kg per hectare.

Millet in the USA

Although pearl millet has long been grown in the United States, few Americans have ever heard of it. That may soon change, however. A number of pioneering researchers see this crop as a valuable grain for the nation. High-yielding cultivars are being selected and bred; even hybrids have been created. However, owing to an oversupply of food, pearl millet is currently being developed mainly as a way to feed animals. Recent results have indicated that it has exceptional promise for the American livestock industry.

Part of the research has been done in Nebraska and Kansas, where the plant's tolerance of drought and acid soils, its resistance to pests, as well as its low requirements for nitrogen fertilizer, make it a potential boon to farmers. The experiments showed the plant could fit into multiple cropping systems for the Great Plains region.

Pearl millet might be used as a quality-protein grain for many livestock-feeding purposes.

Compared with maize, it had higher crude protein and ether-extract concentrations, as well as higher concentrations of all essential amino acids. Already, it is showing promise for feeding both poultry and cattle.

Poultry

Trials in different parts of Georgia have shown that pearl millet grain can fully replace maize in chick rations. It neither reduced the feed-conversion efficiency nor the rate of weight gain.

Indeed, chickens eating pearl millet actually grew faster and healthier than those eating maize, sorghum, triticale, or wheat.

This was an important discovery because although maize is the Southeast's main poultry feed, it grows poorly there and the local poultry industry has to import maize from the

Midwestern states. Some observers now conclude that as transportation costs increase, locally grown pearl millet could soon replace the imported maize as the poultry feed of choice. Several other areas of the country where maize is difficult to grow seem likely to switch over as well.

Cattle

Metabolism and feedlot trials in both the Midwest and the Southeast have shown that pearl millet is also good for feeding cattle. The grain's oil content, which is more than twice that of maize or sorghum, gives it a relatively high energy density. Pearl millet has also proved potentially useful as a source of protein. Compared with maize, it had higher concentrations of both crude protein (about 14 percent of the dry matter) and essential amino acids.

TEMPERATE-ZONE TYPES

Traditionally, pearl millet has been grown within about 30° of the equator, but these days certain types are already growing each year in various parts of the United States - in Georgia, Kansas, and Missouri, for example - that are far from the equator. Moreover, although the plant is almost synonymous with drought and deserts, it is also growing well in mild and humid locations such as the sandy coastal plains of south Georgia and Alabama.

In these temperate areas of America, pearl millet is potentially invaluable as a summer annual grain crop. Maize is poorly adapted to this region where its own shallow roots (blocked by the acid subsoils) and the common summer droughts result in low yields. Hybrid pearl millet develops deep root systems in these acid soils, resulting in much more dependable yields. Pearl millet also resists midges and the lesser cornstalk borer, two insects that severely affect sorghum. Moreover, no aflatoxin problems have been observed with pearl millet.

In addition, pearl millet is giving the farmers in the Southeast undreamed of flexibility.

Whereas maize must be planted within a twoweek window in April, pearl millet can be planted at any time between April and July. This means that it can skirt the hazards of summer and still mature a crop before winter chills cut off all growth.

EARLY TYPES

A driving force behind U.S. pearl millet research is the chance that pearl millet might make double-cropping possible. This is now approaching reality. Rapidly maturing cultivars are soon to be released, and these are the types now seen as promising for the belt stretching from the Carolinas to Colorado. Planted in spring, just after the winter wheat has been harvested, they can ripen a crop before autumn, when the next winter-wheat crop needs to be planted. Key to this rotation is pearl millet's inherent ability to tolerate heat as well as drought. The plant survives and yields grain even during the sweltering summer and on the (often meager) moisture left unused in the soil by the preceding wheat crop. No other cereal can do that.

The global value of such precocious pearl millets could be substantial.

TROPICAL TYPES

Although pearl millet is the quintessential dryland cereal, it is also found in some of Africa's wet and humid tropical zones. Much pearl millet is grown, for example, in relatively high rainfall areas of Ghana. The types there are entirely different from those of West Africa's nearby dry zone. In general, they have seedheads (spikes) that are shorter and fatter; grains that are bigger, rounder, and whiter, and plants that mature much earlier. These differences are so conspicuous that the plants were previously classified as a separate species.

Such types there have been little studied or appreciated by the world at large. Yet they appear to be promising in their own right and are good sources of genes for earliness and large grain size.

The potential of pearl millet for the tropics can be seen in Ghana, where early millet is extremely important to rural people. The type grown there normally matures at the peak of the rainy season, a time when farmers have exhausted their food stocks from the previous harvest. At first, they gather pearl millet when the grains are in the dough stage and are soft and sweet. Usually, the freshly harvested heads are steamed, threshed, and dried. This process - the exact reverse of normal practice - probably makes it possible to recover the immature grains that would otherwise turn to mush when threshed.

SUGARY TYPES

In India, as in Ghana (see above), pearl millet is sometimes roasted and consumed like sweet corn. Here, too, the grain is harvested in the milk or dough stage. This is a facet of pearl millet that has received little (if any) investigation. Yet it is reminiscent of the situation with maize a century or so ago. At that time the practice of eating maize grain in the soft, sweet, doughy stage was known only to a few Indian children and perhaps some adventurous farmers.

Today, "sweet corn" is a major food of North America, and a huge research effort has been expended on selecting strains whose grains convert sugar to starch only slowly so that they stay sweet. Canned sweet corn is in fact America's favorite preserved vegetable and has been outselling all the others since World War I.

Pearl millet, too, should have a big future as a sweet treat to be eaten more like a vegetable than a cereal.

POPPING TYPES

In India pearl millet is commonly popped. Dry grains sprinkled onto hot sand burst like popcorn. The pops are sometimes eaten with powdered sugar or brown sugar (jaggery).

The types that pop best have been given little or no special study. But popping is a promising method for bettering this crop (see Appendix C) and should be investigated further. Select types with round grains and impervious seed coats (so that the steam building up inside can reach the explosive levels necessary for good popping) will probably prove best.

LIGHT-COLORED TYPES

Although most of the pearl millets so far grown are tan or brown, white-grained types for the large-scale commercial production of food for people are now under development. These are attractive to look at and are sweet to the taste. Some have high protein contents. Also known are some yellow-grained pearl millets that are rich in carotene, the precursor of vitamin A. So far, however, they have been little appreciated.

EASY-PROCESSING TYPES

As noted earlier, pearl millet is among the more difficult grains to prepare. For one thing, the whole grain (caryopsis) contains a high proportion of germ. But more important, the germ is embedded inside the kernel and is difficult to remove. It is for this reason that traditional hand decortication often produces low yields of flour (not to mention its tendency to go rancid during storage).

The need for cultivars with improved dehulling properties is critical. Indeed, varieties with large, spherical, uniform, hard kernels that produce high milling yields already exist, but have not been documented systematically or brought into large-scale commercial production.

When pearl millets are processed into food products, there will be a need for larger supplies of more uniform grain with desirable milling properties and acceptable flavor, color, and keeping properties.

CUISINE-SPECIFIC TYPES

Most of the world's cereal breeding is done with foods such as bread, cakes, cookies, crackers, canelloni, or various breakfast concoctions in mind. But for pearl millet to sell in a big way in Africa it must be good for very different foods. In Africa (as well as in India), the major pearl millet foods are unfermented bread, fermented breads, thick and thin porridges, steam-cooked products, beverages, and snacks. Little or no information is currently available on which pearl millets have the best properties for each of these foods. This is a handicap. Undoubtedly, superior types exist and collections and investigations should be made in the houses of the users themselves. As we have said in the previous chapter, however, it is difficult to quantify, let alone breed for, the organoleptic properties of certain foodstuffs.

QUALITY-NUTRITION TYPES

Contrary to general opinion and oft-repeated statements in textbooks, pearl millet is one of the more nutritious of the common cereals. As has been noted, its grain has more fat than most, and its level of food energy (784 kilocalories per kg) is among the highest for whole- grain cereals. It also has more protein, and its level of the essential amino acid lysine is better than in most cereals.

However, some pearl millet grain may suffer (nutritionally speaking) because it is low in threonine and the sulfur-containing amino acids. Also, its lysine level could still be improved.

Of course, the other major grains have the same defect, but in the last few decades highlysine types have been found in maize, sorghum, and barley. It seems likely that a diligent search through the world's pearl millets with an amino-acid analyzer could disclose something similar.

HYBRIDS

As already mentioned, the development of maize hybrids in the 1930s led to a quadrupling of yields. A similar breakthrough, allowing the practical production of pearl millet hybrids, came in the late 1960s, when the first hybrids were created.

High-yielding, hybrids have been in use in India since 1966. Heterosis (hybrid vigor) in pearl millet can be substantial. Indian scientists have succeeded in developing hybrids that can almost double the yield of local cultivars.

Today, hybrid pearl millets are being planted in Kansas and Georgia. They are half the normal height - only a meter or so tall - and are capable of producing more than 3,000 kg grain per hectare. Their short stature and uniform growth make them amenable to harvest by combine. Commercial varieties are now being released to farmers.

APOMICTIC TYPES

As is well known, hybrids have the limitation that farmers must buy new seed every year or so. Although in many countries this is now a routine part of farming and is seldom constraining, the farmer must be able to buy the seed and the suppliers must be able to produce enough and deliver it on time for the planting season. In rural Africa that can be a problem.

Forms of hybrids that maintain their production potential from generation to generation are being developed in pearl millet. These forms, known as apomictic types, are on the verge of being perfected.

TOP-CROSS HYBRIDS

Crop varieties sometimes come to disastrous ends when circumstances change or a new disease arrives. In the case of hybrids, the disaster can be particularly severe because creating a replacement is a long and uncertain process that must start afresh with new genetic material. The whole operation might well take 10 years or more of diligent and dedicated effort. But plant breeders at the International Crops Research Institute for the

Semi-Arid Tropics (ICRISAT) in India have developed a strategy to keep pearl millet hybrids going indefinitely, even when new diseases arise or conditions change.

Normally, hybrids are developed using two inbred parents of known and uniform qualities.

ICRISAT's strategy is to replace one parent with an open-pollinated variety of broad genetic background.

The resulting products, called top-cross hybrids, are now being tested. So far they have yielded as well as the best of the old hybrids and yet have shown greater resistance to disease (presumably because they have a wider range of genes).

This is all well and good, but it is in the prevention of future difficulties that top-cross hybrids really shine. Should one of them ever succumb to disease, plant breeders can introduce resistance through the open-pollinated parent in just a generation or two (in, say, not more than 2 years). It is possible, therefore, to keep a hybrid strong and secure by performing parallel breeding on the openpollinated parent as a sort of ongoing genetic preventive maintenance.

The ICRISAT plant breeders are now taking the strategy a stage further and replacing even the sole remaining inbred parent with a hybrid of broad genetic background. This means that the resulting hybrid has even more genetic variability within it. This method helps, too, in reducing the cost of seed production.

WIDE CROSSES

Pearl millet (that is, Pennisetum glaucum) will hybridize with a few wild Pennisetum species, some of them very distantly related. Crosses with close relatives produce fertile hybrids, thus permitting extensive modifications to the genomes of both. Some hybridization work has already been done involving napier grass (Pennisetum purpureum). Pearl millet x napier grass hybrids have been released for perennial fodder supplies in India, the United States, and various other nations.

Two wild and weedy subspecies (Pennisetum glaucum subspecies monodii and Pennisetum glaucum subspecies stenostachyum) also readily cross with pearl millet. The useful characteristics they can confer include disease- and insect resistance, genes for fertility restoration of the A1 cytoplasm, cytoplasmic diversity, high yield under adverse conditions, apomixis, early maturity, and many inflorescence and plant morphological characteristics.

Among other possibly useful wild species are Pennisetum squamulatun, Pennisetum orientale, Pennisetum faccidum, and Pennisetum setaceum.

Pearl millet has also been crossed with species of completely different genera, including buffer grass (Cenchrus ciliaris).

In an approach that turns normal practice on its head, at least one researcher is using pearl millet to "improve" its wild relatives. The resulting tough, resilient, almost-wild Pennisetum hybrids appear useful for stabilizing decertifying environments, while giving those who live there a chance to get some food.

Genetic Jewels

Pearl millet is not now used as a genetic-research organism, but potentially it could be one of the best plants for illuminating details of both traditional and molecular genetics. A by- product from such fundamental science is likely to be new forms that increase the crop's value for meeting food needs.

THE PLANT WORLD'S DROSOPHILA

As a tool for investigating genetic interactions, pearl millet has the promise to rival drosophila, the fruit fly with which researchers have plumbed the details of animal genetics since the 1930s. Consider the following.

· The pearl millet plant is robust and demands so little space that it can grow in a 5-cm pot.
· It matures so quickly that four generations a year are possible. (Some genotypes flower just 35 days after planting; others can be induced into this by employing short daylengths and high temperatures.)
· It produces masses of progeny. A single inflorescence can produce 1,000 or more seeds, and a single plant (if unrestrained) can produce 25 or more inflorescences.
· Its flowers are small but are ideally set up for genetic

manipulation. Unlike those on most plants, they are receptive to fertilization before shedding their own pollen; researchers can therefore readily cross-pollinate a given flower or merely leave it to self-pollinate.

· Its chromosomes are large and easy to count.

· The plants resulting from cross-pollinations usually grow with pronounced hybrid vigor, so that the genetic interactions are clear.

· There is abundant natural genetic diversity: pearl millet's gene pool encompasses about 140 species or subspecies belonging to the genus Pennisetum.

· Many genetic states can be obtained. The different Pennisetum species have chromosome numbers in multiples of x=5, 7, 8, and 9. For each of these, there are various ploidy levels, ranging from diploid to octoploid and beyond. In addition, both annual and perennial species occur. And there are types that are sexual or apomictic (see below).

FATHERLESS GRAINS

Like most plants, pearl millet produces seeds that have the characteristics of both parents.

Certain of its relatives, however, produce seeds with only their mother's genes. For them, each new generation is identical to the last.

This situation is known as apomixis. It is not unusual in wild grasses, but to introduce it into crops has been considered too complicated, too expensive, or just too far-out. However, all that is now changing. Within the genus Pennisetum, apomictic types have been located in a number of species. If their trait for selfreplication can be transferred to pearl millet, profound benefits would result.

For one thing, with apomictic pearl millet the farmer's fields would be safe from genetic drift. No longer would pollen blowing in from wild and weedy relatives downgrade the elite varieties.

For another, seed from different apomictic varieties could be mixed, and the farmer would retain the security of natural diversity as well as the productivity of man-made varieties.

For a third, apomictic pearl millet hybrids could be propagated by seeds for an unlimited number of generations without losing their genetic edge. Farmers would no longer have to buy fresh seed every year to enjoy the benefits of a hybrid.

The apomictic types of the wild Pennisetum species are not themselves promising as crops.

They produce few seeds and have many weedy characteristics. But their gene for apomixis can be transferred to the pearl millet plant. Indeed, significant progress has already been made transferring this gene from the wild African grass Pennisetum squamulatum to cultivated pearl millet. This development could catapult pearl millet into being a leader in hightech agriculture.

Progress is being made in finding molecular markers associated with apomixis. This association will allow researchers in the future to isolate the gene(s) controlling apomixis and possibly use them to produce true-breeding hybrids in many crops. Indeed, in this way pearl millet's genes have the potential to revolutionize food production around the world.

SWEET-STALK TYPES

At least two grasses - sugarcane and sweet sorghum - produce stems filled with sugar. Apparently, nobody thought to look for this trait in pearl millet until the 1980s, when some Indian scientists stumbled on some during a germplasm-collecting expedition in the southern state of Tamil Nadu. M.H. Mengesha, and V. Subramanian, of ICRISAT. Their first test was to chew on the stalk. Later, they found that Brix readings can vary from 3 to 16 percent. In the area around Coimbatore and Madurai, they found types that at maturity contained more than twice the normal amount of soluble sugars.

These sweet-stalk types had long narrow leaf blades, profuse nodal tillering (with asynchronous maturity), short, thin spikes, and very small grains. They could be easily identified by chewing them at the dough stage.

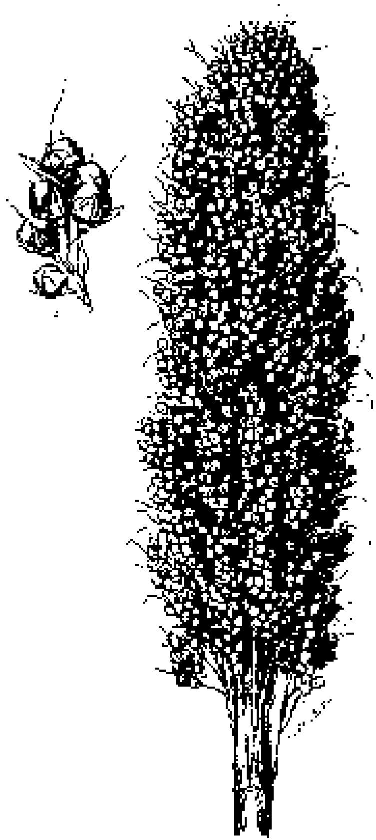
The sweet-stalk pearl millet is used as a fodder that is usually harvested in September, and a subsequent ratoon crop can be taken for grain and straw. The farmers consider them to be superior feedstuffs because livestock love the sweet stalks.

TYPES OF THE FUTURE

As can be seen from the above, pearl millet contains a wealth of genetic strengths and offers almost countless opportunities for innovation and advancement. Eventually, biotechnology could have a huge impact on such a diverse crop. It could, for example, be used routinely to transfer pieces of DNA from variety to variety or from the large numbers of wild Pennisetum relatives (or even from other genera). Probably, it is only a matter of time before techniques for this (by using vectors or electrophoration, for example) are developed.

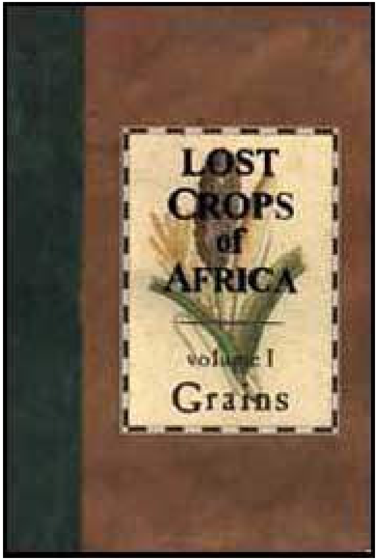
Such transfers are most effective when the crop's protoplasts (wallless cells) can be regenerated into whole plants. Although it is not yet possible to regenerate protoplasts in pearl millet, it is possible to regenerate suspension cultures (including those of pearl millet x napier grass hybrids) into whole plants.

Perhaps the best way to codify the enormous diversity of this crop is to create a chromosome map. This is likely to help make possible all sorts of advances in pearl millet. The task should be easier than with many crops. Pearl millet is a diploid with seven fairly large chromosomes and a large number of genes that are already known and definitively mapped.



FIGURE

Lost Crops of Africa: Volume 1 - Grains (BOSTID, 1996, 372 p.)


LOST
CROPS
of
AFRICA
volume I
Grains

7. Sorghum

To include sorghum in a book on "lost" crops, on the face of it, seems like a gross mistake.

After all, the plant is Africa's contribution to the world's top crops.

The amount produced is not known for certain because sorghum's production statistics (at least in some countries) are lumped together with millet's. Annual world production of the two together exceeds 100 million tons, of which 60 million is certainly sorghum. Based on the FAO figures for 1985, the number of hectares under sorghum are: Africa, 18 million; Asia, 19 million; North and Central America, 9 million; South America, 3 million. The main grain production (in millions of tons) was in the United States (28.70), India (10.30), China (an estimated 6.80), Mexico (6.60), Argentina (6.20), the Sudan (4.25), and Nigeria (3.50). Indeed, it belongs to the elite handful of plants that collectively provide more than 85 percent of all human energy. Globally, it produces approximately 70 million metric tons of grain from about 50 million hectares of land. Today, it is the dietary staple of more than 500 million people in more than 30 countries. Only rice, wheat, maize, and potatoes surpass it in feeding the human race.

For all that, however, sorghum now receives merely a fraction of the attention it warrants and produces merely a fraction of what it could. Not only is it inadequately supported for the world's fifth major crop, it is under-supported considering its vast and untapped potential.

Viewed in this light it is indeed "lost."

But this situation may not continue much longer. A few researchers already see that a new and enlightened era is just around the corner. Accorded research support at a level comparable to that devoted worldwide to wheat or rice or maize, sorghum could contribute a great deal more to food supplies than it does at present. And it would contribute most to those regions and peoples in greatest need. Indeed, if the twentieth century has been the century of wheat, rice, and maize, the twenty-first could become the century of sorghum.

First, sorghum is a physiological marvel. It can grow in both temperate and tropical zones. It is among the most photosynthetically efficient plants.

It has one of the highest dry matter accumulation rates. It is one of the quickest maturing food plants (certain types can mature in as little as 75 days and can provide three harvests a year).

It also has the highest production of food energy per unit of human or mechanical energy expended.

Second, sorghum thrives on many marginal sites. Its remarkable physiology makes it one of the toughest of all cereals. It withstands high rainfall - even some waterlogging.

Recent research in Israel has shown that it also has some tolerance to salt - an increasingly useful feature for any crop these days.

But most importantly, it can endure hot and dry conditions. Indeed, it can produce on sites so burning and arid that no other major grain - with the exception of pearl millet - can be consistently grown.

Its massive and deep-penetrating roots are mainly responsible for this drought tolerance, but the plant has other drought-defying mechanisms as well. For instance, it apparently conserves moisture by reducing its transpiration when stressed (by rolling its leaves and possibly by closing the stomata to reduce evaporation) and it can turn down its metabolic processes and retreat into near dormancy until the return of the rains.

Third, sorghum is perhaps the world's most versatile crop. Some types are boiled like rice, some cracked like oats for porridge, some "malted" like barley for beer, some baked like wheat into flatbreads, and some popped like popcorn for snacks. A few types have sugary grains and are boiled in the green stage like sweet corn. The whole plant is often used as forage, hay, or silage. The stems of some types are used for building, fencing, weaving, broom-making, and firewood. The stems of other types yield sugar, syrup, and even liquid fuels for powering vehicles or cooking meals. The living plants are used for windbreaks, for cover crops, and for staking yams and other heavy climbers. The seeds are fed to poultry, cattle, and swine. On top of all that, sorghum promises to be a "living factory." Industrial alcohol, vegetable oil, adhesives, waxes, dyes, sizing for paper and cloth, and starches for lubricating oil-well drills are just some of the products that could be obtained.

Fourth, sorghum can be grown in innumerable ways. Most is produced under rain-fed conditions, some is irrigated, a little is grown by transplanting seedlings as is done with rice.

Like sugarcane, it can also be ratooned (cut down and allowed to resprout from the roots) to provide crop after crop without replanting. It is ideal for subsistence farmers on the one hand and can be completely mechanized and produced on a vast commercial scale on the other.

Finally, sorghum is relatively undeveloped. It has a remarkable array of untapped variability in grain type, plant type, adaptability, and productive capacity.

Indeed, sorghum probably has more undeveloped and underutilized genetic potential than any other major food crop.

With all these qualities and potentials, it is small wonder that certain scientists regard sorghum as a crop with a great future. Undoubtedly, as the world moves towards the time when its supplies of food will be insufficient for its supplies of people, this plant will increasingly contribute to the happiness of the human race. This will happen sooner rather than later. Population is projected to almost double within most of our lifetimes. How to feed billions of newcomers on diminishing amounts of prime cropland will likely be the overwhelming global issue of the period just ahead. Obviously, vast amounts of the less fertile and more difficult lands must be forced to produce food. Moreover, if the much feared greenhouse effect warms up the world, sorghum could become the crop of choice over large parts of the areas that are today renowned as breadbaskets, rice lands, or corn belts.

In sum, it seems certain that no matter what happens sorghum will assume greater importance, especially to backstop the increasingly beleaguered food supplies of the tropics and subtropics. For a hot, dry, and overcrowded planet, this crop will be an ever-more-vital resource.

This is in fact already starting. Despite only modest international support, sorghum even now seems to be verging on a global breakout. In the United States, its yield improvements have outstripped those of all other major cereals.

In India, it is increasingly employed. And in Mexico, Central America, and the Caribbean - a most unexpected part of the world for this African plant - the most rapid growth of all is occurring.

Indeed, the rapidity with which Mexico has embraced sorghum is little short of spectacular. Before 1953, the crop was so little used in Mexico that, as far as international statistics were concerned, it didn't exist there. However, by 1970 it was being planted on nearly I million hectares, and by 1980 on nearly 1.5 million hectares. The reason is a pragmatic one: sorghum is not only cheaper to produce, it yields about twice as much grain as maize in Mexico (2,924 kg per hectare versus 1,508 kg per hectare in one recent test). Also, where rainfall is unreliable, sorghum is proving the more dependable of the two.

Mexico uses most of its sorghum grain for animal feed, but it is increasingly relying on new, food-quality sorghums. These produce grains suitable for making tortillas, the round flat bread that is Latin America's staple food. In addition, sorghum is also being used to make breakfast cereals, snacks, starch, sugars, and other products that currently come from maize. It is even the basis for some (European type) beers in Mexico, a country renowned for its brewing skills.

Although these developments demonstrate sorghum's capabilities and almost certainly portend a coming boom in production throughout much of the world, much remains to be done before this crop can truly fulfill its international potential. At present, it has several drawbacks, including the following:

· Lack of status. In global terms, sorghum is being held back by the mistaken prejudice that it is a "coarse" grain, "animal feed," and "food of the peasant classes."
· Low food value. In its overall nutrient composition - about 12 percent protein, 3 percent fat, and 70 percent carbohydrate -

sorghum grain hardly differs from maize or wheat. However, sorghum has two problems as far as food quality is concerned. One is tannins, which occur in the seed coats of brown sorghum grains. When eaten, tannins depress the body's ability to absorb and use nutritional ingredients such as proteins. Unless the brown seeds are carefully processed, some tannins remain, and this reduces their nutritional effectiveness. The other problem is protein quality, which affects all sorghums, both brown and white. A large proportion of the protein is prolamine, an alcohol-soluble protein that has low digestibility in humans.

· Difficulty in processing. Sorghum is harder to process into an edible form than wheat, rice, or maize.

Ultimately, none of these drawbacks is a serious barrier to sorghum's grander future, but each is a drag that - like a sea anchor in the tide of progress - is holding the crop from its destiny. Moreover, all of them can be overcome, as the following chapters demonstrate.

This plant's potential is so great that we have devoted the following four chapters to its various types. The next chapter highlights sorghum's promise for subsistence farmers - the millions in Africa and Asia (not to mention Latin America) to whom the plant means life itself.

The subsequent chapter highlights commercial sorghums - the types that are increasingly grown by farmers who produce a surplus. The chapter that follows highlights specialty sorghums - unusually promising food types that are now little known in a global sense but that have outstanding merits for the future. Finally, there is a chapter on sorghum's promise as a source of energy as well as on other special qualities that can benefit farms and farmers.

These divisions are of course arbitrary. They are simply a convenient way to present the vast range of this plant's possibilities. There are many areas that overlap and much common ground between the different types, different purposes, and different users. In addition, major advances specifically in Africa's sorghum production are likely to come from methods and technologies that are beyond the scope of the following chapters: from controlling birds, locusts, and parasitic weeds to new approaches to milling, grain storage, and erosion control. These are discussed in appendixes A and B.

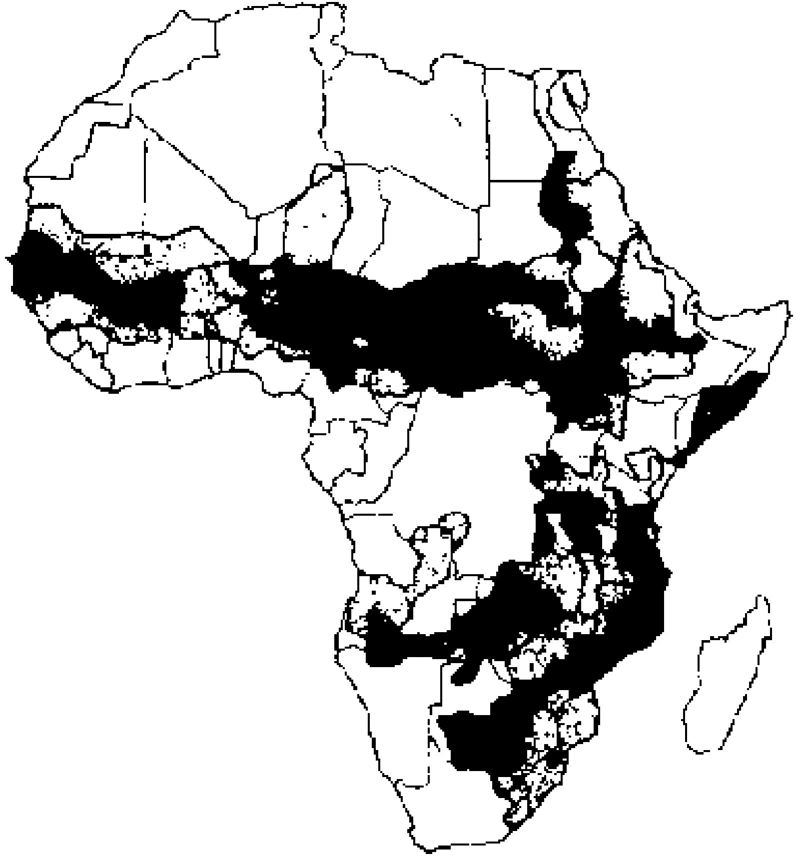


FIGURE: The extent to which Africa stands to benefit from sorghum research can be seen from this map. The crop is perhaps the continent's most widespread and important staple. Beyond the fact that yields can be raised far above the present average, sorghum's adaptation to a wide range of ecological conditions is an enormous asset.

Over the millennia' this ancient food was probably domesticated several times. At least four major types arose in different places. These are shown. One of the oldest, the durra(crook- necked) variety, was eaten in Egypt more than 4,000 years ago. Ethiopia is its center of diversity, and durra sorghum is still the staple food for most of the populace of the Horn of Africa. The region from eastern Nigeria through Chad and western Sudan is a center of diversity for the caudatum race. The region from western Nigeria to Senegal gave rise to the guinea race. The area from Tanzania to South Africa is the center for the kafir race. All of these separate sorghums have fed countless generations.

Africa's Gift to Mexico

The rise of sorghum in Mexico has been so spectacular that it has been called "the country's second Green Revolution." The crop has become the third largest in terms of area (after maize and beans) as well as in terms of value (after maize and cotton). Between 1958 and 1980, the number of hectares sown expanded by almost 1,300 percent and the amount of sorghum production increased 2,772 percent. More than 1.5 million hectares of sorghum were sown in 1980 - more than double the amount of land planted to wheat, Mexico's first

Green Revolution crop. Mexico has become the sixth largest sorghum-producing country in the world; only the United States and China used more of this originally African grain.

The fact that sorghum requires less water than maize or wheat is a significant advantage in Mexico, which has large areas of arid land. This has been true even in irrigated areas because the government has sometimes had to limit irrigation water owing to depleted reservoirs. Also, sorghum is now grown in some areas where irrigation has salinized the soil.

It requires between two and four irrigations per year, compared to wheat's six or seven.

Although average yields per hectare are not as great as those of wheat, they are substantially higher than those of maize.

At the beginning, most of Mexico's sorghum was grown for animal feed. Already, this grain forms a substantial part of the diet of all the chickens, pigs, cattle, sheep, and goats that are raised in the country. Although the animal feed industry also uses maize, barley, wheat bran, soybeans, and other products, sorghum supplies 74 percent of the raw material used in animal feed in Mexico.

Now, however, more and more food-grain sorghum is being grown.

NUTRITION

Like other cereal grains, sorghum is composed of three main parts: seed coat (pericarp), germ (embryo), and endosperm (storage tissue). The relative proportions vary, but most sorghum kernels are made up of 6 percent seed coat, 10 percent germ, and 84 percent endosperm.

In its chemical composition, the kernel (in its whole-grain form) is about 70 percent carbohydrate, 12 percent protein, 3 percent fat, 2 percent fiber, and 1.5 percent ash. In other words, it hardly differs from whole-grain maize or wheat. When the seed coat and germ are separated to leave a stable flour (from the starchy endosperm), the chemical composition is about 83 percent carbohydrate, 12 percent protein, 0.6 percent fat, I percent fiber, and 0.4 percent ash.

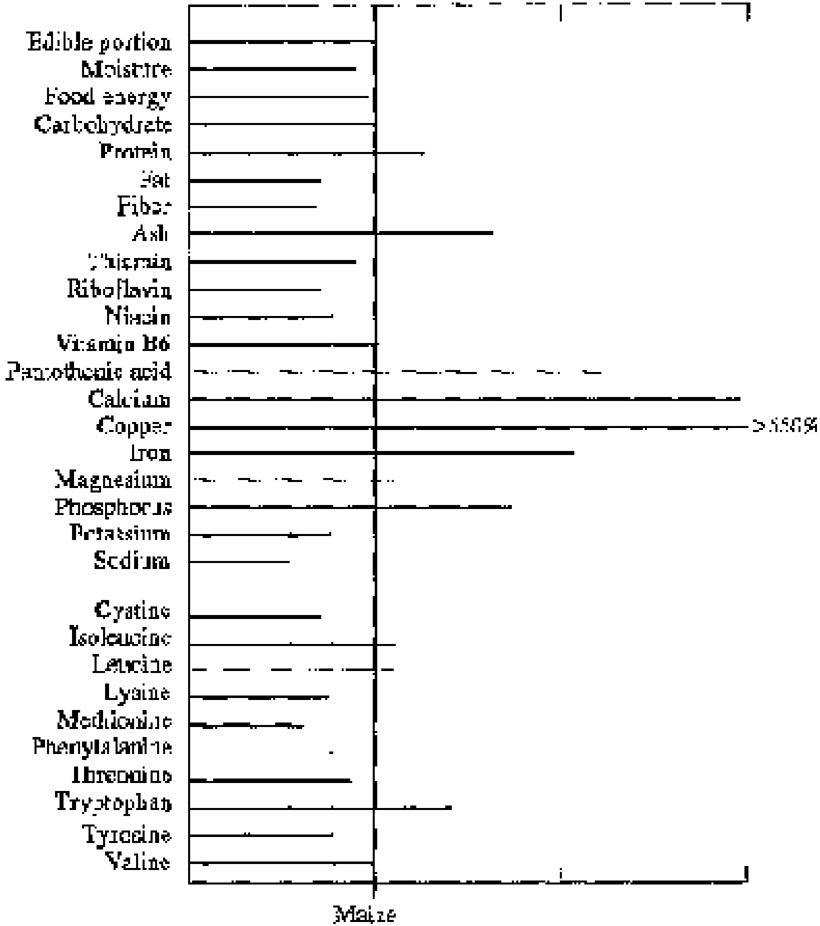
The nutritional components are given in the tables and charts, but some of the details are discussed below.

NUTRITIONAL PROMISE

Main Components		**Essential Amino Acids**	
Edible portion (g)	100	Cystine	1.3
Moisture (g)	9	Isoleucine	4.0
Food energy (Kc)	356	Leucine	13.5
Carbohydrate (g)	71	Lysine	2.1
Protein (g)	12.0	Methionine	1.3
Fat (g)	3.4	Phenylalanine	4.9
Fiber (g)	2.0	Threonine	3.3
Dietary Fiber (g)	8.3	Tryptophan	1.0
Ash (g)	2.0	Tyrosine	3.1
Vitamin A (RE)	21	Valine	5.0

Thiamin (mg)	0.35		
Riboflavin (mg)	0.14		
Niacin (mg)	2.8		
Vitamin B6 (mg)	0.5		
Biotin (µg)	7		
Pantothenic acid (mg)	1.0		
Vitamin C (mg)	0		
Calcium (mg)	21		
Chloride (mg)	57		
Copper (mg)	1.8		
Iodine (µg)	29		
Iron (mg)	5.7		
Magnesium (mg)	140		
Phosphorus (mg)	368		

Potassium (mg)	220		
Sodium (mg)	19		


Edible portion
Moisture
Food energy
Carbohydrate
Protein
Fat
Fiber
Ash
Thiamin
Riboflavin
Niacin
Vitamin B6
Pantothenic acid
Calcium
Copper
Iron
Magnesium
Phosphorus
Potassium
Sodium
Cystine
Isoleucine
Leucine
Lysine
Methionine
Phenylalanine
Threonine
Tryptophan
Tyrosine
Valine
Maize

FIGURE

In composition sorghum is similar to maize. Starch is the major component followed by protein, fat, and fiber. Compared with maize, however, sorghum generally contains 1 percent less fat and more waxes. Its complex carbohydrates have properties similar to those from maize.

The protein content is quite variable. The American literature reports several instances of levels ranging from 8.3 to 15.3 (these were measured on the milo sorghum that is grown throughout the Midwest). Most samples fall in the 9 percent protein category and are almost always 1 or 2 percent higher than in maize.

However, for human nutrition sorghum protein is "incomplete." It is deficient in critical amino acids, most importantly lysine. Today's standard sorghums provide about 45 percent of the recommended lysine requirement.

Although a primary food for millions of Africans, Asians, and Latin Americans, sorghum is low in protein digestibility. It must be properly processed to improve its digestibility. It is perhaps for this reason that much of Africa's sorghum is subjected to fermentation before it is eaten.

Carbohydrates

Carbohydrate is the grain's major component, with starch making up from 32 to 79 percent of its weight. The remaining carbohydrates are largely sugars, which can be quite high in certain rare varieties of sorghum grains.

The starches in most sorghums occur in both polygonal and spherical granules, ranging in diameter from about 5µ to 25µ (average 15µ). Chemically, the starch is normally made up of 70-80 percent branched amylopectin (a non-gelling type) and 20-30 percent amylose (a gelforming type). However, some sorghum starches contain as much as 100 percent amylopectin;

others, as much as 62 percent amylose.

In its properties, sorghum starch resembles maize starch, and the two can be used interchangeably in many industrial and feed applications. When boiled with water, the starch forms an opaque paste of medium viscosity. On cooling, this paste sets to a rigid, nonreversible gel. The gelatinization temperature ranges from 68° to 75°.

Protein

Sorghum's protein content is more variable than that in maize and can range from 7 to 15 percent.

In most common cultivars, as mentioned above, the kernel contains about 12 percent, which is 1-2 percentage points higher than maize.

The protein's amino-acid composition is much like that of maize protein. Lysine is the first limiting amino acid, followed by threonine.

Tryptophan and some other amino acids are a little higher than in maize.

The protein contains no gluten. A large proportion of it is prolamine, a cross-linked form that humans cannot easily digest. In fact, prolamine makes up about 59 percent of the total protein in normal sorghum. This is higher than in other major cereals, and it lowers the food value considerably.

In the long term, sorghums that have less prolamine may come available for routine use. A few of these more nutritious types have already been found: two in Ethiopia and one in the Sudan, for instance. Until such quality-protein sorghums are perfected, however, sorghum grain needs to be processed if its full protein value is to be realized.

Fat

Generally, sorghum contains about I percent less fat than maize. Free lipids make up 2-4 percent of the grain and bound lipids 0.1-0.5 percent. The oil's properties are similar to those of maize oil. In other words, the fatty acids are highly unsaturated. Oleic and linoleic acids account for 76 percent of the total.

Vitamins

Compared to maize, sorghum contains higher levels of the B vitamins pantothenic acid, niacin' folate, and biotin; similar levels of riboflavin and pyridoxine; and lower levels of vitamin A (carotene). Most B vitamins are located in the germ.

Pellagra - a disease caused by too little niacin in the diet - is endemic among certain sorghum eaters (as it is among some maize eaters).

Minerals

The grain's ash content ranges from about I to 2 percent. As in most cereals, potassium and phosphorus are the major minerals. The calcium and zinc levels tend to be low. Sorghum has been reported to be a good source of more than 20 micronutrients.

Nutritional Concerns

Recently, the status of sorghum's future as a global food was thrown into disarray by nutritional experiments conducted on malnourished children in Peru. The conclusion was reached that sorghum was "unfit for human consumption."

Part of the problem was due to the fact that the samples used in Peru came from milled flour (comprising only the grain's endosperm) and they were merely boiled into porridge and fed directly. In Africa, by contrast, the whole grain is ground up (so that the protein- and vitamin- rich germ is also included) and often some form of fermentation is also employed.

At the heart of the issue of sorghum's nutritive effectiveness is the above-mentioned fact that almost 60 percent of the protein is in the highly cross-linked form called prolamine. Human digestive enzymes are unable to break up this indigestible protein. Even bodies desperately in need of more muscle, enzymes, blood, and brain continue passing prolamine that might otherwise provide the necessary amino acids.

However, sorghum has a second problem as far as food quality is concerned. Tannins, which occur in the seed coats of dark-colored sorghum grains' block the human body's ability to absorb and use proteins and other nutritional ingredients. Unless the grain is a low tannin (yellow or white) type or unless brown seed coats are carefully removed, some tannins remain' and this reduces sorghum's nutritional effectiveness.

Yet a third problem is that when sorghum grain is germinated, a cyanogenic glucoside is formed. In the shoots, enzymes act on this to produce cyanide. This is a potential hazard only with germinated sorghum, and not with the grain itself.

SPECIES INFORMATION

Botanical Name Sorghum bicolor (L.) Moench

Synonyms Sorghum vulgare Pers., S. drummondii, S. guineense, S. roxburghii, S. nervosum, S. dochna, S. caffrorum, S. nigricans, S. caudatum, S. durra, S. cernuum, S. subglabrescens.

Common Names

China: kaoliang
Burma: shallu
East Africa: mtama, shallu, feterita
Egypt: durra

English: chicken corn, guinea corn
India: jola, jowar, jawa, cholam, durra, shallu, bisinga
South Africa: Kafir corn
Sandan: durra, feterita
United States: sorghum, milo, sorgo, sudangrass
West Africa: great millet, guinea corn, feterita
Middle East: milo

Description

Sorghum comes in many types. All, however, are canelike grasses between 50 cm and 6 m tall. Most are annuals; a few are perennials. Their stems are usually erect and may be dry or juicy. The juice may be either insipid or sweet-. Most have a single stem, but some varieties tiller profusely, sometimes putting up more than a dozen stems. These extra stems may be produced early or late in the season. Plants that tiller after the harvest has occurred can be cut back, allowed to resprout, and grown without replanting (like sugarcane).

Soil permitting, the plant produces a deep tap root (see picture, opposite). However, a large number of multibranched lateral roots occupy the upper soil levels, particularly the top meter. They can spread laterally up to 1.5 m.

The leaves look much like those of maize. A single plant may have as few as 7 or as many as 24 leaves, according to cultivar. At first they are erect, but later curve downward. During drought they roll their edges together. Rows of "motor cells" in the leaves cause the rolling action and provide this unusual method of reducing desiccation.

The flower head is usually a compact panicle. Each carries two types of flowers: one type has no stalk (sessile) and has both male and female parts (perfect); the other is stalked (pedicellate) and is usually male (staminate).

Pollination is by wind, but self-pollination is the rule. The degree of cross-pollination depends on both the amount of wind and the panicle type, open heads being more liable to cross- pollination than compact ones.

Grains are smaller than those of maize but have a similar starchy endosperm. Most are partially covered by husks (glumes). The seed coat varies in color from pale yellow through purple-brown. Darkcolored types generally taste bitter because of the tannins in the seed coat. The endosperm is usually white and floury as in normal maize, but in some types the outer portion is hard and corneous, as in popcorn.

The crop is always grown from seed. Some seeds show dormancy and will not germinate for a month or so after harvesting. It is a littleknown fact that the plant can also be propagated by stem cuttings: nodes along the stem have tissues (primordia) that can produce both roots and sprouts and thereby grow a new plant.

Sorghum is a diploid (2n = 20).

Distribution

This African crop is now known almost worldwide. Dhows, which have been crossing the Indian Ocean for some 3,000 years, probably first carried it away from Africa and took it to India more than 2,000 years ago. It was almost certainly put on board as seamen's provisions. The sorghums of India are related to those of the African coast between Somalia and Mozambique.

Sorghum probably traveled overland from India and reached China along the silk route about 2,000 years ago. It might also have gone by sea directly from Africa: Chinese seamen reached Africa's east coast more than about 1,000 years ago (probably in the eighth century

AD)1 and they may well have carried some seeds home. Cross-pollination with a wild Chinese sorghum seems the most likely reason why the sorghum now found in China (the kaoliang group) has its own distinctive character.

Broomcorn was first grown in Italy in the 1600s and later spread elsewhere in southern

Europe. This form of sorghum has produced most of the Western world's brooms and brushes ever since. Today, Mexico is a major producer.

Jowar

For perhaps 20 centuries, sorghum has been a staple of South Asia. Today, for example, it occupies at least 20 million hectares in India, more area than any other food crop except rice. In monetary terms "jowar," as it is locally called, is perhaps India's third most valuable food plant, exceeded only by rice and wheat.

Outsiders have often dubbed this African grain "the great millet of India." And no wonder.

Jowar is an important food over much of the country, and especially in the dry areas of the central and southern states. Millions of Indians eat it. Some use it like rice, but most jowar is milled into flour. More or less white in color, this flour is used especially for making traditional unleavened breads (chapatis). Usually the whole-grain flour is employed, but some jowar is also polished to remove the germ and create a flour with a long shelf life. This can be blended with wheat flour (up to 25 percent) for preparing even Western-style raised breads.

Jowar grain is also malted (germinated), and in this form it finds its way into various processed products, including beer and baby foods. The grains of certain varieties pop like popcorn when heated. Indians eat the light and tasty product directly or as a flavoring in baked goods.

And sorghum feeds more than just India's people: its stalks are a major source of fodder.

According to some reports, nothing can match its combination of high yield and nutritional quality. Varieties with juicy, sweet stalks have been developed. Cattle find those particularly delicious.

Perhaps 80 percent of India's cultivated sorghums are those (known as "durras") that are the dominant type in Ethiopia, North Africa, and along the Sahara's southern fringes. Many improved strains have been developed. They are grown mainly in the plains and rely on the summer rains, although some are grown under irrigation.

Jowar is notably important on the black-cotton soils, which are notoriously difficult to farm. It is one of the few crops that withstands the wildly fluctuating water tables that produce bottomless mud in the wet season and something resembling cracked concrete in the dry.

An ability to extract moisture from deep in the heavy vertisol clay is among the crop's greatest qualities for India.

Horticultural Varieties

This crop comes in such an array of widely different types that various botanists have previously recognized 31 species, 157 varieties, and 571 cultivated forms. However, these all cross readily and without barriers of sterility or differences in genetic balance, so it seems preferable to group them into a single species, Sorghum bicolor. Some botanical authorities also include certain wild sorghums, designating them as varieties within the species.

The ease with which cultivated sorghums cross with wild species (such as S. arundinaceum) may be a headache for the taxonomist, but it provides great scope for the plant breeder. Indeed, to synthesize new cultivars, a vast range of genetic characters can be brought together in bewildering numbers of combinations. As a result, many cultivars are recognized in Africa, India, the United States, and elsewhere, and new ones are being continually produced (see later chapters).

Environmental Requirements

Sorghum is adapted to a wider range of ecological conditions than perhaps any other food crop. It is essentially a plant of hot, dry regions but takes cool weather in stride and may also be grown where rainfall is high and even where temporary waterlogging can occur.

Daylength Although many cultivars are insensitive to photoperiod, sorghum is basically a short-day species. Most traditional varieties differentiate from vegetative to reproductive growth when daylengths shorten to 12 hours. This switch to flowering often happens just when the rains diminish, and the crop matures in the dry season that follows, a feature that greatly helps the farmer. Some of these traditional forms are extremely susceptible to photoperiod and reach impossible heights if not planted as daylengths shorten. On the other hand, the dwarf sorghums of the temperate zone are unaffected by daylength and can be planted year-round where climates permit.

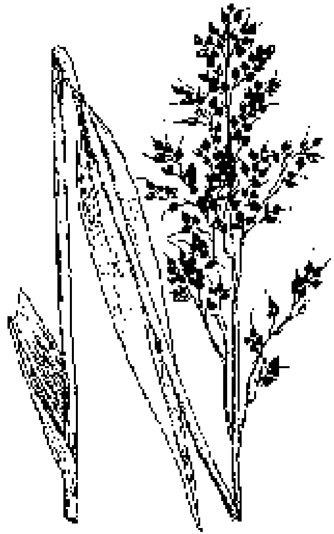
Rainfall Although part of the crop is grown in rainy regions, sorghum is remarkably drought- resistant and is vitally important where the climate is just too dry for maize.

Altitude Sorghum is grown from sea level to above 3,000 m.

Low Temperature The plant is killed by frost. Optimum growth occurs at about 30°C.

High Temperature It is essentially a plant of the tropics or subtropics, roughly between 40° of the equator. However, in the United States it is being pushed ever farther into the cooler latitudes.

Soil Type Sorghum tolerates an amazing array of soils. It can grow well on heavy clays, especially the deep-cracking and black cotton soils of the tropics. It is equally productive on light and sandy soils. It can withstand a range of soil acidities (from pH 5.0-8.5) and tolerates salinity better than maize.



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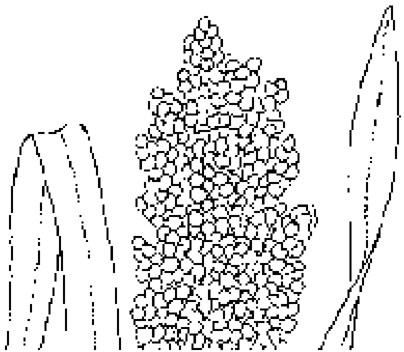

FIGURE

World. CD3WD is a 3rd World Development private-sector initiative, mastered by Software Developer Alex Weir and hosted by GNUveau_Networks (From globally distributed organizations, to supercomputers, to a small home server, if it's Linux, we know it.)ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

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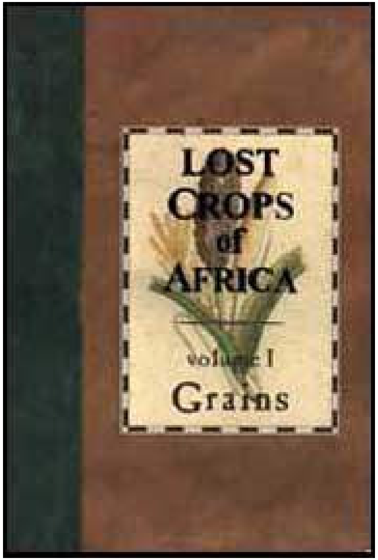


8. Sorghum: Subsistence Types

Of all Africa's cereal grains, sorghum is the most important. It shares top billing with pearl millet in the drier zones and with maize in the wetter ones. In fact, Africa devotes more hectares to sorghum and millet than to all other food crops combined.

And sorghum is more important than the bald figures indicate. It is crucial to a substantial portion of the millions who coax from their meager and often declining lands barely enough to sustain life. Many - perhaps most - of those who grow it could hardly survive without this plant. For them, it provides the dietary energy and nutrients that make the difference between health and hunger.

Sorghum is vital in this way for the majority of the most poverty stricken people in two huge belts that together look like the number 7 superimposed on the map of sub-Saharan Africa.

One belt - spanning some 8 degrees of latitude (from approximately 7° to 15°N) - stretches like a giant sash across West Africa from Senegal to Chad. The other, equally huge, runs north to south covering the drier areas of eastern and southern Africa from the Sudan to South Africa (see map).

The recent past has not been kind to these two vast regions - especially the first. To many observers the picture is already bleak and getting bleaker. The sorghums that provide the subsistence for tens of millions yield on average less than 700 kg per hectare - sometimes much less. Yields have improved little or not at all in decades. Some observers question whether technology can ever make a difference.

The reasons are not unclear. Africa's farmers face a formidable web of interlocking constraints. There are constraints imposed by nature, which seems to take special delight in bedeviling Africa. There are constraints imposed by society and tradition. There are constraints imposed by poverty. And there are constraints imposed by politics, incompetent government, poor roads, and other infrastructural impediments. Subsistence farmers must somehow survive and produce their crops within all of them.

If the constraints were the same throughout Africa, they might be manageable; but they differ in degree and kind from farmer to farmer, village to village, valley to valley, and nation to nation. With all these localized and varying limitations, some people conclude that unified advances of the Green Revolution type that swept across India and Pakistan in the 1960s are inapplicable. Perhaps a different approach is needed.

Actually, that approach might come from Africa's own subsistence sorghums. During thousands of years, farmers have selected varieties to match their local conditions and food preferences. These traditional types are already remarkable for their diversity. In

Sukumaland in Tanzania, for instance, a single researcher once counted 109 named cultivars - all of them in common use. In Samaru, Nigeria, more than 100 local types have been identified. And in the Lake Turkana area of Kenya there is such a variety of distinctly colored sorghums that just by looking at a grain, farmers claim that they can identify who grew it - a form of "natural bar-coding" that is said to ensure against theft.

For Africa as a whole, the number of distinct sorghums must range into the many thousands.

Some have been reverently handed down from generation to generation.

These traditional sorghums are not only varied, they can have remarkable qualities. Perhaps centuries of careful observation have gone into their selection. They incorporate features such as:

· Good seedling emergence and strong early root development (to compensate for the normal brevity of the early rains);
· Good tillering (to compensate for erratic early rains as well as shoot-fly attack);
· Long growing cycles (to make best use of infertile soils);
· Resistance to insects (particularly headbugs);
· Resistance to molds; and
· Tolerance of bird pests and striga, a parasitic plant that is an impossible pest in certain regions.

In addition to the agronomic qualities mentioned above, subsistence sorghums have been carefully selected for features that affect the appearance, texture, taste, preparation, or shelf life of traditional foodstuffs. They are mostly grown by women, and are used primarily in the home to prepare local foods.

Traditionally, people consume the grain as a stiff porridge (tofu or ugali), a thin porridge (uji), or in a range of fermented beverages.

Ethiopians form sorghum flour into dough balls that are boiled to form a staple food (dawa).

In Nigeria, a similar type of dumpling as well as a flaked, dried sorghum-based food are staples. Many people cook the dehulled grain like rice, or grind it into flour like wheat and make biscuits, cakes, or unleavened breads. Some make couscous out of it. Sorghum is also important for brewing native beer or pombe.

As has been noted, Africa has two vast sorghum belts. Surprisingly, the conditions in each are so different that varieties perfected in one are seldom useful in the other.

The following conditions prevail in East and southern Africa:

· Most of the crop is planted as a monoculture and laid out in rows.
· The rainy seasons tend to be short and (in most places) to come once a year.
· The plant varieties tend to have shorter stems, tight seedheads (panicles), and relatively high harvest indexes (the ratio of grain to other tissues).
· Birds are often such serious pests that they alone determine what variety is planted, how it is managed, and what level of inputs is applied (see Appendix A).
· The main striga species (notably in southern Africa) is the Asian type (Striga asiatica), so that plant breeders can use genes from strigaresistant Indian sorghums.

· Sorghums for brewing and for animal feed are increasingly important.
· Both modern varieties and hybrids have been used, at least on a modest scale, and some types introduced from India have proved extremely successful.

In West Africa, on the other hand, the following conditions apply:

· Little of the sorghum is grown in monoculture; most is planted in mixtures with cowpea, pigeonpea, roselle, and other crops.
· The plants are seldom grown in rows, but are scattered randomly and are often far apart. In the drier parts of this zone the land is neither plowed nor otherwise prepared before planting, except that it is sometimes weeded or burned.
· The plants tend to be tall and lanky and have a low harvest index.
· The plants flower toward the end of the rains, thereby helping the grains escape fungi and sucking bugs, which are prevalent

while the rains persist but disappear during the dry months that follow.

· The rainfall can be very erratic.

· Local sorghums are able to produce grains even when severely stressed by drought. (The types grown in higher rainfall areas produce dense, vitreous grains; those grown in dry areas produce floury grains.)

· The seeds are borne in open panicles - a feature generally inimical to high grain yields but one that helps avoid grain molds.

· The main striga is Striga hermonthica, a native species. Most of the striga-resistant sorghums from India or even from eastern Africa are susceptible to this parasitic pest.

NEXT STEPS

Actions to open the vast and promising future of subsistence sorghums include those discussed below.

Sharing Varieties

As noted earlier, truly outstanding sorghums can be found throughout Africa. Many are exquisitely fitted to specific niches for subsistence farmers. Much good could be done merely by making these more widely available. Most are now unknown beyond the valley or village where they are treasured.

Local types are well proven, and moving them within ecological zones could be a powerful way to improve the long-term stability of farm production. Even moving them across ecological zones could become important because there may be increasing climatic change and uncertainty in the future. Farmers now plant cultivars suited to the existing rainfall pattern. However, if the pattern changes (as it did in West Africa in the 1970s) then all local cultivars may become inappropriate. Materials from another area may be the only way to stave off disaster.

Strengthening Farming Methods

To improve sorghum in subsistence production, research on farming methods seems likely to yield quicker benefits than research on breeding plants for higher yield.

Some improvements seem simple, obvious, and uncomplicated. For example:

· Watering. Studies conducted over the last 20 years in Burkina Faso, for instance, suggest that a little extra water applied when the grains are filling profoundly increases grain yield.
· Fertilization. In some areas, dramatic rises in sorghum grain yields can come from providing nutrients to the soil.
· Legume rotations. Many lands where sorghum grows were infertile to begin with or are now worn out. Nitrogen-fixing leguminous plants could well be the key to rejuvenating most such sites.
· Weed control.
· Water-harvesting and other water-conserving techniques.
· Managing the fields to reduce devastating outbreaks of striga.

Tampering with tradition must be done with caution, however. Some seemingly obvious improvements can prove detrimental in the long run. For example, it is not for nothing that West African farmers grow sorghum plants wide apart. The crop is an excellent scavenger of nutrients and will grow successfully in soils in which maize fails completely, but it must then have room to develop large root systems. Typically, agricultural advisers recommend closer plantings, but where soil fertility is the limiting factor this can reduce the yield. (Of course, if fertility levels are increased, plant populations can be too.)

Another trap for the unwary is the preparation of the land. There is a strong interaction between the choice of variety and how the land has been prepared. In the moister areas, land is cultivated and ridged before planting; elsewhere, however, the seeds are broadcast onto unprepared ground. "Improved" varieties will usually outperform local material only where land is cultivated. Local varieties, on the other hand, show little response and cultivating the land before planting can be a waste of time.

Breeding Better Plants

Certain sorghums that yield almost as much as the best grain crops in the world are known (see next chapter). But for helping the subsistence farmer, an 8,000-kg-per-hectare crop is not a suitable target at the present time. Maximum yield is usually not the primary requirement. Reliability is more important. A yield that can be relied upon year after year is the primary goal of those whose life depends on their harvests. Thus, the immediate need is to improve the yield stability, together with whatever yield increase is compatible with that stability. Average yields of only 1,500 kg per hectare would double production in Africa (not to mention India).

Crop-breeding objectives for stabilizing yields for resource-poor farmers in Africa include:

· Raising pest and disease resistance (see below).

· Boosting tolerance to drought, humidity, and other changeable environmental stresses.

(These tolerances, however, are pretty high already. In many locations it would be better to breed for higher yield at the existing tolerance levels.)

· Improving grain quality, especially those qualities that are important in storage and processing.

Some of these resistances and tolerances can be bred for outside the local area. "Hot spots" have been identified for many traits of economic importance. Midge, for example, is constantly severe at Sierra Talhada in northeast Brazil; Busseola fusca is severe at Samaru in northern Nigeria. An appropriate network of national or regional stations in similar areas could provide a powerful method for screening and mobilizing masses of useful local germplasm far more rapidly than at present.

A "Cure" for Sorghum Borers

It is often hard to see how to improve on crops and methods that subsistence farmers have honed to their needs for hundreds or even thousands of years. However, modern ability to probe deeply into genetics, entomology, soil science, plant physiology, and other sciences can provide insights of great potential value. Here is a recent example.

Subsistence farmers value their sorghum stalks so highly that the grains are sometimes almost a secondary consideration. The stalks are vital for building houses, for fencing, and for firewood. But there is a risk in employing them. Larvae of the sorghum stem borer (Busseola fusca) shelter inside. Thus, a farmer who keeps lots of stalks around is providing a haven for his worst enemy; eventually, the larvae will turn into adults that will come out in swarms to devastate the next crop.

A Nigerian researcher, A.A. Adesiyun, has recently been looking into this long-standing problem. By monitoring the population inside the stalks he has come to appreciate the features that affect the pest and can thereby guide farmers on how to keep their stalks and have good harvests as well.

Naturally, farmers stack the stalks out of weather during the off-season. Adesiyun has found that this is good for the bugs: in the shade only 20 percent die, and all the rest eventually emerge, eager for more sorghum to bore into. However, Adesiyun then found that lust stacking the stalks out in the open doubled the number of insects that succumbed. And this was nothing compared to warming the stalks over a fire or spreading them out thinly to bake in the sun for 3 days. This killed a whopping 95 percent of the larvae sheltering inside. The stalks could then be stored safely, even in the traditional stacks in the shade. Moreover, the "cured'' stalks could be used around the house or the farm with little risk of infecting the fields with hordes of hungry hoppers.

Raising Pest Resistance

Among the traditional sorghums of the tropics are some with good resistance to foliar diseases and excellent tolerance to most of the indigenous insect pests. However, to maintain this happy position, research must be continued, especially on the use of systemic insecticides against borers and shoot-fly. Unfortunately, the natural resistance is closely related to the amount of phenolic compounds (particularly the condensed tannins), and these compounds make it harder for people to digest the sorghum grain.

Breeders can also help stabilize yields dramatically by breeding genotypes tolerant of striga.

In fact, this is vital. Any "improved" materials lacking striga tolerance could be catastrophic to farmers in areas where this parasite is serious. A striga plant produces tens of thousands of seeds, each of which can remain viable for a decade or more. If susceptible sorghums are introduced, this terrible pest could quickly get out of hand and fill the soil with seeds that act like

10-year time bombs. Luckily, there now seem to be good possibilities for identifying and breeding striga-resistant types (see Appendix A).

The Dilemma of Daylength

It has been a tenet of modern crop breeding that eliminating sensitivity to daylength is a good thing - the resulting varieties can be grown at many latitudes and in different seasons.

But West African subsistence farmers use daylength-sensitive sorghums in an ingenious and sophisticated manner that helps ensure a harvest even in the shortest and most erratic of seasons.

The actual week when the rains will start in the Sahel is unpredictable. The rains may be early, late, or sporadic. However, when the rains will cease is much more consistent.

Unfortunately, though, once the rains have stopped, the ground rapidly dries out, leaving little chance for more growth. Thus, although the start of the planting season can vary, the crop must complete its cycle by the given time when the rains come to an end.

Traditional cultivars in West Africa have been selected to flower a little before the rains end, no matter whether the rains began early, late, or on time. The length of day triggers the flowering, not the age of the plant nor the status of the rains.

Local sorghums have evolved over centuries under those austere and fluctuating conditions.

They fill out quality grains even under the stress of drought and the boom-and-bust cycles caused by sporadic showers. Introduced varieties and hybrids, by contrast, are "shocked', by the sudden onset and extreme stress of a Sahelian dry season. They seem to collapse physiologically and set floury grains that are useless as food.

Improving Bird Resistance

As noted elsewhere, birds prevent farmers from cultivating the most palatable sorghums in many parts of Africa. Today's bird-resistant types have seed coats containing tannins, which are both bitter and difficult to digest. If a more satisfactory solution can be found, it could be an outstanding contribution to Africa's future, and it would certainly help boost the production of sorghum. New possibilities have recently been discovered (see Appendix A).

Increasing Mold Resistance

In many parts of Africa, molds that destroy grain in the head (panicle) are holding sorghum back. If cultivars more resistant to such damage can be found, then earlier, fast-maturing types could be grown regardless of the humidity during the harvest period. Also, types with dense panicles (a better yielding and more efficient form) could be planted where now only quick-drying open-panicle types are practical. Some strains are inherently resistant to mold regardless of panicle type; these deserve much greater research attention.

Another, relatively easy, intervention is the treatment of seeds against smuts that affect the crop in the seedling stage.

Easing the Burden of Handling

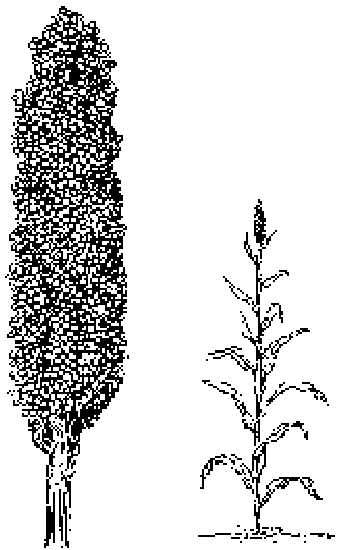
The amount of hand labor needed to prepare the land, control the weeds, and scare away the birds is a serious limit to sorghum production in African subsistence farming. These are significant barriers to increased production. Thus, a major issue raised by any innovation is how much hand labor it demands. This is important to any farmer who has to work the fields by hand. In hoe agriculture one can literally "work oneself to death" by expending more energy than he or she gets out of the harvest.

End Use

As already noted, subsistence sorghums are able to meet the complex array of local requirements. The storage life, processing characteristics, and taste of tofu, ugali, uji, dawa, and other traditional sorghum-based foods are paramount - more important than the absolute level of yield in the field.

Features that affect traditional foods are hard for scientists to quantify and breed for, especially when the research must be done in centralized research facilities. Subsistence- sorghum breeding is made even more difficult by the fact that Africa may have as many sorghum dishes as it has cooks.

Already, sorghums improved with exotic germplasm have been rejected because the toh they produced didn't keep its texture long enough. (The starch gel collapsed overnight.) The sorghum program in Niger, Burkina Faso, and Mali currently uses small diagnostic tests to evaluate advanced breeding materials for toh keeping quality. This approach, by which the plant breeders are directed as much by food technologists and home economists as by yield in the field, is a refreshing and much-needed innovation.



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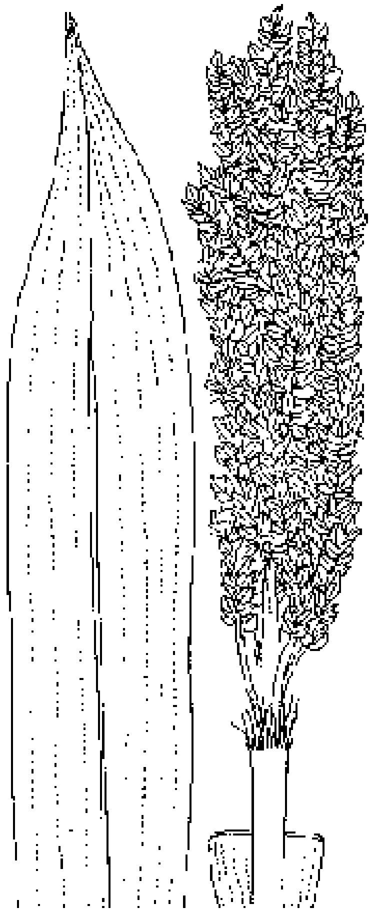


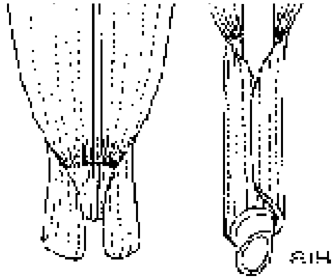
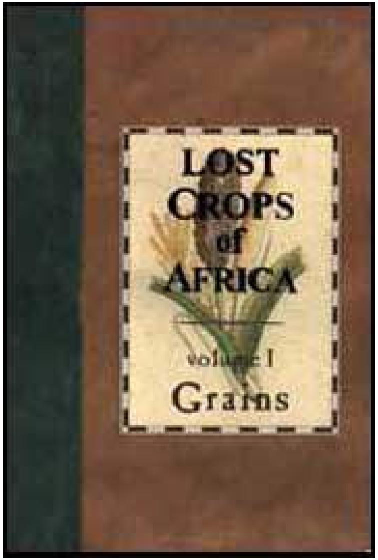


FIGURE: Sorghum Caffrorum



(BOSTID, 1996, 372 p.)

9. Sorghum: Commercial Types

Today in Africa, sorghum is grown mostly for subsistence (see previous chapter). It feeds farmers and families who seldom, if ever, have any surplus to sell. But beyond Africa sorghum production is rising, mainly due to farmers who sell their grain so that others can eat. The United States, Mexico, Honduras, and Argentina are just some of the nations now taking advantage of this crop's powerful performance under pampered conditions. Indeed, it is paradoxical that while Mexico's maize is replacing Africa's sorghum in Africa, in Mexico itself the opposite is happening: sorghum is replacing maize in many areas.

The commercial approach will eventually assist Africa as well. Growing sorghum the way commercial wheat and maize are grown can produce harvests of 3,000 rather than 700 kg per hectare. Indeed, the fact that sorghum has vast untapped commercial potential is important to the future of much of the world. Large areas in Central Asia, northern and central China, South America, and Australia have the potential for expanding the production of sorghum as a large-scale, high-tech competitor of the world's top three grains: wheat, rice, and maize.

Part of the problem in Africa is that so far sorghum has never been developed as a major food for urban areas. Lacking markets, it remains a crop of the small cultivator, consumed largely on the land where it is produced. But this need not - indeed should not - continue as the sole method of sorghum production. As with other crops, sorghum deserves the attention that governments give to any basic food commodity: stockpiling, purchase of surpluses, price supports, research, and policy support, for instance.

One particular restraint on sorghum has been the lack of processed foods - flour, meal, breads, or other materials - for use by those who are not farmers and are not prepared to devote hours of every day making flour from raw grain. The development of a sorghum- based food-processing industry would do much to offset Africa's shift in demand toward imported rice and wheat.

There are good reasons for thinking that this may come about. And soon. For example, recent research has shown that sorghum grain can be parboiled to create a fast-cooking, convenient food just as has been done with rice. Also, various projects are under way to produce sorghum flour for sale in stores. In fact, in Botswana sorghum meal is already commercially available.

By and large, the actions needed to boost commercial farming differ dramatically from those needed by subsistence farming. Whereas subsistence farmers may be tied (for reasons of precedent, poverty, environment, or fear of the unknown) to local varieties, commercial farmers are not. They can use newly created sorghum varieties, including hybrids and the best of research-facility results. Their grain is to be sold, probably to markets where the products of perhaps thousands of other farmers are pooled. In this case, the standard varieties demanded by the mass market take precedence, and the cash earned by selling them may pay for fertilizers and other inputs that are beyond the meager means of subsistence growers.

The evidence is persuasive that - just as in the cases of wheat, maize, and rice - sorghum responds dramatically to modern technology. For instance, although subsistence-sorghum yields have remained static at or below 700 kg per hectare, those of commercial sorghums have jumped like those of the Green Revolution crops in Asia. In the 1970s for instance, yields from India's rainfed sorghum increased 50 percent (from 484 to 734 kg per hectare) and Argentina's rose 55 percent. Irrigated yields are considerably higher: in India, about 1,800 kg per hectare is common. Hybrid sorghums can achieve even more: 4,5006,500 kg per hectare are now not unusual yields in the United States, Europe, China, and on commercial farms in Zimbabwe.

In a few cases, sorghum's yield ceiling has been raised to dazzling heights. For example, yields of 13,000 kg per hectare are being reported under special conditions in Mexico.

In Argentina and the United States 12,000 kg per hectare have been measured. Farmers in China are said to average 10,000 kg per hectare in certain areas.

Given such advances, sorghum's total global production may eventually match that of maize.

And perhaps more important' much of the production will be at sites where maize can barely survive. This will greatly increase the food available in the world.

The rest of this chapter highlights certain forms of sorghum that could help this plant reach its ultimate performance outside the confines and constraints of subsistence farming.

Sorghum in America

When introduced to the United States in the middle of the last century, sorghum was first cultivated on the Atlantic coast. By 1900, it had spread as far west as California. Today, Texas, Kansas, Nebraska, and Missouri are the leading producers. The crop's value now averages about $1.1 billion annually. Much is exported. In 1990, the United States shipped 7,239,000 tons of grain sorghum - almost half of ail it produced. Japan was the largest buyer, followed by Mexico.

In the United States itself, grain sorghum is most commonly used as livestock feed. It is fed to cattle (both beef and dairy), poultry, pigs, lambs, horses, catfish, and shrimp. The grain has many industrial uses as well. It is used in foundry-mold sands, charcoal briquets, and oil-well-drilling mud. In addition, sorghum flour is used in the manufacture of plywood and gypsum to build houses as well as in the refining process of potash and aluminum. Some of the ethanol used to fuel American cars is made from grain sorghum.

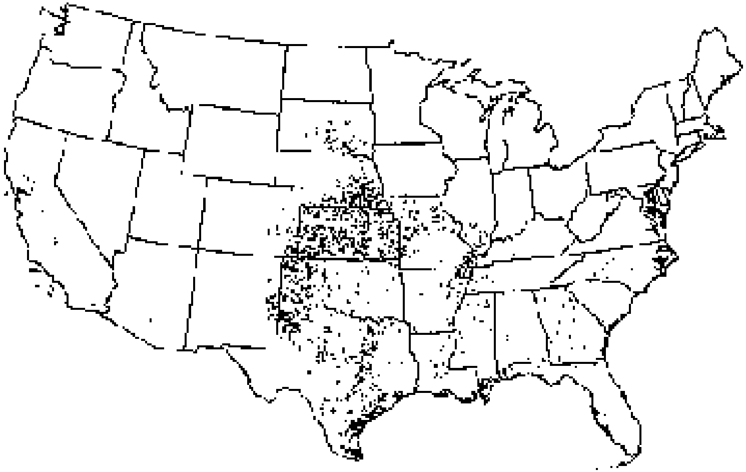


FIGURE: Although it can be found from the Carolinas to California sorghum is grown primarily in the Great Plains in the center of the United States. (One dot equals 2,000 hectares.)

TYPES FOR ALL SEASONS

Sorghum's ultimate promise is perhaps best glimpsed in a research program in Texas and

Puerto Rico. The Sorghum Conversion Project, as it is called, is a concentrated research effort that has catalyzed much of the present improvement in sorghum. It changes tall, late, or nonflowering varieties that produce well only in the tropics into short, early-maturing forms that can be used in many parts of the world, including the temperate zones. Its materials are already opening new horizons in sorghum production. Indeed, it is these materials that have led to the big jump in sorghum production in the United States, Mexico, Central America, parts of South America, and elsewhere. All in all, the result of this project could be one of the most significant advances in food production of this era.

In essence, the conversion program has vastly enhanced the source material available to sorghum breeders. It provides seeds of hundreds of types that are not only productive and adaptable, but also contain genetic resistance to insects and diseases and have desirable food qualities. Of the 1,300 lines in the program, more than 400 have been "converted" as of 1991. These select lines are being used to develop gene pools from which breeders can draw genotypes that best fit their local needs and environments.

This development is described in more detail in the box.

HYBRIDS

In the 1930s, America's maize yields were static. With the advent of hybrids, however, yields doubled and redoubled in just two decades. Maize quickly became not only a food but a "living factory," yielding feeds, sweeteners, starch, oil, and myriad industrial raw materials. It rose to such importance that today the U.S. economy would collapse without it.

Sorghum hybrids have much the same inherent potential, as their brief history shows. The first was produced only in 1957, but the effect was electric. Within 4 years, almost all American sorghum growers had switched, and the mean yield nationwide more than doubled from 1,280 kg per hectare to 2,750 kg per hectare. Within 10 years, as the hybrids improved, the yield had more than tripled to reach 3,810 kg per hectare. In a little over 20 years it had almost quadrupled to reach 4,190 kg per hectare. Seldom has there been such a rapid increase in grain yields in a cereal crop.

The hybrids were developed by crossing sorghums from southern Africa (the so-called kafir type) with others from Central Africa (caudatum types). The benefits come both from the hybrid vigor (which results when widely divergent strains of an organism are crossbred) and from the fact that the plant's heightened potentials and profits encouraged farmers to apply fertilizers and pesticides.

Hybrids have produced quantum jumps in production in India and Latin America as well, but so far, except in the Sudan, Zimbabwe, and South Africa, they are uncommon in Africa itself.

In most of East Africa, for instance, only 5-10 percent of the crop is in the form of hybrids or other improved varieties, and in West Africa the percentage is even lower. This is not unexpected. Occasional U.S. hybrids, such as NK 300, prove productive over a wide range of conditions in Africa, but most do not. Also, most U.S. hybrids were developed for stockfeed and their grains make poor-quality foods. In addition, they lack the necessary resistance to striga, a parasitic plant unknown in most sorghum-growing areas of the United States.

These days, however, hybrids that produce food-quality grain are coming available.

Moreover, it would appear that the problems of poor adaptability and striga resistance will be overcome. On the face of it, then, hybrid sorghums produced for sale rather than for subsistence should play a big role in Africa's future agriculture.

Of course, hybrids are not without drawbacks. They perform best under good production conditions and good quality control. They are suited only to sites where seeds and other materials can be readily delivered. (Farmers must purchase fresh seed for each planting.)

Further, it has been found in Nigeria that during the rainy season the male-sterile plants used in making the hybrid seed are vulnerable to ergot.

Some observers believe that problems such as these make hybrid sorghum appropriate for only a small part of Africa. This may be true, but as the following sections show, there are reasons for thinking that large-scale, efficient, productive, and very profitable sorghum production can indeed become a major part of Africa's agriculture mix.

Honduran Hybrids

The fact that sorghum hybrids can eventually benefit Africa and other regions is suggested by recent experiences in Central America, where a special kind of hybrid has been developed for peasant farmers.

Farmers in Honduras have in recent decades planted more than 60,000 hectares of sorghum, but harvested less than 1,000 kg of grain per hectare - the lowest yield in Central America. This may not be surprising considering that more than 90 percent is grown on marginal land and the varieties are nondescript landraces (locally called maicillos criollos).

These "mixed-breed" strains of unknown ancestry are low yielding, monstrously tall (3-5 m), and late maturing. On face value they should be replaced. However, the farmers resist. As with peasants everywhere, yield is not their top priority. The diverse "mongrels" are preferred because they are dependable.

Also, they mature later than maize so that farmers growing the two crops together have time to harvest both conveniently.

But now a big change is beginning. Now researchers have crossbred maicillos criollos with elite germplasm from overseas.

This has produced new, souped-up forms of the traditional types, called maicillos mejorados (improved indigenous varieties) or maicillos enanos (dwarf indigenous varieties). They are still basically the dependable, convenient types of old, but the new genes have reduced their height, improved their disease resistance, and increased their yields.

These slightly renovated rustic relicts, still retaining the qualities that farmers value, have broken through the yield plateau that for years strangled greater sorghum production.

Improved maicillos (the word means "little maize" and reflects the fact that sorghum and maize are not too distantly related) yield 24-58 percent more than their ancestors, even when little or no fertilizer is applied.

A second phase is now beginning. It involves hybrids made by crossing two local landraces.

Although hybrid sorghums have been known for four decades, they have previously been made by crossing only elite parents. Honduras is unique in using the local "mongrels" as parents. For purposes of producing the necessary hybrid seed to sell to farmers, researchers there have created dwarf lines that can be mechanically harvested using combines. In trials throughout Honduras the resulting maicillos hybrids have outyielded the traditional landraces by 100 percent. Some have produced 6,000 kg per hectare under dryland conditions. The plants are taller than their dwarfed parents (because of complementary height genes), and they can still be used in the traditional maize/sorghum intercropping system.

Unlike other new technologies that tend to benefit the affluent and progressive farmers most, hybrid maicillos are targeted for the poor and less venturesome.

They provide an alternative that may increase yields on perhaps 235,000 hectares throughout Central America. Cost to the farmer? Negligible, according to the researchers involved. The seed needed to plant a hectare (when cropped with maize) costs no more than a chicken or two, or about a third of the cost of a bag of fertilizer.

"Vybrids"

The criticism most commonly aimed at any hybrid crop proposed for poor farmers is that its seed is worthless for replanting. The fact that farmers must purchase new seed each year is often seen as a disastrous financial burden. Much of the criticism has been overemphasized.(9) (9) For example, no hybrid can survive in the marketplace unless its improved performance and the farmer's increased income far outweigh the cost and bother of purchasing seed. Also, experience in India and in Africa is showing that farmers are fully prepared to pay as long as the cost is justified by the hybrid's performance. In addition, it takes very little sorghum seed to plant a hectare. Compared to maize, the cost should be much less.

However, in many developing countries logistical logjams and supply bottlenecks do make it difficult to produce hybrid seed and get it to the farmers on time and in good condition.

With sorghums, however, there is a distant possibility of having the best of both worlds - to grow hybrids that also produce seed that can be planted. These so-called "viable hybrids" or "vybrids" are not yet available, but a few sorghum researchers are hot on their trail.

Vybrids are made possible by the fact that certain rare sorghums are apomictic - they produce offspring without the male and female gametes fusing. In other words, their seed arises from a nonfertilized nucleus, and for this reason each plant produces progeny genetically identical to itself. This special clonal propagation through seed retains the benefits of hybrid performance while not requiring a highly developed industry to produce and distribute seed each year.

The theoretical possibility of producing viable hybrids in crops was discussed as early as the 1930s. Nearly 60 years later, the various attempts at producing them have resulted in some progress. One notable success has been in breeding buffer grass (Cenchrus ciliaris) - a native African species, distantly related to sorghum, that is used as a forage throughout the tropics. Another has been with forage grasses of the genus Dichanthium (Bothriochloa).

Work on sorghum apomixis has now reached the stage where apomicts and vybrids from crosses between them have been formed in research facilities. The scientists are confident that the vybrids can now be developed for farm use.

Vybrids will benefit more than farmers. For sorghum breeders of all stripes' vybrids offer exciting potential. Sexual types can be used in the normal way to develop hybrids with superior characteristics and then induced into apomictic forms that will retain the new qualities, generation after generation, from then on.

Sorghum Beer

In Africa, as in many parts of the world, brewing uses vast amounts of grain. However, in Africa the raw materials are sorghum, maize, pearl millet, and finger millet, not barley, rice, or wheat. Also, the basic process is unique. African brewing includes a lactic-acid fermentation, known as souring. And the resulting beverage is something like a fermenting gruel and has the consistency of malted milk.

Normally called "sorghum beer" or "opaque beer," this drink already constitutes a considerable part of the diet in many areas, and it will likely become an ever bigger commodity. With so many people moving into the cities, it is even now shifting from an exclusively family enterprise to an industrialized one. In South Africa, for instance, sorghum-beer brewing is already a highly specialized industry. Annual production is about one billion liters.

Malting is the first step in brewing this or any type of beer. The grain is soaked and left to germinate. This activates amylases and other enzymes that hydrolyze the grain's starch and proteins to sugars and amino acids. After several days, when germination is complete, the sprouted grains are dried, ground to a coarse powder, mixed with cold water, and added to a preparation of ground-up grain that previously has been steeped in boiling water.* The enzymes continue working, this time turning the new source of starch into sugar. The souring process also takes place as bacteria act on part of the sugars to form lactic acid. The product - a thin gruel called "sweet wort" - may be drunk after less than a day. Its alcoholic content is negligible, but it contains some B vitamins and it is often given to children.

If the brewing is continued, various yeasts multiply, and within a day or so fermentation begins. This produces alcohol, B vitamins, new proteins, and more lactic acid. The resulting brew is normally drunk after 4 or 5 days. Suspended particles of starch, yeast, grain, and malt give it the characteristic milky body. High acidity (resulting from the lactic acid) prevents the growth of pathogenic microorganisms.

Brewing raises the nutritional value of sorghum. It adds vitamins, neutralizes most of the tannins, hydrolyzes the starch to more digestible forms, and increases the availability of minerals and vitamins. South African studies indicate that iron is 12 times more available in sorghum beer than in a boiled sorghum gruel; riboflavin may be almost twice and thiamine almost a third more available; niacin's availability remains unchanged. In principle, 2 liters of sorghum beer could supply a person's daily requirement for thiamine and riboflavin and 40 percent of the requirement for niacin. However, many of these B vitamins are locked up in the yeast cells and cannot be digested unless the beer is first boiled. Unfortunately, this is seldom done.

Special varieties of sorghum are maintained for their brewing qualities. In many places, the dark brown grains are prized. Their most important characteristic is their high level of amylase activity. They have considerable potential as substitutes for barley, even for brewing lager-type (European-style) beers. Nigeria already uses them this way, at least on a semi-commercial scale.

Recently in South Africa, the Council for Scientific and Industrial Research (CSIR) developed three shelf-stable brewed-sorghum products: a pasteurized bottled beer, an aseptically packed still beer, and a wort concentrate that can be diluted and fermented to produce beer. These are safe to transport, and can be distributed to remote areas or even exported.

In South Africa, sorghum beer is the basis of a giant company that was formerly part of a government monopoly but has now been spun off to African entrepreneurs with amazing success.

The beer is more than a mere drink. As one writer has stated: "The whole social system of the people is inextricably linked up with this popular beverage: the first essential in all festivities, the one incentive to labor, the first thought in dispensing hospitality, the favorite tribute of subjects to their chief and almost the only votive offering dedicated to the spirits. Beer is a common means of exchange or payment for services rendered, and in times of plenty it is not only freely consumed, but often is the principal or sole food of many men for days on end. It is evident in all ritual and ceremonial occasions binding together different groups or individuals and affecting a reconciliation when things go wrong. With most tribes, harvest thanksgiving takes the form of beer, preceded by an offering of beer to the ancestors of the chief."

STRIGA-RESISTANT TYPES

One of the tragedies facing Africa is that a parasitic plant is cutting it off from the wealth of sorghums that have been, or are being, developed in a score of countries overseas. Indeed, striga is probably the greatest constraint to the production of foreign sorghums in Africa itself.

Recently, however, researchers have discovered a striga-resistant gene in sorghum. This could be a big breakthrough. For Africa, it will help open the door to the truly remarkable types developed in the Americas and China, for instance.

This topic is treated in Appendix A. It is made suddenly more relevant because a new test has been developed that can determine, within a few days, whether a certain sorghum (or other species) is resistant to striga. Tests in laboratories and greenhouses have been most encouraging. Should these results also prove practical in the field, it could open the way for overcoming the depredations of this vegetative parasite that victimizes desperately needed food plants. For the first time the crops will have the means to defend themselves.

DWARFS

The last 40 years have seen dramatic increases in the yields of wheat, rice, maize, and some other cereals. This has come not from boosting the plants' overall growth (as most people may think), but from rearranging their architectures so that the plants are shorter. With less energy going into stalk, more is left for growing grain. In technical terms, this is called raising the "harvest index." Thus, 50 years ago wheat had a harvest index of 32 percent; now it can be as much as 48 percent in some cultivars. In other words, almost half of the weight of the plant (above ground) is now grain.

Moreover, reducing the height makes the plants less likely to get top-heavy and blow over in a summer storm. In addition, the squat, strong plants are more able to benefit from fertilizer, which otherwise would make them spindly and top-heavy. And dwarfing not only boosts yields: wherever mechanical harvesting is practiced, short stature means that the seedheads can be efficiently captured by combine harvesters so that larger areas can be planted.

So far, only a few of the world's sorghums have had their architecture refashioned in this way. Nonetheless, an increasing number of shortstalked sorghums that mature at an even height and can be harvested by combine are becoming available. Most have been created in North America. Indeed, all of America's commercial grain types are now dwarfs.

Initially, sorghums in the United States were tall and had a harvest index of 21 or 22 percent (about the same as in the spindly subsistence types now grown in West Africa), but careful selection, followed by intensive breeding, has reduced the internode length. Now the harvest index for many improved types used in the United States, Mexico, and Argentina is 48-52 percent, as high as that of wheat.

Dwarf sorghums have also been created at research stations in Zambia. These local dwarfs, as well as those from overseas, could eventually usher in a new era for the continent.

Sorghum's Miraculous Conversion

At first glance, sorghum seems almost impossibly diverse. Seed banks hold more than 25,000 samples, all distinct and all able to produce fertile intercrosses. How to extract from the myriad combinations the particular ones most useful worldwide is a monumental problem that might seem beyond the realm of reason. However, remarkable progress is already being made, thanks to a project that exemplifies how many of the cereals in this book might be advanced in the future.

In the 1950s, U.S. Department of Agriculture scientist Joseph Stevens developed a "blueprint" for systematically enhancing the genetic base of the world's sorghum crop. Along with several colleagues in the United States and India, he began assembling, evaluating, characterizing, and classifying a base collection of sorghum samples. This collaborative effort was carried out in India and continued into the early 1960s. The Indian government, as well as dozens of African and Asian countries, contributed their germplasm and support. Eventually, about 11,000 different sorghums were on hand.

As a first step in sorting useful genetic materials out of the vast sorghum collection, a unique "shuttle-breeding" procedure was devised. The breeders produced and grew a first generation of random crossbreeds in the tropics (mainly at Mayaguez, Puerto Rico) where the days are short. They collected seeds from a wide range of the most desirable looking progeny and took them to a temperate zone (Texas) where days are long during the growing season. There, the seeds were grown out and a new generation of seeds were gathered again from the most promising specimens. This dual-latitude screening ensured that the resulting seeds (and their subsequent generations) could grow and produce grain under both tropical and temperate conditions.

The next step was to partially refine these genetically diverse populations. Again, a wide array of different specimens were grown and the most desirable selected' this time emphasizing short stature and early maturity. The final result was a cornucopia of various sorghums - all broadly adaptable to various daylengths, all short in stature, and all early maturing. Out of the myriad tall, slow, and sensitive types, suitable only for small farms in the tropics, have come universally useful types for use throughout the world, on any scale.

Although the resulting plants were selected for basic qualities, they were deliberately kept diverse. Now, that welter of gene types is being fine-tuned to meet the specialized demands of dozens of different localities. Specific characteristics now being "custom-designed" include:

· Resistance to disease (downy mildew, striga, anthracnose, and smuts)
· Resistance to insects (aphids, midges, worms, shootfly, and others)
· Resistance to stressful conditions (drought, heat, soil acidity, and salinity)
· Strong stalks (to stop the plants breaking or failing over in wet soil)
· Nonsenescence (to keep plants green and functional, even under stress)
· Twin-seed (making both florets in the grain-producing spikelet fertile)
· Easy threshing

· Erect leaves (to increase the amount of sunlight intercepted)
· Higher yield (more grains of good size in each seedhead)
· Greater root development (to help the plants withstand stresses)
· Faster grain filling (to reduce danger from drought and insects)
· Resistance to weathering (seeds that do not soften)
· Light colors (to make the most widely acceptable food products)
· Increased protein content (more than 10 percent)
· Superior amino-acid balance (high lysine, in particular)
· Improved flavor
· Greater digestibility
· Expanded diversity for food products (notably specialty types for convenience foods)

Materials from the sorghum conversion program are already helping transform this formerly obscure and often scorned grain into a major contributor to world food supplies. Indeed, their seeds have become cornerstones for much of the present rise in sorghum production worldwide.

All in all, the Sorghum Conversion Program has become one of the most successful plant-breeding programs ever; a model of achievement for crop scientists everywhere and with every crop. It provides populations that are reservoirs of genes, rather than a single, highly inbred variety.

CONVENIENCE FOODS

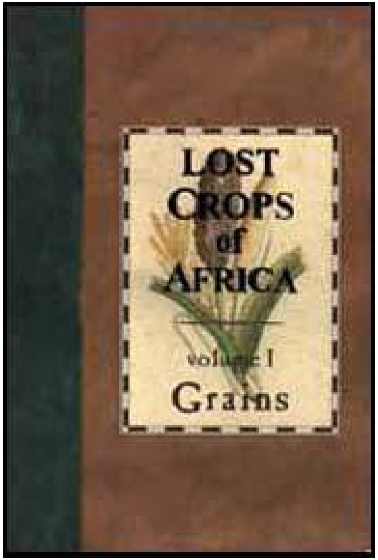
As has been noted, commercial sorghum's major problem in Africa is that markets for flour and foods are undeveloped. If this were overcome, a large and healthy trade between a country's own sorghum farmers and its cities could operate to everyone's benefit. Today, ever increasing numbers of city folk are being weaned onto wheat-flour bread and white rice, and any resulting economic benefits go mostly to farmers and traders a world away. The tragedy is that many of the city dwellers, especially newcomers, are accustomed to sorghum foods and would continue to purchase them if they could.

It is not inconceivable that Africa could produce vast amounts of sorghum flour and sorghum-based processed foods for sale in the cities and towns (see Appendix B). This could result in opportunities for much innovation.

More than 30 years ago, for example, South African researchers developed a precooked sorghum product. They slurried raw sorghum flour with water and passed it through a hot roller that both cooked and dried it. The product proved very palatable and would keep for at least 3 months without deteriorating. Whole milk or skim milk could be used in place of water, producing a tasty flour rich in protein, calcium, and phosphorus. Processing costs reportedly were low.

This is just one of many approaches by which sorghum might be produced for urbanized peoples. Many recipes using milled sorghum grits or flour have already been developed and tested by several universities. (13) And the recent development of parboiled products from sorghum could open up even more markets that could benefit millions of Africa's farmers (see Appendix B).

FIGURE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10. Sorghum: Specialty Types

Sorghum's range of genetic diversity is truly amazing. Some types look so abnormal that until recently they were classified as separate species. However, all of them cross readily with one another, all have a chromosome complement of 2n= 20, and all are recognized today as variants of the same plant, Sorghum bicolor.

Many of the unusual types are promising resources in their own right. Some have properties and uses quite unexpected of a cereal. A few hold out the possibility of producing far better grains than those of today's major sorghums. Others could provide entirely new types of sorghum foods. Yet others can yield feed, forage, fertilizer, fiber, fuel, sugar, and raw materials for factories of many kinds. In this array of plant types, the vast potential of this remarkable species can be seen. Examples of promising, but little-known, food types are discussed below.

POPPING SORGHUMS

In parts of Africa and Asia, sorghums that pop like popcorn can be found. These have seldom received much scientific or entrepreneurial recognition. There is probably, however, a huge latent market for them. They make tasty foods, and they may have worldwide promise. Popping boosts the flavor of sorghum, and it is energy efficient and nutritionally desirable. (Compared with boiling, for instance, popping is so rapid that it takes little fuel and it denatures or hydrolyzes the proteins and vitamins only slightly.)

Popped sorghum is already a favorite in central India, and it is starting to find favor in several other countries as well. In India, people sprinkle a handful of dry grain onto a bed of hot sand or a hot sheet of metal. The popped kernels are brushed off as they form. Most are consumed by school children as a snack.

They may be balled with crude sugar (jaggery). They may also be pounded into a nutty- flavored flour, which is typically mixed with milk and sugar, buttermilk, salt, or chilies.

A world collection of sorghums is maintained at ICRISAT. Of

3,682 accessions tested, 36 have shown good popping qualities. Most originated in India. These could be the starting point for breeding popping sorghums on a scientific basis. Indeed, they could create a new and very tasty food that could quickly establish itself in most of the 30 or more nations that grow sorghum as a staple - not to mention in at least that many more nations that now look on sorghum as "barely fit for cattle."

As with popcorn, the best popping types usually have small grains with a dense, "glassy" (corneous) endosperm that traps steam until the pressure builds to explosive levels.

VEGETABLE SORGHUMS

In certain countries, sorghum is eaten like sweet corn. The whole seedhead (panicle) is harvested while the grain is still soft (dough stage). It is roasted over open coals, and the soft, sweet seeds make a very pleasant food. These strains are found notably in Maharashtra, India. Like sweet corn, they have sugary endosperms containing 30 percent glycogen as well as grains that shrivel when dry. They are a treat for anyone.

This unique method turns sorghum into a vegetable crop - more like broccoli than like barley. It has so far received little or no serious study from scientists, but it could be a powerful way to capitalize on the plant's ability to produce food in sites where most crops fail. The types that perform this way should be collected, compared, and cultivated in trials.

The traditional processes by which they are used should be analyzed, as should the nutritional value. Seedheads in the dough stage may have a better-than-expected food value.

VITAMIN-A SORGHUM

In some developing countries a lack of vitamin A in the daily diet blinds many children.

However, certain sorghums with yellow grains may solve the problem, at least among sorghum-eating societies. The color comes from xanthophyll and from the carotene pigments that are vitamin-A precursors. People eating them have a better-than-normal production of vitamin A.

Yellow sorghums are especially well known in Nigeria but probably can be found elsewhere, too. The carotene levels are typically only a fraction of those normally found in yellow maize.

However, because of poverty or locality, sorghum eaters often have no chance to vary their diets. Yellow varieties may be the most practical way to protect their eyesight.

TANNIN-FREE SORGHUMS

Some sorghum types contain invidious ingredients that "lock up" protein and starch so that a person's body cannot fully get at them. Traditionally, these ingredients have been called "tannins," although strictly speaking, this is not an exact term.

Many sorghums, especially those now grown in East Africa, are high in tannins. To a large extent they have been deliberately selected because birds hardly touch them (see Appendix A). These birds include the quelea - a small, rather nondescript weaverbird that has replaced the locust as the most serious pest of small-grain crops in parts of Africa. This voracious seed-eater may well be the most abundant bird species on earth, and its importance as a pest has increased in recent years despite all the control operations that have been mounted against it.

Today, people can eat the dark-seeded sorghums only if the tannins are first removed. There are two approaches for getting around this. One is to use the seeds in processes that neutralize tannins - making beer or fermenting the grain with wood ash are examples.

The second relies on the fact that the tannins are located primarily in the grain's outer layer.

Milling this off makes the rest of the grain edible. This is not easy to do, however, and the seemingly endless task of pounding seeds with heavy poles causes untold hours of daily drudgery throughout most of rural Africa. Indeed, it is one of the fundamental barriers to the wider use of this crop (see Appendix B).

Overcoming the tannin problem would open new possibilities for sorghum as a world food grain. Research in the 1980s has demonstrated that the genes controlling tannin production can be reduced through crossbreeding. Tannins can be eliminated or at least reduced to negligible quantities. White-seeded, tannin-free types are known and are particularly promising for the future.

BIRD-RESISTANT SORGHUMS

Removing tannins makes sorghum a far better food for humans, but in parts of Africa, unfortunately, it would seem also to be good for the birds. However, some white-seeded types that are both tannin free and shunned by birds are already available.

Two sorghums that are bird resistant and free of tannin were identified in 1989. These two genotypes (Ark 1097 and a Brazilian hybrid) were assayed and found to contain absolutely no tannin throughout the whole time their seeds were developing. In addition, both showed good bird resistance in trials in Indiana, USA. In Puerto Rico, where bird pressure is greater, each was damaged, but only in one of two replications; in the other, it remained untouched. All in all, these white-seeded, tannin-free genotypes appear to be slightly less bird resistant than the standard strongly resistant, high-tannin types. Nonetheless, the level of resistance was enough that these sorghums can be very useful in areas where bird damage is normally severe.

The nutritional quality of these two is not yet fully determined, but all indications are that both are fully comparable to the low-tannin (bird-susceptible) sorghums. In a feeding trial, for example, laboratory rats grew much faster and showed more efficient feed utilization than the (high-tannin, bird-resistant) control. Remarkably, they were even better than the low- tannin types. Indeed there were no apparent nutritional problems associated with consuming the grain.

Trials of these sorghums are under way in Kenya.

QUICK-COOKING SORGHUMS

The starches in the grains of most sorghums have gelatinization temperatures around 70°C.

They must reach that temperature to become cooked and edible. However, research has shown that some sorghums have starches whose gelatinization temperature is only about 55°C.

This can reduce the cooking time required. These sorghums have waxy kernels (endosperm) rather than hard vitreous ones. Thus, they cannot always be used in the normal manner. Nonetheless, there is a good possibility that they will make nontraditional quick-cooking products that will appeal to many.

These unusual types are found especially in East Asia. The starch in their grains is entirely amylopectin, rather than amylose and other normal forms.

AROMATIC SORGHUMS

Some sorghums in Sri Lanka and northeastern India are said to have the aroma of basmati, the fragrant rice preferred by millions of Asians. Although bland-tasting rice has dominated international markets, the basmati type has always been tropical Asia's favorite, and it is now increasingly sold worldwide (even in the United States) as a highpriced specialty. The discovery of sorghum counterparts opens up similar opportunities. They, too, might become specialty foods of high value. Also, they might help boost the acceptance of sorghum - normally the blandest of grains - even where it is a staple.

All in all, flavorful types like these present good opportunities for improving markets and increasing consumption, not to mention boosting the returns to farmers.

QUALITY-PROTEIN SORGHUMS

Deep in the misty green valleys of Ethiopia's highlands is hiding a unique sorghum that, in both nutrition and palatability, far surpasses the thousands of types found elsewhere.

Ethiopians call these types "milk in my mouth" (wetet begunche) and "honey squirts out of it" (marchuke). To anyone who has tasted normal, bland, sorghum flour, the names alone indicate something special. Both varieties produce somewhat lower yields than normal but everyone likes to eat them. The taste of roasted marchuke, for instance, has been likened to that of roasted chestnuts. People gather the grains, roast them over a fire, and pop them down like peanuts. Both are often used to enhance the flavor of local dishes made from regular sorghums. The taste comes from the reducing sugars that caramelize as they are roasted.

Until 1973 these two varieties were restricted to a tiny upland area of north-central Ethiopia.

The growers hid them in the middle of their sorghum fields (mainly so the landlords wouldn't find out and raise the rents based on the extra income from these elite types). In 1973, however, researchers analyzing different sorghums for their food value stumbled onto them. Of 9,000 varieties tested, these two were unique. They contained 30 percent more protein, but more important, their protein had about twice the normal level of lysine, an amino acid critical to nutritional quality.

This finding is significant because the more than 500 million people for whom sorghum is the main source of sustenance are relying on a food that is not great, nutritionally speaking.

Its protein content is modest (averaging about 9 percent), and its protein quality is among the lowest of any cereal - mainly owing to its dismal lysine level.

In the years since 1973, neither of the two quality-protein sorghums has fulfilled its promise.

There are several reasons for this. Both types produce floury grains with small and soft endosperms, a feature that makes them more susceptible to birds, fungi, and insects. More important, however, soft grains are not favored for traditional purposes. Upon pounding or milling in a machine, they form a paste rather than a flour. Also, there is not much endosperm there to make a flour from in the first place.

This fundamental problem with grain type is a big barrier: either a laborious breeding program is needed to transform the grains into the hard-endosperm form or people must use the soft form in foods differing from their normal grain-sorghum fare.

A promising immediate use of these remarkable varieties is as feed. Animals are less fussy than humans, and lysine-rich feeds, which are particularly necessary for pigs, are critically short in many places. Fish meal and soybean meal (the main lysine sources for livestock) are often unavailable or too expensive, especially in remote Third World areas. High-lysine sorghum with its inbuilt robustness and drought tolerance could well become a vital feedstuff for northern China; large, dry areas of the Soviet Union; much of the Middle East; the semiarid zones of India and Pakistan; substantial portions of Mexico; and other places that are dry, salty, and lacking in lysine-rich feeds.

Moreover, the single gene responsible for the high lysine may be invaluable for boosting the quality of conventional sorghums.

Researchers at several research facilities are trying to transfer this gene. They hope to enhance the nutritional value of normal sorghums without affecting the grain structure or other important traits.

The Super Sorghum of the Sudan

Although it is perhaps the most important grain in Africa, sorghum still has tremendous untapped potential. Many remarkable types are yet to be discovered by science, as the following example shows.

When word leaked out in 1984 that a disastrous famine was impending in Dafur and Kordofan, the horror that swept the world energized many people into action. No one took a more original approach than the organizers of "Band Aid," a project in which rock and roll stars staged a free concert for worldwide television. The donations from dozens of countries then went to help those stricken provinces of the Sudan. Part ended up in a far-sighted study of sorghum.

With Band Aid funding, David Harper, Omar Salih, and Abdelazim Nour visited 150 villages in the drought-devastated area, checking on the people's welfare and gathering samples of the local crops - especially those that had best survived the drought. A sorghum variety called "Karamaka" proved to be truly remarkable.

For one thing, Karamaka had a protein that was unusually nutritious. It had more than the normal amount of protein but, more importantly, its protein had about twice the nutritional value of other sorghum proteins. Its lysine content (3.4 percent) was 62 percent above normal, and the other essential amino acids were not diminished to any significant extent.

As a result, Karamaka protein had a chemical score of 62 rather than the 30-40 figure of regular sorghum protein. Its nutritional value was therefore almost two-thirds that of milk protein, the usual standard of protein perfection.

For another, Karamaka grain possessed an unusual combination of carbohydrates, containing less starch and much more sugar than normal. Indeed, the total sugars in the grain amounted to 35 percent. The individual sugars were composed of both sucrose and reducing sugars, but the sucrose level alone was approximately twice normal.

The ultimate star of the Band Aid concerts may be this drought tolerant crop, whose palatability and protein might lead sorghum into a new era of significance for feeding the world at large. Karamaka not only foiled the famine, it proved a nutritional gem, on a par with the best quality cereals.

SORGHOS

Sorghum and sugarcane are fairly closely related, and certain sorghums (often termed "sorghos") have stems that are just as rich in sugar as sugarcane's. These sweet sorghums are surprisingly poorly known compared with sugarcane and sugar beet. Nonetheless, they have a big potential in a world increasingly in need of renewable sources of energy (see next chapter). Also, as food crops they deserve more attention.

Unlike sugarcane, sweet sorghum grows in a wide geographic range. It can be considered "the sugarcane of the drier and temperate zones." It has a production capacity equal or superior to sugarcane's, at least when considered on a monthly basis.

Two types have been developed by breeders:

· Syrup sorghums, which contain enough fructose to prevent crystallization; and
· Sugar sorghums, which contain mostly sucrose and crystallize readily.

RICELIKE SORGHUMS

The shall'' type of sorghum (the margaritifera subrace of the guinea race) has small, white, vitreous seeds, which are boiled like rice.

As of today, little or nothing is known about this interesting form of sorghum, but it could have a good future and deserves exploratory research.

TRANSPLANT SORGHUMS

In certain regions of semiarid West Africa, various special sorghums are transplanted like rice. These are used particularly by peoples living in the bend of the Niger, including parts of Cameroon, Chad, Niger, and Nigeria.

Little is known about these. However, transplant sorghums are produced in the dry season - growing and maturing entirely on subsoil moisture. They are ephemerals that must get through their life cycle before the soil dries back to powder or pavement.

They must mature quickly to survive. Some can produce a crop in 90 days - merely half the time the rainfed types require in that area.

One fascinating example has been identified at Gao in northern Mali. It is cultivated by ex- nomad Tuareg, and yields more than 1,000 kg per hectare on residual moisture from the runoff water remaining after light rains. Two others are masakwa and moskwaris.

These dry-season sorghums have special traits including:

· Large, hard, high-quality grains, locally considered special delicacies;
· Heat tolerance at the seedling stage;
· Drought resistance or tolerance; and
· Ability to flourish on residual moisture in heavy clay soil.

Transplant sorghums grow only on clay pans with a high water table. They are often cultivated on vertisols, which are among the world's most refractory and frustrating soils to deal with. Wet, these soils become soft, sticky, and plastic; dry, they become iron hard and deeply cracked. At least once a year they go from one extreme to the other. Few plants can withstand the trauma. For all that, however, vertisols have high fertility. Any crop that can perform in such recalcitrant sites could be a boon to several parts of the tropics that are now languishing for lack of a crop suited to vertisols. Transplant sorghums therefore deserve international attention.

The yields from transplant sorghums depend on the amount of moisture stored in the soil, but are relatively high by the standards of the very difficult sites where they are grown. (Their high yields probably result from the fertility of the swamp clays.)

These transplant types apparently are uniquely adapted to the unusual conditions of inundated clays and perhaps are unsuited to dry or infertile soils.

FREE-THRESHING SORGHUMS

Despite general opinion, some sorghums thresh easily. The heads hold onto the seeds during the harvest as well as during drying and transport; however, the farmer can separate the seeds from the heads with hardly more effort than is used to thresh wheat or rice. For example, the sorghum variety called "Rio" has an "easy thresh" characteristic. Another variety line being used currently in U.S. breeding programs is SCS99. It is both free threshing and tolerant of drought in the post-flowering stage.

The term "free threshing" is also applied to the involute glumes of some West African guinea sorghums. Their seeds are completely exposed and they easily thresh completely free of the plumes.

Sorghum Comes to America

Sorghum has been in the United States for a long time. The grain types commonly called "guinea corn" and "chicken corn" were introduced from West Africa at least two centuries ago. Both were probably packed as provisions on slave ships and reached the New World only inadvertently. Americans first grew these grains along the Atlantic coast but later took the crop westward where it found a better home in the drier regions. Later-arriving grain types include some that were deliberately introduced by seedsmen and scientists towards the end of the 1800s. By 1900, sorghum grain was well established in the southern Great

Plains and in California; indeed, it had become an important resource in areas too hot and too droughty for maize.

The sorghum known as "broomcorn" was supposedly first cultivated in the United States by Benjamin Franklin. He is said to have started the industry in 1797 with seeds he picked off an imported broom. The stiff bristles that rise from the plant's flower head have produced many of America's brooms and brushes ever since. By the 1930s, for example, American farmers were cultivating 160,000 hectares of broomcorn.

The so-called "sweet'' sorghum, with its sugar-filled stems, reached these shores in about the mid-1800s. It landed first in the Southern states - supposedly introduced as a cheap treat for slaves. Within 50 years, however, it had spread so widely and become so popular that sorghum was known as "the sugar of the South." Each locality in the Southern farm belt had a mill to crush sorghum stalks. The resulting syrup, a little thinner than molasses, became the sweetener of the region: poured over pancakes, added to cakes, and everywhere employed in candies and preserves. Today, this golden liquid is not so well known, but many rural communities still hold annual sorghum festivals and crude old mills squeeze out an estimated 120 million liters of syrup each year.

Sudangrass was introduced in 1909. This form of "grass sorghum" is now used for animal feed throughout the nation's warmer regions.

Sorghum in China

In China, sorghum is amazingly popular. In the northern parts, especially, millions of villagers consider kaoliang a part of everyday living. Many employ every part of the plant - from top to bottom.

Grains. For millions of Chinese, sorghum is a daily staple. The grains are eaten at perhaps every meal. Certain types of waxy grains are baked into cakes. Other types are fermented and distilled into strong spirits. To connoisseurs, China's best liquors are those made from sorghum - the famous (or infamous) maotai and samshu, for example. Certain grains, particularly the darker-colored varieties, are vital for feeding horses, donkeys, and other livestock.

Seedheads. In some varieties, the empty heads are converted into brooms and brushes.

Stalks. Sweet-stemmed sorghums are a major source of sugar to millions of Chinese. Some are also harvested green and cut up like sugarcane batons. (Children are particularly fond of chewing on them.) The stalks of more woody varieties are bound together, cemented with clay, and used for partitions and walls and fences. The supple green stems are split and woven into baskets and fine matting. The strong dry stems are widely used in making handicrafts and many types of small household utensils, including plate-holders and pot covers. Sorghum stalk is, moreover, a favorite for making children's toys and many types of containers. (Sorghum cages are used to keep pet birds and insects, for example.) In some places, woody sorghum stems are the basic fuel for cooking.

Leaves. In parts of China the leaves are frequently removed before the grain harvest and used for fodder. They are vital for raising cattle, goats, horses, and rabbits.

Roots. The roots are grubbed out and dried for fuel.

All this is not just an ancient traditional practice. In modern China, hybrid sorghum has played a vital role in increasing food supplies. These days, sorghum is a high-yield crop - both for grains and for stems. In sum, the experiences in China demonstrate just how universally valuable this African grain can become.

CHINESE SORGHUMS

All sorghums are indigenous to Africa, but the plant reached Asia so long ago that thousands of cultivars developed there. Indeed, the Far East devotes a huge area to this crop. It is especially surprising to find this tropical crop in chilly climes as far north as Manchuria. Throughout northern China, however, farmers rely on sorghum not only to keep themselves fed when wheat fails but also for many of their household needs (see box opposite). Even when wheat is available, the people often eat a cheap and rather coarse sorghum bread. Special steamed breads are made from sorghum in some areas. Sorghum also goes into noodles, porridges, and boiled (ricelike) dishes. A significant proportion is used to produce strong liquor. Sorghum is also eaten, although to a lesser extent, in Japan.

China contains a cornucopia of types that are unknown elsewhere. The Flora of Chinese Sorghum Varieties, for example, lists more than 1,000 local varieties: 980 for food, 50 for industrial use, and 14 for sugar. All of these should be rapidly gathered and tested elsewhere in the world. They undoubtedly offer many genetic benefits. Eventually, they and their genes may become critical to human survival in many areas outside China.

Reuniting the genes of these Far Eastern types with those of Africa after a 2,000-year separation could be an extremely powerful genetic intervention leading to a whole new line of "Chinaf" hybrids.

COLD-TOLERANT SORGHUM

When CIMMYT first tried growing sorghum in the Valley of Mexico, the crop would not set seed. The problem was low temperatures at night. The researchers then got some high-elevation sorghums from Ethiopia, made crosses, and now have types adapted for that upland valley with its chilly nights. Cold tolerance is available in the germplasm but has not yet been fully exploited.

HEAT-SHOCK SORGHUM

Sorghum thrives under searing conditions. Air temperatures of 45°C leave it unfazed. Even at that temperature, young plants have been known to grow 20 percent in height in a single day. But sorghum has its limits. When soil temperatures climb above

50°C, its seedlings struggle to survive. Such temperatures are not uncommon at the soil surface in semiarid areas, and the consequences for sorghum farmers are often dire, sometimes even disastrous. Now, researchers at ICRISAT have found that certain sorghums withstand heat better than others. No one has paid attention to this quality before, and almost all of today's sorghums produce seedlings susceptible to burning hot soils.

By sowing seed in hot fields and seeing which survived, lines with heat-tolerant seedlings have been identified. But such tests are expensive, time-consuming, and subject to hosts of uncertainties. Now, researchers at the Welsh Plant Breeding Station are devising mass- screening techniques that can be performed in a laboratory and with much more precision.

One Welsh technique, already adopted by ICRISAT, monitors the amount of protein synthesized by the germinating seeds. In hot surroundings, the most heat-tolerant types produce the most protein. However, this test is expensive and cumbersome to run on thousands of samples, so now the Welsh researchers are developing a second generation test based on 'heat-shock proteins" (HSPs).

All living things make HSPs when exposed to temperatures above their normal range. They do it quickly - often within 15 minutes. Once made, the proteins - which are similar in plants, animals, and bacteria - seem to confer an ability to prosper in the heat. Their exact function is still uncertain, but they may protect the organism's proteins, messenger RNA, or membranes from damage. One HSP - often called HSP70 because it has a relative molecular mass of 70,000 - may ensure that heat-damaged proteins regain their proper shape so that they can continue working as enzymes, muscles, and antibodies.

The researchers now have found that briefly exposing a sorghum seedling to temperatures between 40°C and 45°C induces it to produce a characteristic set of HSPs. From then on, the plant can tolerate temperatures of 50°C or even more without suffering damage.

Although all sorghum seedlings make HSPs, those that tolerate heat best make HSPs much sooner after germinating. Speed is the secret of their success.

This response is being studied in the hope of finding an easily recognizable feature that can identify heat tolerance without torturing the seeds. If successful, this will open the way to mass screening so that farmers in the hottest areas will no longer face the heartbreak of seeing their fields wilting in the blazing sun before the plants have even grown more than knee-high.

Another approach is to find the regions of the chromosomes which are important for survival of heat stress. DNA probes are being used as markers by the researchers in Wales to follow regions of the chromosomes linked to the thermotolerance trait from parents to subsequent generations.

TROPICAL SORGHUMS

A few sorghums grow in the humid lowland tropics. Although they are not well studied, the guineense and other related groups (roxburghii and conspicuum, for example) could be useful as genetic sources for improvement of genotypes for humid tropical regions.

WILD SORGHUMS

At least two undomesticated forms show extremely robust growth under the harshest of conditions. One, the verticiliflorum form (previously known as Sorghum verticiliflorum) is a wild grass, distributed from the Sudan to South Africa. It is often found in damp areas (along stream banks and irrigation ditches, for example) or as a weed in cultivated fields. On the other hand, it is also a dominant climax species in many of the area's dry, tall-grass savannas. It is thought to be a progenitor of the modern bicolor,caudatum, and kafir races of sorghum but has seldom been considered a genetic resource in its own right. Nonetheless, in research now under way, this plant is proving extremely useful in foragebreeding programs. No doubt it contains disease-fighting abilities and pest resistances that could be deployed to help sorghum.

The other (previously known as Sorghum arundinaceum) is a wild and weedy rainforest species that flourishes in Africa's wet tropics, where today's domesticated sorghums are poorly adapted. Although very little information is available, it appears to be more photosynthetically efficient at low light intensities than cultivated sorghum.

As of now it is not cultivated, but it may have a future as a domesticated crop for humid and forested regions. It is a robust species, very common along roadsides, vacant lots in cities, and other "wastelands."

WIDE CROSSES

Sorghum can be crossed with grasses genetically distant enough to be classified in different genera or even in different subfamilies. It is certainly highly speculative to think that these crosses might have any economic merit, but exploratory research efforts seem well worth undertaking. A few possibilities are discussed here.

Crosses between sorghum and certain types of Chrysopogon, Vetiveria, and Parasorghum are possible. Crosses with Pseudosorghum and selected members of the Bothriochloeae and the Sorgheae also seem possible.

Crosses between subtribes might be possible if certain members of Chrysopogon and Capillipedium were used.

American researchers are currently performing experimental crosses between sorghum and johnsongrass (Sorghum halepense), a perennial forage that has already introgressed with sorghum to become a pernicious weed in the United States.

It is hoped the grain qualities of sorghum can be united with the rhizomatous habit of johnsongrass to create a powerful new perennial cereal.

Recently, crosses between sorghum itself and its sudangrass subspecies (Sorghum bicolor subspecies sudanense) have produced hybrid grasses with outstanding vigor. Their productivity and performance have boosted even more the acreage and overall yield of forage sorghum, a main part of the livestock-grazing industries of America and Argentina.

They also promise to help in reclaiming salt-affected lands (see next chapter).

It has long been known that sorghum can be crossed with sugarcane. Chinese researchers now report developing a hybrid between the two that contains more sugar and produces more stalk and grain than either parente University Press. Such a cross might prove a method for boosting sorghum's grain yield.

In a sorghum flower, only one spikelet of each pair is fertile. In sugarcane and its relatives, both spikelets of a pair are fertile. Moreover, this trait can be transferred to sorghum, at least at the tetraploid level. See Gupta et al., 1978.

Research along these lines might turn up fascinating new resources of undreamed-of usefulness.

Will Sorghum Go High-Tech?

Since the 1960s, when tissue culture was developed for replicating plants such as potato and tobacco on a mass scale, researchers have attempted to apply this technique to grasses. For a decade or two it was considered an impossibility, but recent discoveries have changed that, and a few grasses can now be propagated this way. In 1989, for example, Indian researchers L. George and S. Eapen of the Bhaba Atomic Research Centre in Bombay reported replicating certain cultivars of sorghum using tissue culture. This development could open a new world of understanding and advancement for the world's fifth major food crop.

The Indian scientists studied seven sorghum cultivars (C021, C022, C023, C024, TNS24, TNS25, and TNS30). Cells from the stems refused to form callus (the first step in the tissue- culture process), but cells from the base of the leaves formed callus in every case. Also, cells from the seeds of one cultivar (C023) formed callus in about one-third of the samples.

When the researchers added hormones to induce the undifferentiated callus tissues to produce plantlets, all the callus samples formed roots. However, only three of the cultivars (C023, TNS24, and TNS25) formed shoots, and then only in 10-15 percent of the samples.

This discovery, while limited, is one upon which further refinements and higher efficiencies can be built. With tissue culture, powerful techniques such as restriction fragmentation length polymorphisms, the production of pathogen-free plants, and challenge breeding can be applied to understanding and improving this crop, which is so vital to Africa and the world.

Techniques like these could open possibilities even for far-out developments such as introducing into sorghum the gluten genes from wheat, adding virus-resistance genes, making somaclonal selections, and sorting through the crop's massive genetic diversity in ways that are far more efficient than any imaginable even just a few years ago.

FIGURE