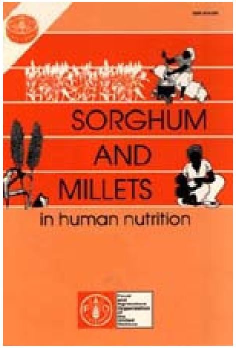

Sorghum and millets in human nutrition

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Preface

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For millions of people in the semi-arid tropics of Asia and Africa sorghum and millets are the most important staple foods. These crops sustain the lives of the poorest rural people and will continue to do so in the foreseeable future. Sorghum and millets grow in harsh environments where other crops do not grow well. Improvements in production, availability, storage, utilization and consumption of these food crops will significantly contribute to the household food security and nutrition of the inhabitants of these areas.

Sorghum and millets in human nutrition is a new addition to the FAO Food and Nutrition Series. The publication is broad in scope and coverage, starting with the history and nature of sorghum and millets and dealing with production, utilization and consumption. It provides extensive information on the nutritional value, chemical composition, storage and processing of these foods. In addition, the anti-nutritional factors present in these foods and ways of reducing their health hazards are discussed. The authors have described formulations of various popular foods prepared from sorghum and millets and their nutritional composition and quality, and they have compiled many recipes for the preparation of foods from regions where sorghum and millets are important dietary staples. An extensive bibliography is included as well.

Readers of this book may also be interested in the standards for sorghum and pearl millet grains and flours prepared by the Codex Alimentarius Commission under the Joint FAD/WHO Food Standards Programme.

FAO appreciates the collaboration and assistance of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in the preparation of this book. The Organization acknowledges the contributions of Dr R. Jambunathan and Dr V. Subramanian, both of ICRISAT, to Chapters 1, 2, 3 and 5 as well as those of Dr Y.G. Deosthale, of the National Institute of India, to Chapters 1, 4 and 6 and the Annex.

Sorghum and millets in human nutrition is intended to provide up-to-date scientific and practical information to scientists, government officials, extension workers, university professors and others interested in these foods. It is hoped that this text will assist them in the development of training programmes for their staff and students.

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Director
Food and Nutrition Division

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[1] Codex Alimentarius Commission, 1990. *Codex standards for cereals, pulses, legumes and derived products*. Supplement 1 to Codex Alimentarius Vol. XVIII. Rome, FAO/WHO. 33 pp

Chapter 1 - Introduction

Sorghum and millets have been important staples in the semi-arid tropics of Asia and Africa for centuries. These crops are still the principal sources of energy, protein, vitamins and minerals for millions of the poorest people in these regions.

Sorghum and millets are grown in harsh environments where other crops grow or yield poorly. They are grown with limited water resources and usually without application of any fertilizers or other inputs by a multitude of small-holder farmers in many countries. Therefore, and because they are mostly consumed by disadvantaged groups, they are often referred to as "coarse grain" or "poor people's crops". They are not usually traded in the international markets or even in local markets in many countries. The farmers seldom, therefore, have an assured market in the event of surplus production.

The cereals considered in this publication include sorghum, pearl millet, finger millet, foxtail millet, common millet, little millet, barnyard millet and kodo millet (Table 1). Teff (Eragrostis tef), which is extensively cultivated in Ethiopia, is not strictly a millet and is therefore not included. Other millets such as fonio (Digitaria exilis) and Job's tears (Coix lancryma-jobi) are of minor importance and are not described here.

Sorghum

Sorghum, Sorghum bicolor (L.) Moench, is known under a variety of names: great millet and guinea corn in West Africa, kafir corn in South Africa, dura in Sudan, mtama in eastern Africa, jowar in India and kaoliang in China (Purseglove, 1972). In the United States it is usually referred to as milo or milo-maize (Table 1). Sorghum belongs to the tribe Andropogonae of the grass family Poaceae. Sugar cane, Saceharum officinarum, is a member of this tribe and a close relative of sorghum. The genus Sorghum is characterized by spikelets borne in pairs. Sorghum is treated as an annual, although it is a perennial grass and in the tropics it can be harvested many times.

TABLE 1: Origins and common names of sorghum and millets

Crop	***Common names***	***Suggested origin***
Sorghum bicolor	Sorghum, great millet, guinea corn, kafir corn, aura, mtama, jowar, cholam. kaoliang, milo, milo-maize	Northeast quadrant of Africa (Ethiopia-Sudan border)
Pennisetum glaucum	Pearl millet, cumbu, spiked millet, bajra, bulrush millet, candle millet, dark millet	Tropical West Africa
Eleusine coracana	Finger millet, African millet, koracan, ragi, wimbi, bulo, telebun	Uganda or neighbouring region

Setaria italica	Foxtail millet, Italian millet, German millet, Hungarian millet, Siberian millet	Eastern Asia (China)
Panicum miliaceum	Proso millet, common millet, hog millet, broom-corn millet, Russian millet, brown corn	Central and eastern Asia
Panicum sumatrense	Little millet	Southeast Asia
Echinochloa crus-galli	Barnyard millet, sawa millet, Japanese barnyard millet	Japan
Paspalum scrobiculatum	Kodo millet	India

In 1753 Linnaeus described in his Species platarum three species of cultivated sorghum: Holcus sorghum, Holcus saccaratus and Holcus tricolor. In 1794 Moench distinguished the genus Sorghum from the genus Holrcus, and in 1805 Person suggested the name Sorghum vulgare for Holcus sorghum (L.). In 1961 Clayton proposed the name Sorghum bicolor (L.) Moench as the correct name for cultivated sorghum and this is currently being used.

The classification of sorghum by Snowden (1936) is detailed and complete. Other classifications proposed since that time have been modifications or adaptations of the Snowden system. Harlan and de Wet (1972) published a simplified classification of sorghum which has been checked against 10 000 head samples. They divided cultivated sorghum into five basic groups or races: bicolor, guinea, caudatum, kafir and durra. The wild type and shatter cane are considered two other spikelet types of S. tricolor. A study of polymorphism of 11 enzymes permitted classification of sorghum into three enzymatic groups. The first includes mainly guinea varieties of West Africa; the second southern African varieties of all five races; and the third durra and caudatum types of Central and East Africa (Ollitrault, Escoute and Noyer, 1989).

The cultivated sorghum of the present arose from a wild progenitor belonging to the subspecies verticilliflorum. The greatest variation in the genus Sorghum is observed in the region of the northeast quadrant of Africa comprising Ethiopia, the Sudan and East Africa (Doggett, 1988). It appears that sorghum moved into eastern Africa from Ethiopia around 200 AD or earlier. It was adopted and carried to the savannah countries of eastern and southern Africa by the Bantu people, who used the grain mainly to make beer. The Bantu people probably began their expansion from the region of southern Cameroon about the first century AD, moved along the southern border of the Congo forest belt and reached eastern Africa possibly before 500 AD. The present-day sorghums of central and southern Africa are closely related to those of the United Republic of Tanzania and more distantly related to those of West Africa, as the equatorial forests were an effective barrier to this spread.

Sorghum was probably taken to India from eastern Africa during the first millennium BC. It is reported to have existed there around 1000 BC. Sorghum was probably taken in ships as food in the first instance; chow traffic has operated for some 3 000 years between East Africa (the Azanean Coast) and India via the Sebaean Lane in southern Arabia. The sorghums of India are related to those of northeastern Africa and the coast between Cape Guardafui and Mozambique.

The spread along the coast of Southeast Asia and around China may have taken place about the beginning of the Christian era, but it is also possible that sorghum arrived much earlier in China via the silk trade routes.

Grain sorghum appears to have arrived in America as "guinea corn" from West Africa with the slave traders about the middle of the nineteenth century. Although sorghum arrived in Latin America through the slave trade and by navigators plying the Europe-Africa-Latin America trade route in the sixteenth century, the crop did not become important until the present century. The case is similar for Australia.

Grain sorghum grown primarily for food uses can be divided into milo, kafir, hegari, feterita and hybrids (Purseglove, 1972). There are other classes of sorghums such as sorghos, grass sorghums, broom-corn

sorghum and specialpurpose sorghum.

The sorghum kernel varies in colour from white through shades of red and brown to pale yellow to deep purple-brown. The most common colours are white, bronze and brown. Kernels are generally spherical but vary in size and shape. The caryopsis can be rounded and bluntly pointed, 4 to 8 mm in diameter (Purseglove, 1972). The I 000-kernel weight has a very wide range of values, from 3 to 80 g, but in the majority of varieties it is between 25 and 30 g. The grain is partially covered with glumes. Large grains with corneous endosperm are usually preferred for human consumption. Yellow endosperm with carotene and xanthophyll increases the nutritive value. Sorghum grain that has a testa contains tannin in varying proportions depending on the variety.

Pearl millet

Pearl millet, Pennisetum glaucum, is also known as spiked millet, bajra (in India) and bulrush millet (Purseglove, 1972). Pearl millet may be considered as a single species but it includes a number of cultivated races. It almost certainly originated in tropical western Africa, where the greatest number of both wild and cultivated forms occurs. About 2 000 years ago the crop was carried to eastern and central Africa and to India, where because of its excellent tolerance to drought it became established in the drier environments.

The height of the pearl millet plant may range from 0.5 to 4 m and the grain can be nearly white, pale yellow, brown, grey, slate blue or purple. The ovoid grains are about 3 to 4 mm long, much larger than those of other millets, and the 1 000-seed weight ranges from 2.5 to 14 g with a mean of 8 g. The size of the pearl millet kernel is about one-third that of sorghum. The relative proportion of germ to endosperm is higher than in sorghum.

Minor millets

Minor millets (also referred to as small millets) (Seetharam, Riley and Harinarayana, 1989) have received far less attention than sorghum in terms of cultivation and utilization. They include finger millet (Eleusine coracana), foxtail millet (Setaria italica), kodo millet (Paspalum scrobiculatum), common or prove millet (Panicum miliaceum), little millet (Panicum sumatrense) and barnyard or sawa millet (Echinochloa crus-galli and Echinochloa corona) (Table 1). More information is available on finger millet than on any of the others. Minor millets account for less than one percent of the foodgrains produced in the world today. Thus they are not important in terms of world food production, but they are essential as food crops in their respective agro-ecosystems. They are mostly grown in marginal areas or under agricultural conditions where major cereals fail to give sustainable yields. Detailed descriptions of these millets are given by Purseglove (1972).

Finger millet

Finger millet, Eleusine coracana L., is also known as African millet, koracan, ragi (India), wimbi (Swahili), bulo (Uganda) and telebun (the Sudan). It is an important staple food in parts of eastern and central Africa and India. It is the principal cereal grain in northern and parts of western Uganda and northeastern Zambia. The grains are malted for making beer. Finger millet can be stored for long periods without insect damage (Purseglove, 1972) and thus it can be important during famine. Numerous cultivars have been identified. In India and Africa, two groups are recognized: African highland types with grains enclosed within the florets; and Afro-Asiatic types with mature grains exposed outside the florets. It is believed that Uganda or a neighbouring region is the centre of origin of E. coracana, and it was introduced to India at a very early date, probably over 3 000 years ago. Though finger millet is reported to have reached Europe at about the commencement of the Christian era, its utilization is restricted mostly to eastern Africa and India.

The height of cultivars varies from 40 cm to I m and the spike length ranges from 3 to 13 cm. The colour of grains may vary from white through orange-red deep brown and purple, to almost black. The grains are smaller than those of pearl millet, and the mean I 000-seed weight is about 2.6 g.

Foxtail millet

Foxtail millet, Setaria italica L., is also known as Italian, German Hungarian or Siberian millet. It is generally considered to have been domesticated in eastern Asia, where it has been cultivated since ancient times. The main production area is China, but S. italic a is the most important millet in Japan and is widely cultivated in India (Purseglove, 1972). It is believed to have been one of the five sacred plants of ancient China (from 2700 BC). Because of its short duration it is a suitable crop for growing by nomads, and it was probably brought to Europe in this way during the Stone Age, as seeds abound in the Lake Dwellings in Europe.

The height of the plants varies from 1 to 1.5 m and the colour of the grain varies from pale yellow, through orange, red and brown to black. The 1 000-seed weight is about 2 g.

Common millet

Common millet, Panicum miliaceum L., is also known as prove millet, hog millet, broom-corn millet, Russian millet and brown corn. This millet is of ancient cultivation. It is the milium of the Romans and the true millet of history. It was cultivated by the early Lake Dwellers in Europe. It is believed to have been domesticated in central and eastern Asia and because of its ability to mature quickly was often grown by nomads.

The shallow-rooted plant varies in height between 30 and 100 cm. The grain contains a comparatively high percentage of indigestible fibre because the seeds are enclosed in the hulls and are difficult to remove by conventional milling processes. The 1 000-seed weight is about 5 g (varying between 4.7 and 7.2 g). Common millet is particularly suited to dry continental conditions and grows in more temperate climates than other millets.

Little millet

Little millet, Panicum sumatrense Roth ex Roemer & Schultes, is grown throughout India to a limited extent up to altitudes of 2 100 m but is of little importance elsewhere. It has received comparatively little attention from plant breeders. The plant varies in height between 30 and 90 cm and its oblong panicle varies in length between 14 and 40 cm. The seeds of little millet are smaller than those of common millet.

Barnyard millet

Barnyard, Japanese barnyard or sawa millet [Echinochloa crus-galli (L.) P.B. and Echinochloa colona (L.) Link] is the fastest growing of all millets and produces a crop in six weeks. It is grown in India, Japan and China as a substitute for rice when the paddy fails. It is grown as a forage crop in the United States and can produce as many as eight harvests per year. The plant has attracted some attention as a fodder in the United States and Japan. The height of the plant varies between 50 and 100 cm.

Kodo millet

Kodo millet, Paspalum scrobiculatum L., is a minor grain crop in India but is of great importance in the Deccan Plateau. Its cultivation in India is generally confined to Gujarat, Karnataka and parts of Tamil Nadu. It is classified into the groups Haria, Choudharia, Kodra and Haria-Choudharia depending on panicle characters. Kodo is an annual tufted grass that grows to 90 cm high. Some forms have been reported to be poisonous to humans and animals, possibly because of a fungus infecting the grain. The grain is enclosed in hard, corneous, persistent husks that are difficult to remove. The grain may vary in colour from light red to dark grey.

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Grains and their structure

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Kernels of sorghum and millets show considerable diversity in colour, shape, size and certain anatomical components (Table 2).

The basic kernel structure is similar in sorghum and different millets. The principal anatomical components are pericarp, germ or embryo and endosperm. In finger, prove and foxtail millets the pericarp is like a sack, loosely attached to the endosperm at only one point. In these utricle-type kernels the pericarp easily breaks away, leaving the seed-coat or testa to protect the inner endosperm. The kernels of sorghum and pearl millet are of the caryopsis type, in which the pericarp is completely fused to the endosperm.

The relative distribution of the three main kernel components varies. In the sorghum kernel the distribution by weight is pericarp 6 percent, endosperm 84 percent and germ 10 percent (Hubbard, Hall and Earle, 1950). In pearl millet, it is pericarp 8.4 percent, endosperm 75 percent and germ 16.5 percent (Abdelrahman, Hoseney and Varriano-Marston, 1984). The ratio of endosperm to germ in pearl millet is 4.5:1, while in the sorghum kernel it is 8.4:1. In finger and prove millets the germ is very small and therefore the endosperm-togerm ratio, 11:1 to 12:1, is much higher than in sorghum.

Pericarp

Pericarp is the outermost structural component of the caryopsis and is composed of three sublayers, namely epicarp, mesocarp and endocarp. The epicarp is further divided into epidermis and hypodermic. In the sorghum caryopsis, the epidermis is composed of thick, elongated, rectangular cells which have a coating of cutin on the outer surface. Often a pigment is present in the epidermis. The hypodermic is composed of

slightly smaller cells than the epidermis and is one to three cell layers in thickness. The mesocarp, the middle part, is the thickest layer of the sorghum pericarp, but its thickness varies widely among genotypes. Mould resistance in sorghum is associated with thin mesocarp. Grains with thick mesocarp on a hard endosperm are preferred for dehulling by hand-pounding. The endocarp, the innermost sublayer of the pericarp, consists of cross cells and a layer of tube cells which transport moisture into the kernel. During dry milling of sorghum, the breakage occurs at the cross and tube cell layers.

TABLE 2: Structural features of kernels of sorghum and some millets

Grain	**Type**	**Shape**	**Colour**	**1 000-kenel weight (g)**
Sorghum	Caryopsis	Spherical	White, yellow, red, brown	25-30
Pearl millet	Caryopsis	Ovoid, hexagonal, globose	Grey, white, yellow, brown, purple	2.5-14
Finger millet	Utricle	Globose	Yellow, white, red, brown, violet	2.6
Proso millet	Utricle			4.7-7.2
Foxtail millet	Utricle			1.86

	Seed - coat	Alcurone

Grain	Number of layers	Pigmented	Thickness (pm)	Number of layers	Cell size (pm)
Sorghum	1	Sometimes	0.4	1	
Pearl millet	1	Sometimes	0.4	1	16-30 x 5-15
Finger millet	5	Yes	10.8-24.2	1	18 x 7.6
Proso millet	1	No	0.2-0.4	1	12 x 6
Foxtail millet	1			1	

	Starch granules				Protein bodies		
Grain	Diameter (m)	Peripheral zone (m)	Corneous zone (m)	Floury zone (m)	Type	Size (m)	Location
Sorghum	20-30				Simple	0.3-3	All areas
Pearl millet	10-12	6.4	6.4	7.6	Simple	0.6-0.7	All areas
Finger millet	3-21	8-16.5	3-19	11-21	Simple/ compound	2.0	Peripheral/ corneous
Proso millet	2-10	3.9	4.1	4.1	Simple	0.5-1.7	Peripheral
Foxtail millet	10						

TABLE 2 (continued)

Grain	**Germ**	
	Size (m)	**Endosperm:germ**
ratio		
Sorghum		8.4:1
Peart millet	1 420 x 620	4.5:1
Finger millet	980 x 270	11:1
Proso millet	1 100 x 310	12:1
Foxtail millet		12:1

The pericarp of the pearl millet caryopsis consists of an epicarp with one or two cell layers, a mesocarp that varies in thickness because of genetic factors and an endocarp made up of cross and tube cells. The mesocarp layer of pearl millet does not contain starch granules; these are found only in sorghum mesocarp. During decortication or milling, the pericarp of pearl millet breaks at the cross and tube cell layers and fragments of endocarp may remain with the endosperm.

Seed-coat or testa

Just underneath the endocarp is the testa layer or seed-coat. In some sorghum genotypes the testa is highly pigmented. The presence of pigment and the colour are a genetic character. The thickness of the testa layer is not uniform. It is thick near the crown area of the kernel and thin near the embryo portion. In some genotypes there is a partial testa, while in others it is not apparent or is absent. In pearl millet the testa layer is thin and sometimes pigmented. In other millets the testa is always pigmented and is only a single layer thick. In finger millet the testa is very thick, with five cell layers, and is also pigmented.

Endosperm

The largest component of the cereal kernel is the endosperm, which is a major storage tissue. It is composed of an aleurone layer and peripheral corneous and floury zones. In all the millets and sorghum, the aleurone layer is a single layer of cells which lies just below the seed-coat or testa. The aleurone cells are rich in minerals, B-complex vitamins and oil and contain some hydrolysing enzymes.

The peripheral endosperm is distinguished by long rectangular cells which are densely packed and contain starch granules and protein bodies enmeshed in the protein matrix. The starch in these cells is therefore not easily available for enzyme digestion, unless the protein associated with it is also reduced (Chandrashekar and Kirleis, 1988). The matrix protein in general is alkalisoluble glutelin and the protein bodies are alcohol-soluble prolamins which account for the largest proportion of total protein in the kernel.

The protein bodies in the endosperm of sorghum and millets are spherical and differ in size among species and also within the endosperm of a single kernel. In sorghum the number of protein bodies decreases as the starch content increases from the peripheral zone to the central core where the floury endosperm is located. In pearl millet the protein bodies are more numerous in the floury than in the corneous zone. Adams, Novellie and Liebenberg (1976) have reported the presence of several enzymes, e.g. protease, 3-glucosidases, 3galactosidase and phosphatases, in the protein bodies of sorghum. The protein bodies of sorghum, pearl millet and finger millet also contain phosphorus, calcium, potassium and magnesium.

The starch granules of corneous endosperm are polyhedral and differ in size in different millet species. In floury endosperm the starch granules are spherical and bigger than the starch granules of the corneous zone. The starch in the floury zone is more amenable to enzyme digestion. In pearl and finger millets, the starch granules of the floury endosperm are spherical and big. The starch in pearl millet is hydrolyzed more slowly than that of sorghum by hog pancreatic amylase (Sullies and Rooney, 1977).

The proportions of corneous and floury endosperm determine the texture of the millet kernel. In soft-textured kernels there is more floury than corneous endosperm. In hard-textured kernels, on the other hand, there is more densely packed corneous endosperm than floury endosperm. Foxtail millet contains very little floury endosperm and is of a hard, corneous texture. Finger and prove millet kernels, with the endosperm evenly divided between the corneous and floury zones, are of intermediate texture. In pearl millet and sorghum the kernel texture varies widely, from all floury, very soft endosperm to all corneous, very hard or vitreous endosperm.

Grain texture is one of the most important determinants of the processing and food quality of sorghum and millets (Rooney, Kirleis and Murty, 1986). Hardendosperm sorghum when decorticated gives fewer brokers and more full grains than softer-endosperm sorghum (Desikachar, 1982). In dry milling, the flour yield is higher in corneous than in soft floury types. On the other hand, in wet milling the starch yield is higher in soft-endosperm genotypes. In the preparation of thick porridge, varieties with a higher proportion of vitreous endosperm are preferred. Such varieties are also suitable for popping (Chandrashekar and Desikachar, 1986; Murty, Patil and House, 1982). For preparation of bread, fermented or unfermented, the flour of soft-endosperm sorghum is highly preferred (Rooney, Kirleis and Murty, 1986).

Germ

The embryonic axis and the scutellum are the two major parts of the germ. The scutellum is a storage tissue rich in lipids, protein, enzymes and minerals. In pearl millet the ratio of germ to endosperm is larger than in sorghum and other millet kernels. The oil in the sorghum germ is rich in polyunsaturated fatty acids and is similar to corn oil (Rooney, 1978).

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Chapter 2 - Production and utilization

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The production and consumption data on sorghum and millets can be considered as only the best estimates that are available, as production data from small subsistence farms are difficult to obtain in any country. It is also likely that grain distribution and consumption throughout the semi-arid tropical regions vary widely among seasons, communities and families. Detailed and reliable data on the variety of products made from sorghum and millets and the prevalence of their use are either scanty or currently unavailable. One reason for the lack of information is the fact that to collect this information extensive surveys are needed. Several factors such as cost, time, labour, transportation and accessibility of villages in rural areas have to be considered before a survey is carried out. In several developing countries, inadequate infrastructure and other constraints have contributed to the lack of information on consumption of sorghum and millets.

Sorghum production

The total production of sorghum in the world in 1990 was 58 million tonnes, a decrease from 60 million tonnes in the year 1989 and 62 million tonnes in 1988 (FAO, 1991). A decrease in yield from 1 340 kg/ha in 1989 to 1 312 kg/ha in 1990 was reported, while the area remained around 44 million hectares in both years. Table 3 provides data on area, yield and production of sorghum in various regions of the world.

The five largest producers of sorghum in the world (Table 4) are the United States (25 percent), India (21 .5 percent), Mexico (almost 11 percent), China (9 percent) and Nigeria (almost 7 percent). Together these five

countries account for 73 percent of total world production.

Of the total world area devoted to sorghum, over 80 percent is in developing countries. In Africa, sorghum is grown in a large belt that spreads from the Atlantic coast to Ethiopia and Somalia, bordering the Sahara in the north and the equatorial forest in the south. This area extends through the drier parts of eastern and southern Africa, where rainfall is too low for the successful cultivation of maize. Sorghum is the second most important cereal (after maize) in sub-Saharan Africa.

TABLE 3: Area, yield and production of sorghum by region, 1990

Region	**Area**		**Yield (kg/ha)**	**Production**	
	(10 ha)	**(% total)**		**(10 ha)**	**(% total)**
North and Central America	5 970	13.5	3 572	21 325	36.7
Asia	18451	41.6	1 023	18 867	32.4
Africa	17 799	40.1	718	12 784	22.0
South America	1353	3.1	2 614	3 537	6.1
Oceania	407	0.9	2 298	934	1.6
World (1990)	44 352		1 312	58190	
World (1989)	44 695		1 340	59 991	

***Source:* FAO, 1991.**

TABLE 4: Leading sorghum producers, 1990

Country	**Area**		**Production**	
	(10 ha)	**(% total)**	**(10 ha)**	**(% total)**
United States	3 674	8.3	14 516	25.0
India	15300	34.5	12500	21.5
Mexico	1 830	4.1	6 230	10.7
China	1900	4.3	5310	91
Nigeria	6 000	13.5	4 000	6.9
Argentina	688	1.6	2 016	3.5
Sudan	2 925	6.6	1 502	2.6
Ethiopia	870	2.0	1000	1.7
Australia	406	0.9	933	1.6
Burkina Faso	1 250	2.8	917	1.6
Total	34 843	78.6	48 924	84.1
World	44 352	1 00	58190	1 00

***Source*: FAO, 1991.**

Because of higher yield per unit area, North and Central America produce the highest quantity of sorghum (37 percent of total production). In Central and South America sorghum is grown in the drier parts of Mexico, El Salvador, Guatemala, Nicaragua, dry lowland interior areas of Argentina, dry areas of northern Colombia, Venezuela, Brazil and Uruguay. In North America, sorghum is cultivated in parts of the central and southern plains of the United States where rainfall is low and variable. Kansas, Texas, Nebraska and Arkansas are the major producing states, accounting for about 80 percent of total production in the United States.

In Asia, sorghum is extensively cultivated in India, China, Yemen, Pakistan and Thailand. Production in Europe is limited to a few areas in France, Italy, Spain and the southeastern countries. In Oceania, Australia is the only producer of significance; the production is concentrated in Queensland and northern New South Wales, where about 95 percent of the total crop is produced.

World sorghum production expanded from 40 million tonnes at the beginning of the 1960s to 66 million tonnes in 1979-81. However, by 1990 it had fallen to 58 million tonnes, though the area under sorghum declined only slightly, from 45.6 million to 44.4 million hectares, during the same period. The reduction in production from 1979-81 to 1990 was largely due to a decline in two major sorghum-producing countries, the United States and China. These two countries accounted for 6.2 million tonnes or 85 percent of the reduction in the global production figures. There are several reasons for the declining trend in the production of sorghum, including unpredictable and erratic distribution of rainfall (most of the sorghum grown is rain-fed), declining soil fertility, the inefficient production systems employed in individual countries, biotic and abiotic stresses and declining demand for sorghum. The growth in food demand (2.9 percent) for the period 1980 to 2000 in 90 developing countries will marginally exceed projected agricultural production growth (2.8 percent) (FAO, 1981). However, the imbalance will be more pronounced in Africa (demand 3.4 percent, production growth 2.6 percent). In the least-developed countries, production growth is predicted to lag 25 percent below the growth of demand.

TABLE 5: Sources of energy and protein in the food supply of the world's ten leading sorghum producers, 1987-89

Country	Energy per caput per day (kcal)				Protein per caput per day (g)			
	Total	From vegetable products	Percentage of total	From animal products	Total	From vegetable products	Percentage of total	From animal products
United States	3676	2430	66.1	1 246	109.6	36.4	33.2	73.2
India	2196	2 048	93.3	2 048	53.2	45.6	85.7	7.6
Mexico	3048	2 497	81.9	551	77.9	46.9	60.2	31.0
China	2634	2 365	89.8	269	62.8	50.7	80.7	12.1
Nigeria	2306	2 248	97.5	58	49.5	43.6	88.1	5.9
Argentina	3110	2 145	69.0	965	100.3	36.5	36.4	63.8
Sudan	2028	1 677	82.7	351	57.8	37.6	65.1	20.2
Australia	3186	2 036	63.9	1 150	97.4	31.7	32.5	65.7
Burkina Faso	2286	2 186	95.6	100	69.8	62.6	89.7	7.2

***Source*: FAO, 1991.**

In 1987-89, vegetable products supplied the bulk of dietary energy (90 percent or more) and more than 80 percent of total daily protein in four of the ten major producers of sorghum in the world, namely, India,

China, Nigeria and Burkina Faso (Table 5). In Mexico and the Sudan, vegetable products supplied more than 80 percent of dietary energy.

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Sorghum utilization

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Total consumption of sorghum closely follows the global pattern of output, since most of it is consumed in the countries where it is grown. Sorghum is used for two distinct purposes: human food and animal feed. Although in the early 1960s a very large part of the sorghum output was used directly as human food, its share has continuously declined since then. In fact, consumption of sorghum as animal feed has more than doubled, from 30 to 60 percent, since the early 1960s, while the volume of total food use has remained unchanged or has slightly declined (Table 6). In North and Central America, South America and Oceania most of the sorghum produced is used for animal feed.

TABLE 6: Sorghum utilization, 1981-85 average and growth from 1961-65 to 1981 - 85

Region	1981-85 average (million tonnes)				Annual growth from 1961-65 to 1981 (%)			
	Food	Feed	Other	Total	Food	Feed	Other	Total

			uses				uses	
Africa	8.0	0.4	2.3	10.7	1.5	3.5	-0.6	1.0
Asia	15.1	6.3	2.1	23.5	-	7.8	0.2	1.2
Central America	0.3	8.4	0.2	8.9	2.0	13.2	-	12.1
South America	-	4.6	0.3	4.9	-	8.5	5.7	8.3
North America	-	12.6	0.1	12.7	-	0.5	-	0.5
Europe	-	1.4	-	1.4	-	-2.5	-	-2.5
USSR	-	2.3	0.3	2.6	-	17.0	-	17.0
Oceania	-	0.4	-	0.4	-	3.5		3.5
World	23.4	36.4	5 3	65.1	0.5	3.8	0.4	2.1
Developing countries	23.2	15.6	4.8	43.6	0.5	10.3	0.1	1.7
Developed countries	0.2	20.8	0.5	21.5	3.5	1.7	4.7	2.2

***Source*: FAO, 1988.**

Human food

While total food consumption of all cereals has risen considerably during the past 35 years, world food consumption of sorghum has remained stagnant, mainly because, although nutritionally sorghum compares well with other grains, it is regarded in many countries as an inferior grain. Per caput consumption of sorghum is high in countries or areas where climate does not allow the economic production of other cereals and where per caput incomes are relatively low. These include especially the countries bordering the

southern fringes of the Sahara, including Ethiopia and Somalia, where the national average per caput consumption of sorghum can reach up to 100 kg per year. Other countries with significant per caput consumption include Botswana, Lesotho, Yemen and certain provinces in China and states in India. In most other countries food consumption of sorghum is relatively small or negligible compared to that of other cereals.

More than 95 percent of total food use of sorghum occurs in countries of Africa and Asia (Table 6). In Africa, human consumption accounts for almost three-quarters of total utilization and sorghum represents a large portion of the total calorie intake in many countries. For example, in Burkina Faso about 45 percent of the total annual calorie intake from cereals comes from sorghum, although its share has declined from 55 percent in the early 1960s. China and India account for about 90 percent of total food use in Asia.

Available data from Africa indicate that despite an increase in total food use between the early 1960s and the mid-1980s, the average per caput consumption declined from 20 to 15 kg per year (FAO, 1988). Decreases were concentrated in Kenya, Mozambique, Nigeria and Somalia but occurred also in Botswana, Ethiopia, Lesotho and Zimbabwe. In Asia, both total and per caput food use of sorghum declined.

This decline in per caput consumption in many countries was due in part to shifts in consumer habits brought about by a number of factors: the rapid rate of urbanization, the time and energy required to prepare food based on sorghum, inadequate domestic structure, poor marketing facilities and processing techniques, unstable supplies and relative unavailability of sorghum products, including flour, compared with other foodstuffs. Changes in consumption habits were concentrated in urban areas. Per caput food consumption of sorghum in rural producing areas remained considerably higher than in the towns. In addition, national policies in a number of countries had a negative influence on sorghum utilization as food. For instance, large imports of cheap wheat and rice and policies to subsidize production of those crops in some countries had considerable negative impact on the production of sorghum.

Animal feed

Grain use for animal feed has been a dynamic element in the stimulation of global sorghum consumption. The demand for sorghum for feed purposes has been the main driving force in raising global production and international trade since the early 1960s. The demand is heavily concentrated in the developed countries, where animal feed accounts for about 97 percent of total use, and in some higher-income developing countries, especially in Latin America where 80 percent of all sorghum is utilized as animal feed. The United States, Mexico and Japan are the main consuming countries, followed by Argentina, the former Soviet Union and Venezuela. These countries together account for over 80 percent of world use of sorghum as animal feed.

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Millet production

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Several kinds of millets are grown in the world, but FAO data on area, yield and production of all millets are given together under the general heading of millet. Pearl millet, finger millet and prove millet account for a large proportion of the world production. Millet production increased from 26 million tonnes in 197981 to 31 million tonnes in 1988 and was similar in 1989 and 1990. Asia, Africa and the former Soviet Union produce almost all the world's millets, as shown in Table 7. The major producers of millets in 1990 were India (39 percent), China (15 percent), Nigeria (13 percent) and the Soviet Union (12 percent) (Table 8).

The area under millet production decreased marginally from 38.1 million hectares in 1979-81 to 37.6 million hectares in 1990. However, production increased by 17 percent, from 25.6 million tonnes in 1979-89 to 29.8 million tonnes in 1990, largely because of production increases in Nigeria (65 percent), India (25 percent) and the Soviet Union (207 percent). However, there was a 24 percent decrease in production in China during the same period.

In all of the ten leading millet-producing countries except the Soviet Union, vegetable products supplied 90 percent or more of total dietary energy in 198789 (Table 9). In India, China, Nigeria, the Niger, Mali, Uganda, Burkina Faso and Nepal, vegetable products supplied more than 80 percent of protein. Thus in many sorghum- and millet-producing countries, vegetable products, especially cereals, provide the bulk of energy and protein.

TABLE 7: Area, yield and production of millet, by region, 1990

Region	**Area**		**Yield (kg/ha)**	**Production**	
	(10 ha)	**(% of total)**		**(10 t)**	**(% of total)**
Asia	20 853	55.5	804	16 767	56.2
Africa	13 548	36.1	669	9 066	30.4
USSR	2903	7.7	1 256	3647	12.2
North and Central America	150	0.4	1 200	180	0.6
South America	55	0.2	1 655	91	0.3
Oceania	34	0.1	882	30	0.1

World	37565	100	794	29817	100

Source: **FAO,1991.**

TABLE 8: Leading millet producers, 1990

Country	Area		Production	
	(10 ha)	(% of total)	(10 t)	(% of total)
India	17 000	45.3	11 500	38.6
China	2 601	6.9	4 401	14.8
Nigeria	4 000	10.7	4 000	13.4
USSR	2 903	7.7	3 647	12.2
Niger	3 100	8.3	1 133	3.8
Mali	900	2.4	695	2.3
Uganda	400	1.1	620	2.1
Burkina Faso	1 150	3.1	597	2.0
Senegal	865	2.3	514	1.7
Nepal	200	0.5	240	0.8
Total	33 119	88.2	27 347	91.7
World(1990)	37 565		29 817	
World (1989)	37 409		29 962	

***Source*: FAO. 1991.**

TABLE 9: Sources of energy and protein in the food supply of the world's ten leading millet producers, 1987-89

Country	Energy per caput per day (kcal)				Protein per caput per day (g)			
	Total	Vegetable products	Percentage of total	Animal products	Total	Vegetable products	Percentage of total	Animal products
India	2196	2 048	93.3	148	53.2	45.6	85.7	7.6
China	2634	2 365	89.8	269	62.8	50.7	80.7	12.1
Nigeria	2306	2 248	97.5	58	49.5	43.6	88.1	5.9
USSR	3380	2 444	72.3	936	106.2	50.1	47.2	56.1
Niger	2297	2 152	93.7	145	64.0	53.2	83.1	10.8
Mali	2234	2 090	93.6	144	62.5	50.1	80.2	12.4
Uganda	2136	2 010	94.1	126	48.1	38.7	80.5	9.4
Burkina Faso	2286	2 186	95.6	100	69.8	62.6	89.7	7.2
Senegal	2374	2 160	91.0	214	68.2	49.9	73.0	18.3
Nepal	2074	1 937	93.4	137	52.5	44.8	85.3	7.7

***Source*: FAO,1991.**

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Millet utilization

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Of the 30 million tonnes of millet produced in the world about 90 percent is utilized in developing countries and only a tiny volume is used in the developed countries outside the former Soviet Union. Exact statistical data are unavailable for most countries, but it is estimated that a total of 20 million tonnes are consumed as food, the rest being equally divided between feed and other uses such as seed, the preparation of alcoholic beverages and waste. Six countries (China, Ethiopia, India, the Niger, Nigeria and the former Soviet Union) are estimated to account for about 80 percent of global millet utilization (Table 10).

TABLE 10: Estimated millet utilization, 1981/82 to 1985/86 average

Region or country	**Food (10 t)**	**Feed (10 t)**	**Other uses[a] (10 t)**	**Total (10 t)**	**Per caput food use (kg/yr)**
Africa[b]	7 094	122	1 921	9 137	13.5
Burkina Faso	381	-	60	441	50.8
Ethiopia	1 020	-	196	1 216	24.9
Mali	516	1	88	605	67.7

Niger	977	21	215	1 213	168.9
Nigeria	2 365	86	700	3 151	26.5
Senegal	397	2	80	479	64.4
Uganda	259	47	150	456	17.8
Asia	14441	1 665	1 305	17411	5.3
China	4 857	1 120	480	6 457	4.7
India	8794	150	710	9664	11.9
Central America	-	-	-	-	-
South America	-	91	5	96	-
North America	-	104	6	110	-
Europe	-	104	6	110	-
USSR	800	1	107 400	2 307	2.9
Oceania	-	13	2	15	-
World	22 335	3 144	3 642	29 121	4.8
Developing countries	21 535	1 878	3 231	26 644	6.1
Developed countries	800	1 266	411	2 477	0.7

a Food seed, manufacturing purposes and waste.
b Including fonio, and teff.

***Source*: FAO,1990b.**

Human food

Per caput food consumption of millet varies greatly among countries, though it is highest in Africa. In the Sahel, millet is estimated to account for about one-third of total cereal food consumption in Burkina Faso, Chad and the Gambia, roughly 40 percent in Mali and Senegal and over twothirds in the Niger. Other countries in Africa where millet is a significant food item include Ethiopia, Nigeria and Uganda. Millet is also an important food item for the population living in the drier parts of many other countries, especially in eastern and central Africa but also in the northern coastal countries of western Africa. In developing countries outside Africa, millet has local significance as a food in parts of some countries such as China, India, Myanmar and the Democratic People's Republic of Korea. Although national per caput levels are rather low in the countries that consume the most millet, i.e. China and India, food use of millet is important in certain areas of these countries.

World consumption of millet as food has only grown marginally during the recent past in contrast to the significant increase in consumption of other cereals. There has been a tendency in all countries for the per caput consumption of millet to decline when per caput income exceeds certain levels because of the lower prestige associated with its consumption. The other reasons for stagnating consumption are the same as those discussed above for sorghum.

Animal feed

Utilization of millet as animal feed is negligible in absolute terms and compared with other uses and other cereals. It has been estimated that only about 10 percent of the millet used globally is fed to animals.

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Regional trends in production and utilization of sorghum and millets

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West Africa

The West African semi-arid tropics are defined as those areas where rainfall exceeds potential evapotranspiration for two to seven months annually. This area encompasses all of Senegal, the Gambia, Burkina Faso and Cape Verde, major southern portions of Mauritania, Mali and the Niger and the northern portions of Cte d'lvoire, Ghana, Togo, Benin and Nigeria. Cereals occupy nearly 70 percent of total cultivated area in this region and engage 50 to 80 percent of total farm-level resources (Matron, 1990). Millets and sorghum account for 80 percent of cereal production. During the last 25 years growth in millet and sorghum production has been slow and the total output has been about I percent lower than the population growth per year. Average yield per unit area of millet and sorghum has declined during this period, and the small production increases have primarily resulted from expansion of cropped area. Many factors have contributed to the decreased productivity, including demographic pressure and ecological degradation.

The West African semi-arid tropics can be classified into four agroclimatic zones: Sahelian (annual rainfall <350 mm), Sudano-Sahelian (350 to 600 mm),Sudanian (600 to 800mm) and Sudano-Guinean (800to 1 100 mm). According to Matlon (1990), the potential for major increases in sorghum and millet supply exist only in the Sudano-Guinean zone and to a lesser extent in the Sudanian zone. Yield stabilization and land conservation technologies should be given highest priority in these two zones.

Reardon and Matlon (1989) reported the food consumption patterns of the population of two villages, one representing Sahelian savannah and the other the Sudano-Sahelian zone. Market dependence was considerably lower among households in the Sudano-Sahelian village and was more equally distributed across income strata than in the Sahelian village. The poor were especially vulnerable in the rainy season when they were more dependent on the market. In fact, purchased food products contributed 60 to 70 percent of all calories consumed by poor and middle-income households during the rainy season. In the Sahelian village white sorghum accounted for only 4 percent of the cropping area but provided nearly 25 percent of the calories consumed outside the harvest season by poor households. Red sorghum and maize accounted for only 10 percent of the cultivated area but provided up to 60 percent of the calories consumed by the poor during non-harvest seasons.

Table 11 shows household expenditures on various cereals (represented by shares of total expenditure) in Burkina Faso, the Gambia, Mali, the Niger and Senegal (Reardon, 1993). These data were obtained from surveys done in good and poor harvest years. They show that rice is an important item in the urban diets of the Sahel, perhaps because of the relatively low cost of imported rice as a result of the decline in coarse-grain production, the perceived desire of consumers to emulate the dietary habits of high-income groups or the West, the relatively easy processing and fast cooking time for rice and the availability of fast foods made with rice from street vendors. Generally the combined share of millets and sorghum exceeds that of maize in the urban diets of the Sahel. In rural diets, however, coarse grains dominate except in a few isolated cases. However, purchased food forms a substantial share of rural diets.

TABLE 11: Cereal consumption in the Sahel: survey results[a]

Population sample	Rice	Millet	Sorghum	Maize	Wheat	Other	Total
BURKINA FASO							

Ouagadougou (1984/85)							
Overall	41	16	12	15	17	-[b]	100
Poorest tercile	45	17	15	15	9	-	100
Richest tercile	35	13	8	12	32	-	100
Ouagadougou (1982183)							
Overall	52	6	31	4	7	-	100
Poorest tercile	55	8	33	1	3	-	100
Richest tercile	52	3	20	5	20	-	100
Rural (1984/85)							
Sahelian zone	1	47	29	21	1	-	100
Sudanian zone	0	11	72	16	1	-	100
Guinean zone	6	22	57	14	1	-	100
GAMBIA							
Rural (1985/86)							
Overall	75	23[c]		3	-	-	100
MALI							
Bamako (1985/86)							
Overall	57	19	<0.5	1	17	6	100

Poorest quarter	55	20	1	<0.5	16	8	100
Richest quarter	54	21	1	0	19	5	100
Other cities (1985/86)							
Overall	54	21	1	0	19	5	100
Rural							
Bougouni	8	83[c]		6	-	3	100
Kayes	4	21[c]		74	-	1	100
NIGER							
Niamey (1988/89)[d]							
Overall	55	36	2	16	<0.5	-	100
Rural (1988/89)							
Tillabery	17	70	15	<0.5	<0.5	-	100
Diffa	1	53	16	24	5	-	100
SENEGAL							
Dakar (1983)							
Overall	66	31	-	3	-	-	100
Other urban							
Dioubel	37	48[c]		<0.5	13	-	100
Rural							

Mid-Casamance	87	8[c]		5	<0.5	-	100
Rural Kaolack	11	78[c]		8	3	-	100
Sahelian zone	48	26	0	4	<0.5	-	100
Sudanian zone	15	74	<0.5	<0.5	<0.5	-	100

a This table presents expenditure or budget shares which are product shares of total expenditure in cash terms (the sum of the imputed value of own consumption plus transfers plus purchases).
b: -:Not reported.
c. Millet and sorghum reported together.
d. Figures only given in shares of cereal budget in physical terms.
Source: Reardon, 1991.

There is an urgent need to develop suitable processing and milling methods for sorghum and millets. Development of innovative ready-to-eat products from these grains that could be sold by street vendors and markets would open up new avenues of utilization and could reduce the dependence on imported rice.

Eastern and southern Africa

Sorghum and millets account for 23 percent of the cereal production of the South African Development Community (SADC) countries, which include Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, Swaziland, the United Republic of Tanzania, Zambia and Zimbabwe. However, they are dominant grain crops only in Botswana and Namibia, where they account for 86 and 50 percent of total cereal production, respectively. Sorghum and millets are important in those areas that receive less than 650 mm of annual rainfall. The productivity of these crops is low, and in most SADC countries there is no strategy for the development of sorghum and millet subsectors.

In most SADC countries formal-sector (government-regulated) markets handle only a very small proportion of total sorghum and millet production (Table 12). They handle less than 10 percent of total production in Lesotho, Swaziland, the United Republic of Tanzania, Zambia and Zimbabwe. Most of the sorghum and millets produced in the SADC region is consumed by producing households or sold in informal markets, primarily for traditional beer production. Maize is cheaper than sorghum in many informal markets across the SADC region, and there may be good potential for expanding the production of sorghum and millets in view of the price differences.

One of the reasons that have been suggested for not increasing the production of sorghum and millets is that the productivity of these crops is low. Their average yields are lower than those of maize even in the semi-arid areas of the SADC. Although the total production costs are often lower than those for maize, the productivity of small grains measured in terms of returns of labour tends to be low. Under certain conditions, finger millet has been reported to offer higher economic returns than maize (Table 13). However, it requires more labour input than maize, which limits its production (Rohrbach, 1991).

To make sorghum and millets competitive it is necessary to improve their productivity with an assured quality of the grain. The area under sorghum and millets will not increase significantly unless the productivity of these grains is improved substantially. Therefore there is an urgent need to improve the production technologies for these grains and to disseminate this knowledge to the farmers' fields. Only in this way can these cereals compete locally with maize. Identifying a few well-researched alternative uses for sorghum would yield new avenues for increased utilization and thus act as a catalyst to improve production and productivity.

TABLE 12: Coarse grain production sold through formal market channels in SADC countries (%)

Country	Sorghum	Pearl millet	Finger millet	Maize

Zimbabwe (1989/90)	8	9	3	62
Tanzania (1986/87)	1[a]	-	-	7
Zambia (1987/88)	1	1	1	69
Botswana (1985)	25	-	-	62
Lesotho (1989)	1	-	-	-
Swaziland (1990)	1	-	-	-

a Sorghum and millets combined. Source: Rohrbach, 1991.

TABLE 13: Returns per labour hour in Zimbabwe during the 1988-189 cropping season[a]

Sector/crop	**Total labour (hr)**	**Average yield (t/ha)**	**Average price (Z$/kg)**	**Gross margin (Z$/ha)**	**Returns per labor hour (Z$/ha)**
Smallholder sector					
Maize	411	1.76	0.23	233.36	0.59
Pearl millet	521	0.38	0.34	30.95	0.06
Finger millet	545	0.45	0.61	173.81	0.38
Sorghum	308	0.32	0.42	54.43	0.16
Nyajena					

Maize	360	0.44	0.30	46.71	0.13
Pearl millet	551	0.27	0.45	35.31	0.07
Finger millet	567	0.38	0.68	175.37	0.40
Sorghum	398	0.24	0.36 8/td>	32.44	0.08

a Favourable rainfall in higher average-rainfall zones, poor rainfall in Nyajena. Source: Rohrbach, 1991.

India

India is the world's second largest producer of sorghum. At present most of the sorghum produced in India is consumed as a human food in the form of roti or chapatti (unleavened flat bread). Walker (1990) analysed the supply and demand prospects for sorghum in India. He found that in the past three decades the average per caput sorghum consumption declined markedly in both rural and urban households. Average rural consumption fell from 1.74 to I kg per caput per month. Urban consumption dropped from 0.74 to 0.46 kg per caput per month. It was projected that sorghum consumption would continue to fall at about 0.5 percent per annum. The declining trend in sorghum consumption is partly due to the decline in per caput consumption of total cereals.

Decreases in consumption of sorghum were found to be proportional to increases in expenditure. Increased income is accompanied by increased consumption of wheat and rice, as products made from these cereals are easy to prepare and have better keeping quality. There is also a tendency to eat a greater variety of foods as income and urbanization increase. The price of sorghum relative to those of wheat and rice has not increased in the major sorghumconsuming regions. Therefore other factors are probably more influential than direct price considerations in explaining the fall in per caput sorghum consumption. Prospects of technological change could perhaps change the scenario for improved production and utilization of sorghum.

China

China is the fourth largest producer of sorghum in the world and in Asia it is second only to India in area and production of sorghum. About 30 percent of the sorghum produced is used for human consumption and 60 percent for animal feed and the manufacture of alcoholic beverages (Kelley, Parthasarathy Rao and Singh, 1992). However, the importance of sorghum as a human food has declined over time. The area under sorghum has also declined, from about 2.8 million hectares in 1979-81 to 1.9 million hectares in 1990. Production has decreased correspondingly, from 7 million tonnes in 1979-81 to 5.3 million tonnes in 1990. In recent years more attention has been given to sorghum fodder and to developing suitable cultivars for this purpose.

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Chapter 3 - Storage and processing

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When sorghum or millet is stored in developing countries, it is usually stored in small quantities in traditional containers, often on the farm. Large quantities are seldom accumulated and bulk storage is uncommon.

Processing involves the partial separation and/or modification of the three major constituents of the cereal grain - the germ, the starch-containing endosperm and the protective pericarp. Various traditional methods of processing are still widely used, particularly in those parts of the semi-arid tropics where sorghum and

millets are grown primarily for human consumption. Most traditional processing techniques are laborious, monotonous and carried out by hand. They are almost entirely left for women to do. To some extent, the methods that are used have been developed to make traditional foods to suit local tastes and are appropriate for these purposes. Traditional techniques that are commonly used include decorticating (usually by pounding followed by winnowing or sometimes sifting), malting, fermentation, roasting, flaking and grinding. These methods are mostly labour intensive and give a poor-quality product. Sorghum and millets would probably be more widely used if processing were improved and if sufficient good-quality flour were made available to meet the demand (Eastman, 1980).

In general, industrial methods of processing sorghum and millets are not as well developed as the methods used for processing wheat and rice, which in most places are held in much higher regard than sorghum and millets. The potential for industrial processing of sorghum and millets is good, and attempts to develop improved industrial techniques have been made in several countries. Custom milling has had a significant impact in several African countries where it has recently been introduced. In Nigeria alone, where about 80 percent of sorghum and millets is now custom milled into whole flour, over 2.5 million tonnes of sorghum have been processed in this way (Ngoddy, 1989).

To some extent for storage, but particularly for processing, the type of sorghum - brown, white or yellow - is important. The outward appearance is no indication of the variety's type; all three types can appear white, yellow, brown, red or purple, although brown sorghums generally have darker seed-coats than yellow and white sorghums. (Subsequently in this chapter the more widely recognized term "white" is used for both white and yellow types.) The important difference is whether there is a testa. The testa is usually brick red, and even a small amount of red testa left in the flour will give it a pronounced pinkness, which many people find objectionable. If the variety contains tannin, most of it will be found in the testa. Tannin is objectionable for two reasons: it competes for available protein and it has a bitter taste. However, this bitter taste is also a major advantage, because it makes graniverous birds dislike high-tannin sorghums. For this reason these

varieties are widely grown in places where bird damage to white sorghum is severe.

The presence of a testa is controlled by two dominant genes, B1 and B2 (Hulse, Laing and Pearson, 1980). Wild sorghum will usually contain some of these dominant genes, so open pollination of white hybrids will tend to degenerate them to brown varieties. Repeated replanting of harvested seeds is often accompanied by increasing occurrence of seeds with a testa. Seeds with a testa are much harder to mill than seeds without a testa.

Brown sorghums tend to be softer than white sorghums and are more susceptible to insect damage under storage than white sorghums. However, they are markedly less susceptible to fungal damage in the field and in storage.

It is in processing that brown sorghums present the most difficulty, for the following reasons.

- **When the pericarp is progressively removed from the outside, the testa is almost the last layer to be removed.**
- **When a brown sorghum has recently been wetted, the pericarp tends to separate just above the testa. If the pericarp is then rubbed off, the damp testa is still firmly attached to the endosperm.**
- **Brown sorghums are often quite soft and the endosperm tends to break apart if the seed is subjected to mechanical impact.**

The best way of separating the testa of a brown sorghum from the endosperm is to cut the endosperm from the inside of the pericarp, as happens in roller milling. However, this is not possible using traditional methods. It is for these reasons that brown sorghums are usually only used in the production of beer, where some bitterness and some colour are not only acceptable but often preferred.

Storage

The objective of storage is to preserve as much as possible of the value of the grain for its intended future use. This means either retaining as high a proportion of viable seeds as possible for planting at the next harvest or preserving as much as possible of the food value of the grain for as long as possible. Several factors lead to the loss of both viability and nutrients, but globally the main causes of loss are the depredations of pests (insects, birds and rodents) and mould damage. Germination of the grain (sprouting) also results in losses, but on a smaller scale. Grain is stored by consumers and by processors for future consumption. It is also stored by commercial traders for resale, usually on the home market but occasionally for export.

Moisture in the grain and the temperature of storage are the most important physical factors that contribute to losses (FAO, 1970b). Most activity that causes losses occurs more rapidly as the temperature increases. With even minor changes in temperature, moisture will migrate and accumulate in certain areas, either near the top of the container or in places that are cooler than the rest. This often allows microbiological activity to occur in comparatively dry grain. Microbiological activity usually produces heat, and in unventilated stores, moist areas can get so hot that charring can occur. At this stage the grain is ruined. It may even burst into flames when it is exposed to air.

Storage bins are best filled early in the day when the air is cool and the humidity is often at its lowest. The grain should be packed as tightly as possible to allow insects the minimum space to move around and to breed. Sand is sometimes mixed with the grain to reduce the free space further.

TABLE 14: Damage and weight loss of sorghum and millets under home storage, India

Storage period	Percent damage		Percent weight loss	Increase in uric acid (mg/100 g)

	By weight	By number		
Sorghum				
1 month	3	3	0.2	0.0
5 months	5	6	1.5	4.3
9 months	9	11	2.4	5.4
Pearl millet				
1 month	0	0	0.1	0.0
5 months	2	2	0.2	3.3
9 months	2	4	1.0	3.6
Finger millet				
1 month	0	1	0.0	0.0
5 months	0	1	0.0	1 4
9 months	0	1	0.1	1 6

***Source*: Pushpamma et al., 1985.**

Studies conducted in Senegal showed that when properly dried and threshed sorghum and millets were mixed with 30 percent sand, storage losses were reduced.

Pushpamma et al. (1985) found in India that the storage loss of sorghum over seven months was greater than that of pearl millet, which was in turn greater than that of finger millet (Table 14). They also found that the moisture content of all the stored grains increased and the levels of niacin and protein fell (Table 15). Rao and Vimala (1993) showed that pretreatment of sorghum grain with 2 percent tricalcium phosphate reduced

the development of rancidity during storage.

The influence of seed moisture (relative humidity), temperature and the surrounding atmosphere on sorghum germination was studied by Bass and Stanwood (1978). Sorghum seeds were stored in sealed metal cans in six different atmospheric conditions (air, nitrogen, carbon dioxide, helium, argon and a vacuum) at three different moisture levels and at five different temperatures over a 1 6-month period. Temperature was the only parameter that affected the rate of germination, which was lowest at -12C.

TABLE 15: Chemical composition of sorghum and millets stored for different periods (moisture-free basis)

Storage period	**Number of samples**	**Moisture (%)**	**Protein (g)**	**Non protein nitrogen (mg)**	**Thiamine (mg)**	**Riboflavin (mg)**	**Niacin (mg)**
Sorghum							
1 month	26	10.4	8.5	326	0.32	0.18	2.3
5months	26	10.4	8.2	240	0.31	0.16	2.1
		(0)	(-3.5)	(+1.7)	(3.1)	(-11.1)	(-8 7)
9months	22	11.1	7.6	246	0.24	0.16	2.0
		(+67)	(-106)	(+4.3)	(-25.1)	(-11.1)	(-13.0)
Pearl millet							
1 month	18	9.3	10.0	282	0 33	0.21	2.4
5months	18	11.0	9.9	285	0.29	0.21	2.4

		(+18.3)	(-1.0)	(+1.1)	(-12 1)	(0)	(0)
9months	12	10.7	8.9	297	0.20	0.21	2.0
		(+15.1)	(-11.0)	(+5.3)	(-39.4)	(0)	(-16.7)
Finger millet							
1 month	7	10.9	7.6	193	0.37	0.19	1.3
5months	7	10.9	7.4	216	0.33	0.18	1.3
		(0)	(-2 6)	(+12.0)	(-10.8)	(-5.3)	(0)
9months	7	11.6	7.2	275	0.21	0.17	1.1
		(+6 4)	(-5.3)	(+42.5)	(-43.2)	(-10.5)	(-15.4)

Note: Figures in parenthese indicate percentage decrease (-) or incrrease (+) from the values at tile initial (one - month) sampling.
***Source*: Pushpamma et al., 1985.**

Methods used for storing grains are influenced by the value of the crop, the quantity stored and environmental conditions. Compared to other cereal crops, sorghum and millets are not widely traded internationally, and within those developing countries where they are grown for human food there is usually a balance between local production and local demand. Farmers and rural householders in developing countries store most of what is grown in small storage structures. There is not much need for bulk storage of these crops.

Storage containers vary from small traditional on-farm or domestic containers to silos which are sometimes found on large farms. In many countries, small granaries are made by weaving plant materials such as bamboo, stalks, bark and small branches and then sealing any gaps with mud or dung. These structures may

be built directly on the ground or raised off the ground on platforms or stilts.

Storage practices in Africa

In some countries in West Africa sorghum and millet grains are mixed with wood ash and stored in clay pots (Vogel and Graham, 1979). In Nigeria sorghum and millets are stored as unthreshed heads in a solid walled container called a rumbu. For short-term storage, bundles of sorghum and millet heads are arranged in layers in the rumbu. For long-term storage of three to six years, the heads are laid out individually rather than in bundles. Some farmers spread the leaves of gwander daji (Anona senegalensis) on the bottom of the rumbu and between each layer of grain. When a rumbu is full, the mouth is sealed with clay.

In Uganda, sorghum is threshed and stored in gunny sacks, whereas millets are stored unthreshed. In the Sudan, pits holding 2 to 5 tonnes of grain are used as underground stores.

Storage practices in India

Most of the sorghum and millets grown in Andhra Pradesh are grown for personal consumption. Pushpamma and Chittemma Rao (1981) described the various ways these grains are stored there. Occasionally sorghum and millets are stored on the ground, usually unthreshed. The earheads are heaped in a pile (either indoors or outdoors) and covered with straw. As the grain is needed, earheads are removed and threshed. More often, grain is stored in gunny sacks, which are stacked either on the floor or on raised wooden platforms. Underground pits, which may be located underneath the house or outside, are also used. The pit is lined with paddy straw or sorghum straw. When it is full of grain the grain is covered with straw and soil. For longer-term storage, the top is plastered over with mud. Storage jars, silos and bins are made from a number of different materials. On the smallest scale, grain is stored in clay pots. Larger containers are made from wood, brick or stone or from bamboo made into a basket which is then sealed with clay or dung. When these containers are kept indoors they are sometimes left uncovered, but when they are kept outdoors they are

covered with either a lid or a thatched roof. If the grain is to be stored for a long time, the top of the bin is plastered over with mud or dung. Occasional exposure to sunshine is the most commonly used measure for preventing insect infestation.

Storage of flour

Flour is usually produced as it is needed and is not often stored for long periods because it tends to turn rancid. This is particularly evident with pearl millet flour, because of its very high tat content. Sorghum and millets, particularly pearl millet, are therefore best stored as whole grain.

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Traditional processing methods

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Processing untreated grains

Flour made by grinding whole grain is occasionally used, particularly with the smaller millets, but in most places where sorghum and millets are consumed the grain is partially separated into its constituents before food is prepared from it.

The first objective of processing is usually to remove some of the hull or bran - the fibrous outer layers of the

grain. This is usually done by pounding followed by winnowing or sieving. The grain may first be moistened with about 10 percent water or soaked overnight. When hard grains are pounded, the endosperm remains relatively intact and can be separated from the heavy grits by winnowing. With soft grains, the endosperm breaks into small particles and the pericarp can be separated by winnowing and screening.

When suitably prepared grain is pounded, the bran fraction contains most of the pericarp, along with some germ and endosperm. This traction is usually ted to domestic animals. The other fraction, containing most of the endosperm and much of the germ along with some pericarp, is retained for human consumption. Retaining the germ in the flour will improve aspects of its nutritional quality, but at the same time it will increase the rate at which the flour will become rancid. This is particularly important in the case of pearl millet.

Dry, moistened or wet grain is normally pounded with a wooden pestle in a wooden or stone mortar. Moistening the grain by adding about 10 percent water facilitates not only the removal of the fibrous bran, but also separation of the germ and the endosperm, if desired. Although this practice produces a slightly moist flour, many people temper the grain in this way before they pound it. Pounding moist or dry grain by hand is very laborious, time consuming and inefficient. A woman working hard with a pestle and mortar can at best only decorticate 1.5 kg per hour (Perter, 1983). Pounding gives a non-uniform product that has poor keeping qualities.

Many pearl millet grains have an irregular indentation in the pericarp. This makes it more difficult to decorticate pearl millet than it is to decorticate most other cereal grains (Kent, 1983).

The particle size of the endosperm fraction can be reduced by crushing or grinding to produce coarse grits or fine flour. This unpleasantly hard work is almost always done by women. Traditional grinding stones used to grind whole or decorticated grain to flour usually consist of a small stone which is held in the hand and a larger flat stone which is placed on the ground (Subramanian and Jambunathan, 1980; Vogel and Graham,

1979). Grain, which should be fairly dry, is crushed and pulverized by the backward and forward movement of the hand-held stone on the lower stone. The work is very laborious, and it is hard work for anyone to grind more than 2 kg of flour in an hour. In a traditional process used in many countries of Africa and Asia, decorticated grain is crushed to a coarse flour either with a pestle and mortar or between stones. Grain is also ground to coarse or fine flour in mechanized disk mills now located in many villages.

In wet milling, the sorghum or millet is soaked in water overnight (and sometimes longer) and then ground to a batter by hand, often between two stones. Soaking makes the endosperm very soft and the pericarp quite tough and makes grinding much easier, but it gives a batter or paste instead of flour.

Processing malted grains

Malting involves germinating grain and allowing it to sprout. Typically the grain is soaked for 16 to 24 hours, which allows it to absorb sufficient moisture for germination and for sprouts to appear. However, germinated sorghum rootless and sprouts contain very large amounts of dhurrin, a cyanogenic glucoside, which on hydrolysis produces a potent toxin variously known as prussic acid, hydrocyanic acid (HCN) and cyanide (Panasiuk and Bills, 1984). The fresh shoots and rootless of germinated sorghum and their extracts must therefore never be consumed, either by people or by animals, except in very small quantities (e.g. when the germinated grain is used just as a source of enzymes). Dada and Dendy (1988) showed that the removal of shoots and roots and subsequent processing reduced the HCN content by more than 90 percent.

Malted sorghum has traditionally been used in several countries in Africa, but always after careful removal of the toxic parts. Hullu-murr is an important traditional food prepared from malted sorghum in the Sudan (Bureng, Badi and Monawar, 1987). Alcoholic beverages and dumplings are prepared in Kenya from germinated sorghum and millet.

In the germination process, the grain produces a-amylase, an enzyme that converts insoluble starch to

soluble sugars. This has the effect of thinning paste made by heating a slurry of starch in water, in turn allowing a higher caloric density in paste of a given viscosity, since as much as three times more flour can be used when the grain has been germinated. The energy that young children can consume is often limited by the bulk that they can consume. Thus using germinated grain can make food more suitable for certain categories of young children. Flour from malted grain is consequently used quite widely in the production of children's food, but when such foods are made from sorghum, great care must always be taken to ensure that the level of cyanide is adequately low, as children are particularly vulnerable to cyanide.

In India, malted finger millet is common and is considered to be superior to malted sorghum and malted maize. Studies have shown that finger millet develops higher amylase activity than sorghum and other millets (Seenappa, 1988). Germination of grain is reported to change the amino acid composition, convert starch into sugars and improve the availability of fat, vitamins and minerals.

Pal, Wagle and Sheorain (1976) measured the changes in the constituents of sorghum and various millets (finger, pearl, prove, kodo and barnyard) during malting. The malting losses for finger millet and foxtail millet were high. Pearl millet had the highest a-amylase activity. Amylolytic and proteolytic enzyme levels in malted pearl millet were comparable to those in malted barley.

The use of only 5 percent malted sorghum or finger millet was found to reduce the viscosity of weaning foods (Mosha and Svanberg, 1983; Seenappa, 1988).

Processing grain treated with alkali

To produce a particular type of tortilla that is popular in Mexico, sorghum grains are cooked in lime water for a short time and steeped overnight, washed to remove the excess alkali and then ground to a paste (Rizley and Suter, 1977).

Wood ash is used in traditional treatments to reduce the level of tannin in brown sorghums and improve the nutritional quality. Muindi and Thomke (1981) reported the use of wood ash in the United Republic of Tanzania. Mukuru (1992) described a tannin-reducing technique used in parts of eastern and central Africa where, because of grain-eating birds, only "high-tannin" sorghums are grown. The sorghum is first soaked overnight in a slurry of wood ash in water. After draining it is left for three or four days to germinate. The germinated grains are sun-dried and pounded to loosen the adhering wood ash and to remove the sprouts, with their high levels of cyanide. The grain is then ground and used to prepare either a non-alcoholic beverage called obushara or an alcoholic drink containing about 3 percent alcohol called omuramba.

Processing parboiled grain

Parboiling is reported to help in dehusking kodo millet (Shrestha, 1972) and to eliminate the stickiness in cooked finger millet porridge (Desikachar, 1975).

Industrial processing

While there are many machines available for processing hard white sorghum, there is unfortunately no well-proven industrial process available that is entirely satisfactory for making white products from coloured sorghums and millets.

Cereal grains can be milled wet, in the form of a thin aqueous slurry, usually to produce starch, or in an essentially dry form (often suitably dampened or "tempered") which usually produces meal (coarse or fine flour). A factory in Texas, United States, for wet milling sorghum operated intermittently from the 1940s to the 1970s (Rooney, 1992) but is now closed. No millets have ever been wet milled commercially to produce starch. The following technologies are all for dry and semi-wet milling.

In industrial processing, once the grain has been cleaned, the first operation is usually the separation of offal (the portion not normally used for human consumption) from the edible portion. The offal consists of the pericarp and sometimes the germ. Offal removal is frequently called decortication or dehulling.

Following the removal of offal, the edible portion is often milled to reduce the particle size of the edible fraction. There is usually a choice of techniques and mills that may be used for particle size reduction if a finer product is desired. Some of the earliest research and development work on milling technology for pearl millet and sorghum was promoted by FAO in 1964, initially on a laboratory scale in Senegal and later on a semi-industrial scale in the Sudan. The conclusion was reached that the technology for milling wheat is not optimal for milling sorghum and millet (Perter, 1977).

Most industrial operations that can be carried out on untreated grain can also be used with grain that hats been prepared in some way, for example grain that has been germinated and then suitably dried.

Three types of processors can be used to mill sorghum and millets on a commercial scale: abrasive decorticators, which abrade the pericarp away, i.e. progressively remove offal from the outside; machines that rub (rather than abrade) the pericarp off the endosperm; and roller mills, which cut the endosperm from the inside of the pericarp.

Abrasive decortication

Abrasive decorticators work by abrading away the fibrous pericarp. Obviously, the outer layers of the seed-coat are abraded away first and the innermost layers, which in many varieties contain those factors that most need to be removed, are the last to be abraded away. If all parts of all grains could be abraded away at the same rate, abrasive decortication would be an efficient way of removing the pericarp. However, different parts of individual grains are abraded away at very different rates, and there is some loss of endosperm (particularly from damaged grains) even when the grain is only lightly abraded. Also, non-spherical seeds, e.g.

pearl millet grains, tend to abrade away much more quickly at some points than at others.

When hard white sorghum grains, uncontaminated with seeds with a red testa, are decorticated in an abrasive decorticator, any pericarp left on the grain is hard to see, and when the pearled grain is milled, the presence of pericarp goes largely unnoticed. However, the ability of abrasive decorticators to produce an adequately white product falls sharply with increasing levels of contamination from seeds with a coloured seed-coat. When the contaminating seeds have a red testa (which is deeply coloured and is practically the last layer to be abraded away) a decorticator's ability to produce an acceptably white product falls even more sharply. The problem is compounded by the fact that many contaminating seeds are comparatively soft and their exposed endosperm is ground away quickly. As a result, milling yields often fall to unacceptably low levels.

Decorticators produce what is visually a very acceptable product in a good yield from grain well suited to abrasive decortication. However, if the grain to be ground is not always going to consist of a very high proportion of hard, white, spherical seeds of fairly regular size, a very careful analysis of the economics of operating an abrasive decorticator should be made on the basis of recovery rates derived from trial runs.

Even though decorticators are well suited to small-scale operations, these machines have often proved to be too large for the system into which they were introduced. In many cases they have been introduced less successfully than originally hoped, either because of a lack of supplies of the high-quality grain that is needed for them to work properlyor because of insufficient local demand for the product. Very small units are likely to be run less efficiently than larger ones.

Most decorticators are based on a prototype put out by the Prairie Regional Laboratory (PRL) in Canada. This type of decorticator has the enormous advantages of being relatively inexpensive to install and relatively simple to maintain and operate. Bassey and Schmidt (1989) described the development of this type of decorticator and its use in Africa. More recently it has been introduced in India.

In 1976, a prototype decorticator was established in Maiduguri, Nigeria. A larger unit to process 5 to 10 tonnes of sorghum per day was installed at Pitsane in southern Botswana in 1978 but the demand for the product was inadequate to keep the equipment running at full capacity. The Centre national de recherches agronomiques (CNRA) in Bambey, Senegal, began to use a PRL decorticator to decorticate sorghum and millet in 1979. The capacity of this decorticator also exceeded the demand for the product.

FAO supplied the Food Research Centre (FRC) in the Sudan with a pilot plant including a decorticator manufactured in Germany after FRC had compared decorticators made by several different manufacturers. FRC is currently decorticating white sorghum for a local urban market. The centre has also produced pearled sorghum as a substitute for rice (Bad), Perten and Abert, 1980); although the product has to be cooked much longer than rice, it was well accepted. Of the five most popular varieties of sorghum grown in the Sudan, two (Feterita and Mayo) are unsuitable for abrasive decortication.

James and Nyambati (1987) described the industrial preparation of pearled brown and white sorghum in Kenya using a decorticator that could mill sorghum in batches or continuously, but they found it was difficult to obtain sufficient sorghum suitable for processing. The product was sold at 60 percent of the price of rice and consumer acceptance was very good. Flour was also produced from the pearled grain.

Various modifications have been made to the PRL design to suit specific conditions. A variant of the PRL decorticator was developed in the early 1980s by Palyi and tested in Canada. The Palyi-Hanson BR 001-2 can mill 3 tonnes per hour. Under local management in the Gambia a PRL decorticator processed 50 tonnes of pearl millet over a one-year test period, after which modifications were made to the design. In 1986 the Rural Industrial Innovation Centre (RIIC) introduced a modification that enabled the machine to handle small quantities of grain (Bassey and Schmidt, 1989). By 1989, about 35 RIIC decorticators had been installed in Botswana, but for one reason or another, not all of these machines are still being used for milling sorghum or millet. In turn, local agencies in some of the main countries to which the RIIC design has been exported (e.g.

Zimbabwe, Senegal) have deemed it necessary to modify the RIIC design for improved operation for local grain.

In Zimbabwe, decorticators were placed in five rural locations for evaluation. A local research group, Environment Development Activities, produced a modified version that can process one tonne of grain in eight hours. In Senegal, a local modification was evaluated in ten villages. Decorticators based on a second local design (called the mini-SISMAR/ISRA), which can mill about 600 kg of grain in eight hours, were then introduced.

Equipment of RIIC design was introduced at Morogoro, United Republic of Tanzania, in 1982. Although the first unit was unsuccessful, four pilot systems were established locally for evaluation. In 1982, a mill with an RIIC decorticator was established in Ethiopia, but the supplies of grain for it were inadequate because of the drought.

There has also been an intensive effort to introduce RIIC decorticators in Andhra Pradesh. Decortication improved the quality of the flour from sorghum and millets so that it could be used in new ways (Geervani and Vimala, 1993).

High-yielding sorghums introduced in Mali were soft and could not be decorticated in PRL-type decorticators (Scheuring et al., 1983).

A number of large decorticators have been installed around the world with capacity ranging from 1 to 2.5 tonnes per hour. Typically, they are vertical axis units with abrasive disks that have been carefully selected for the optimal degree of abrasion. The grain is first cleaned to separate sand, dust, coarse material and other impurities. An aspirator removes the abraded bran through a screen. The bran is sometimes further separated into fine bran (mostly pericarp) and a mixture of germ, broken grain and coarse bran. A l-t/hour decorticator manufactured in Switzerland was run for several years in Zimbabwe, preparing coarse sorghum

flour that was introduced into a wheat flour mill. A 2.5-l/hour unit manufactured in Germany was installed in the Sudan. Other large units are reportedly in operation in Nigeria. As with small units, high-quality sorghum is needed to produce an acceptably white product in these larger decorticators. Sufficient quantities of high-quality sorghum to keep large mills running at full capacity are not often available.

Rubbing techniques

Munck, Bach Knudsen and Axtell (1982)describedanew industrial milling process developed in Denmark, which does not involve abrasive milling. Decortication is achieved by a steel rotor rotating the grain mass within a generally cylindrical chamber. When the grain is properly tempered, the pericarp is rubbed off by the movement of one seed against another. However, when the grain is too dry, as was the case in a factory in the Sudan, abrasion of the internal components of the mill becomes severe. The hulls and the endosperm fragments are separated in a cyclone and the endosperm particles are milled in a proprietary mill. These units have a capacity of 2 tonnes of sorghum per hour. The system was reported to yield 80 percent flour with whiteness comparable to traditional milling, but to do this it requires grain with specifications similar to those required for efficient abrasive decortication.

Roller mills

Most wheat is milled in a type of mill called a roller mill. Roller mills are the most efficient mills for separating the constituents of cereals. Two types of rollers are used: rollers with axial grooves, which cut the endosperm from the pericarp (effectively cutting it away from the inside), and smooth rollers, which progressively crush the endosperm pieces into finer and finer flour. Normally the grain is passed through a number of roller mills, often 20 or more. Wheat milling technology is suitable for milling large quantities of grain, but it requires a large investment and experience in operating and maintaining the equipment. For all these reasons, it is therefore not suitable for milling sorghum and millets in very small-scale operations. However, roller mills are very efficient in separating the edible portion of cereals from the offal and can do so with sorghum and

millets regardless of the physical characteristics of the grain; it does not matter if the grain is soft, coloured or broken. Roller milling might therefore have a place where high-quality products are required from comparatively large quantities of grain of poor or indifferent quality, particularly where there is spare capacity in an existing wheat mill.

To withstand the stresses of roller milling, the pericarp of sorghum and millets has to be much moister than that of wheat. Early efforts to roller-mill sorghum and millets always ended in failure because the grain was dry when it was milled. It would shatter, the pericarp breaking into small pieces that were too brittle to allow separation of the endosperm. Using conventional tempering techniques, Perten (1983) was unable to achieve efficient separation of the offal of either sorghum or millets from the endosperm. He concluded that sorghum and millets are more difficult to grind than wheat and that they produce a coarser and much darker flour which contains high levels of fat and ash.

The use of moisture levels much higher than those used for milling wheat was first reported by Abdelrahman, Hoseney and Varriano-Marston (1983) for milling pearl millet and by Cecil (1986, 1992) for milling other millets and sorghum. The term semi-wet milling was adopted for this technique. For millets, about 10 percent water must be equilibrated in the grain for four hours before it is ready for milling; for sorghum, about 20 percent moisture must be added and the grain conditioned for six hours. The damp material flows almost as easily as normally tempered wheat products do, and no holdup problems were encountered in several hours of running 2 tonnes per hour of red sorghum in a commercial mill. In early experiments, comparatively low yields of fine flour were obtained, but subsequent work produced low-fibre, low-tannin grits from red sorghum in a commercial mill with six roller passes with a yield of 72 percent (compared with typical wheat recovery of 70 percent). In a laboratory mill with three milling passes, 84 percent yield of grits was obtained from commercial white sorghum from Botswana and 83 percent from white sorghum from Lesotho. All the grits contained very low levels of fibre.

Semi-wet milling has several advantages, including the excellent separation of the offal from the edible portion and the opportunity for using well-tested existing commercial wheat-milling equipment without the need for any changes in the set-up of the mills. White flour with practically no tannin, which tastes better, looks better and is nutritionally better than flour that contains tannin, can be produced from high-tannin coloured varieties. Mixtures of sorghum or millet varieties, soft varieties, misshapen seeds and mixtures of sorghum with other grains (including wheat) can all be milled together if necessary. Moistening the endosperm softens it to such an extent that very little energy is needed to mill it. Semi-wet milling of pearl millet, unlike abrasive decortication, may also help eliminate substances that cause goitre (Klopfenstein, Leipold and Cecil, 1991).

Redundant or underutilized wheat mills can be used with minimal additions and the mill can be reverted to milling wheat within a few minutes. Alternatively, any type of sorghum can be milled together with wheat. For a period of about five days, 0.6 tonnes of red sorghum and 14 tonnes of wheat per hour were milled together without difficulty in a commercial mill in Zimbabwe.Semi-wet milling has some disadvantages. Although it would not be difficult or very expensive in a commercial system to dry the products of semi-wet milling, they are usually too damp for long-term storage. In semi-wet milling, microbiological growth might be more vigorous than in conventional milling of wheat, but reasonable attention to hygiene will minimize this problem. Semi-wet milling is not suitable for very small operations. Finally, although it has been shown that sorghum can be milled semi-wet without any difficulty in commercial equipment, the technique has not yet been proved over an extended period of operation.

Size reduction

Many mills can be used to reduce the size of the particles obtained by decortication, but the type that is usually used (and is also probably the simplest to use and the cheapest to install) is the hammer mill. Hammer mills are available in all sizes. They consist of blunt blades rotating rapidly in an enclosed cylinder

with an outlet covered by a screen. The size of the holes in the screen determines the size of the particles of flour, but small holes will reduce the throughput of the mill, and if they are too small overheating may result.

If roller mills are used for separating the endosperm from the offal, the particle size is usually reduced in roller mills with smooth rollers.

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Chapter 4 - Chemical composition and nutritive value

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The composition of the kernel fractions of sorghum and pearl millet is given in Table 16. The sorghum bran is low in protein and ash and rich in fibre components. The germ fraction in sorghum is rich in ash, protein and oil but very poor in starch. Over 68 percent of the total mineral matter and 75 percent of the oil of the whole kernel is located in the germ fraction. Its contribution to the kernel protein is only 15 percent. Sorghum germ is also rich in B-complex vitamins. Endosperm, the largest part of the kernel, is relatively poor in mineral matter, ash and oil content. It is, however, a major contributor to the kernel's protein (80 percent), starch (94 percent) and B-complex vitamins (50 to 75 percent).

The pearl millet bran is low in mineral matter like that of sorghum, but it is remarkably rich in protein (17.1 percent). The germ fraction in pearl millet is relatively large, 16 percent as against 10 percent in sorghum. It is also rich in oil (32 percent), protein (19 percent) and ash (10.4 percent). Practically all the oil (87 percent) of

the whole kernel is in the germ fraction, which also accounts for over 72 percent of the total mineral matter. Greater concentration of minerals in the germ and the bran layers than in endosperm is typical of cereal grains (MacMasters, Hinton and Bradbury, 1971). The total fat content of pearl millet is higher than that of other millets and sorghum because of the size of the germ and its high oil content and because of somewhat higher levels of fat in the bran fraction.

Variation in grain composition

Like other cereals, sorghum and millets are predominantly starchy. The protein content is nearly equal among these grains and is comparable to that of wheat and maize (Table 17). Pearl and little millet are higher in fat, while finger millet contains the lowest fat. Barnyard millet has the lowest carbohydrate content and energy value. One of the characteristic features of the grain composition of millets is their high ash content. They are also relatively rich in iron and phosphorus. Finger millet has the highest calcium content among all the foodgrains. High fibre content and poor digestibility of nutrients are other characteristic features of sorghum and millet grains, which severely influence their consumer acceptability. Generally the whole grains are Important sources of B-complex vitamins, which are mainly concentrated in the outer bran layers of the grain.

TABLE 16: Nutrient content of whole kernel and its fractions[a]

Kernel fraction	% of kernel weight	Protein[b] (%)	Ash (%)	Oil (%)	Starch (%)	Calcium (mg/kg)	Phosphorus (mg/kg)	Niacin (mg/100g)	Riboflavin (mg/100 g)	Pyridoxin (mg/100g)
Sorghum										

Whole kernel	100	12.3	1.67	3.6	73.8			4.5	0.13	0.47
Endosperm	82.3	12.3	0.37	0.6	82.5			4.4	0.09	0.40
		(80)	(20)	(13)	(94)			(76)	(50)	(76)
Germ	9.8	18.9	10.4	28.1	13.4			8.1	0.39	0.72
		(15)	(69)	(76)	(20)			(17)	(28)	(16)
Bran	7 9	6.7	2.0	4.9	34.6			4.4	0.40	0.44
		(4 3)	(11)	(11)	(4)			(7)	(22)	(8)
Pearl millet										
Whole kernel	100	13.3	1.7	6.3		55	358			
Endosperm	75	10.9	0.32	0.53		17	240			
		(61)	(14)	(6)		(25)	(56)			
Germ	17	24.5	7.2	32.2						
		(31)	(71)	(87)						
Bran	8	17.1	3.2	5.0		168	442			
		(10)	(15)	(6)		(36)	(15)			

a Values in parentheses represent percentage of whole kernel value.
b N 6.25
***Sources*: Hubbard. Hall and Earle. 1950 (sorghum): Ahdelrahman. Hoseney and Varriano-Marston, 1984 (pearl**

millet).

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Sorghum and millets do not contain vitamin A, although certain yellowendosperm varieties contain small amounts of 13-carotene, a precursor of vitamin A. No vitamin C is present in the raw millet grains.

Considerable variation in the grain composition of these cereals has been reported, particularly for sorghum and pearl millet (Hulse, Laing and Pearson, 1980; Jambunathan and Subramanian, 1988; Rooney and Serna-Saldivar. 1991) (Table 18). Genetic factors play a major part in determining grain composition. Environmental factors also have a role. In several cereal grains, including sorghum, an inverse correlation has been observed between grain yield and protein content (Frey, 1977). The protein content of the grain is also significantly and inversely correlated with its weight and starch content. On the other hand, the ash content and protein content of the sorghum grain are positively correlated with each other (Subramanian and Jambunathan, 1982).

Goswamy and co-workers (Goswamy, Sehgal and Sharma, 1969; Goswamy, Sharma and Gupta, 1969; Goswamy, Sehgal and Gupta, 1970; Goswamy, Sharma and Sehgal,] 970) analysed a number of pearl millet

varieties of African, American and Indian origin and observed that variations in protein, fat, total ash, calcium, phosphorus and iron were large but were similar in the three types. Singh et al. (1987) compared the grain composition of five pearl millet varieties, of which three were inbred lines with high protein content (14.4 to 19.8 percent) and two were normal-protein (9.9 to 11.3 percent) cultivars. In the five genotypes, the values for fat, crude fibre, total ash and starch content were within the normal ranges as reported by Goswamy and co-workers and others (Jambunathan and Subramanian, 1988). Further, the high-protein lines contained 60 percent more protein than the normal varieties but had 40 percent less carbohydrate and 20 percent less fat. The high-protein lines were also high in fibre.

TABLE 17: Nutrient composition of sorghum, millets and other cereals (per 100 g edible portion; 12 percent moisture)

Food	**Protein[a] (g)**	**Fat (g)**	**Ash (g)**	**Crude fibre (g)**	**Carhohydrate (g)**	**Energy (kcal)**	**Ca (mg)**	**Fe (mg)**	**Thiamin (mg)**	**Riboflavin (mg)**	**Niacin (mg)**
Rice (brown)	7.9	2.7	1.3	1.0	76.0	362	33	1.8	0.41	0.04	4.3
Wheat	11.6	2.0	1.6	2.0	71.0	348	30	3.5	0.41	0.10	5.1
Maize	9.2	4.6	1.2	2.8	73.0	358	26	2.7	0.38	0.20	3.6
Sorghum	10.4	3.1	1.6	2.0	70.7	329	25	5.4	0.38	0.15	4.3
Pearl millet	11.8	4.8	2.2	2.3	67.0	363	42	11.0	0.38	0.21	2.8
Finger millet	7.7	1.5	2.6	3.6	72.6	336	350	3.9	0.42	0.19	1.1

Foxtail millet	11.2	4.0	3.3	6.7	63.2	351	31	2.8	0.59	0.11	3.2
Common millet	12.5	3.5	3.1	5.2	63.8	364	8	2.9	0.41	0.28	4.5
Little millet	9.7	5.2	5.4	7.6	60.9	329	17	9.3	0.30	0.09	3.2
Barnyard millet	11.0	3.9	4.5	13.6	55.0	300	22	18.6	0.33	0.10	4.2
Kodo millet	9.8	3.6	3.3	5.2	66.6	353	35	1.7	0.15	0.09	2.0

a N x 6.25.

***Sources*: Hulse. Laing and Pearson. 1980: United States National Research Council/National Academy of Sciences. 1982. USDA/HNIS. 1984.**

TABLE 18: Chemical composition of sorghum and pearl millet genotypes from the world germplasm collection at ICRISAT[a]

Food	**Protein (%)**	**Fat (%)**	**Ash (%)**	**Crude fibre (%)**	**Starch (%)**	**Amylose sugar**	**Soluble sugar**	**Reducing sugar**	**Calcium (mg/100g)**	**Phos phorus (mg/100 g)**	**Iron (mg/ 100 g)**
Sorghum											
No. of											

genotypes	10 479	160	160	100	160	80	160	80	99	99	99
Low	4.4	2.1	1.3	1.0	55.6	21.2	0.7	0.05	6	388	4.7
High	21.1	7.6	3.3	3.4	75.2	30.2	4.2	0.53	53	756	14.1
Mean	11.4	3.3	1.9	1.9	69.5	26.9	1.2	0.12	26	526	8.5
Pearl millet											
No. of genotypes	20 704	36	36	36	44	44	36	16	27	27	27
Low	5.8	4.1	1.1	1.1	62.8	21.9	1.4	0.10	13	185	4.0
High	20.9	6.4	2.5	1.8	70.5	28.8	2.6	0.26	52	363	58.1
Mean	10.6	5.1	1.9	1.3	66.7	25.9	2.1	0.17	38	260	16.9

a All values except protein are expressed on a dry-weight basis.
Source: Jambunathan and Subramanian. 1988.

Differences in grain composition in genotypes of other millets have also been reported. In finger millet, the value ranges reported by Pore and Magar (1977) are protein, 5.8 to 12.8 percent; fat, 1.3 to 2.7 percent; total ash, 2.1 to 3.7 percent; and carbohydrate 81.3 to 89.4 percent. Variations in the mineral content of these varieties were also large. Differences in the protein and mineral composition of finger millet hybrids have also been reported by Babu, Ramana and Radhakrishnan (1987). In foxtail millet from the world germplasm collection the protein content ranged from 6.7 to 15 percent and the ash content from 2.06 to 4.81 percent (Dhindsa, Dhillon and Sood, 1982). Monteiro et al. (1988) observed similar variations in protein (11.1 to 15 percent), ash (1.1 to 1.6 percent), fat (4.7 to 6.3 percent) and carbohydrate (65 to 75.7 percent) in 12 cultivars

of foxtail millet.

Environmental factors including agronomic practices affect grain composition. Grain protein and its amino acid composition in sorghum differ with the location at which the crop is grown (Deosthale and Mohan, 1970; Deosthale, Nagarajan and Visweswar Rao, 1972; Deyoe and Shellenberger, 1965). The level of nitrogen fertilizer also influences the quantity and quality of protein in sorghum (Deosthale, Nagarajan and Visweswar Rao, 1972; Waggle, Deyoe and Smith, 1967) and also in pearl millet (Deosthale, Visweswar Rao and Pant, 1972; Shah and Mehta, 1959). Warsi and Wright (1973) noted that application of nitrogen fertilizer increased the grain yield and protein. Higher protein in response to fertilizer nitrogen was mainly the result of increased accumulation of prolamin, a poor-quality protein, in the grain (Sawhney and Naik, 1969). The level of nitrogen fertilizer had no effect on the mineral composition of grain sorghum. However, the mineral content of the sorghum increased with increasing levels of phosphorus fertilizer (Deosthale, Nagarajan and Visweswar Rao, 1972). The mineral composition of sorghum grain was influenced more by location than by variety (Deosthale and Belavady, 1978). Other factors such as the density of the plant population, season, water and stress also contribute to variations in gram composition.

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Carbohydrate

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Starch is the major storage form of carbohydrate in sorghum and millets. It consists of amylopectin, a

branched-chain polymer of glucose, and amy-lose, a straight-chain polymer.

The digestibility of the starch, which depends on hydrolysis by pancreatic enzymes, determines the available energy content of cereal grain. Processing of the grain by methods such as steaming, pressure-cooking, flaking, puffing or micronization of the starch increases the digestibility of sorghum starch. This has been attributed to a release of starch granules from the protein matrix rendering them more susceptible to enzymatic digestion (McNeil! et al., 1975; Harbers, 1975).

The physico-chemical properties of the starch affect the textural characteristics of the food preparations made from grain. The behaviour of starch in water is temperature and concentration dependent (Whistler and Paschall, 1967). Grain starches in general show very little uptake of water at room temperature, and their swelling power is also small. At higher temperature water uptake increases and starch granules collapse, which leads to solubilization of amylose and amylopectin to form a colloidal solution. This is the gelatinization stage. Genetic and environmental factors affect the gelatinization temperature of grain starch (Freeman, Kramer and Watson, 1968). Heat treatment of starch in a limited amount of water leads to swelling of the granules with very little loss of soluble material and partial gelatinization of the starch.

On cooking, the gelatinized starch tends to return from the soluble, dispersed and amorphous state to an insoluble crystalline state. This phenomenon is known as retrogradation or setback; it is enhanced with low temperature and high concentration of starch. Amylose, the linear component of the starch, is more susceptible to retrogradation. Some characteristics of sorghum and millet starches are presented in Table 19; soluble sugar composition and total sugar content are given in Table 20.

TABLE 19: Characteristics of isolated starches of sorghum and millets

Grain	Amylose	Gelatinization	Water-	Swelling	Solubility	Viscosity

	(%)	temperature (C)		Binding capacity (%)	at 90C (%)	at 90C (%)	(amylograph - Brabender units)			
		Initial	Final				At 93-95C	After holding at 95 C	Cooled to 35 or 50C	After holding at 35C or 50C
Sorghum	24.0	68.5	75.0	105	22	22	600	400	580	520
Sorghum (waxy)	1.0	67.5	74.0	-	49	19	380	290	390	350
Pearl millet	21.1	61.1	68.7	87.5	13.1	9.16	460	396	568	536
Proso millet	28.2	56.1	61.2	108.0	12.0	6.89	688	520	826	1 203
Foxtail millet(a)	-	53.5	59.5	128.5	11.2	4.65	840	620	1 100	1 220
Foxtail millet (b)	17.5	55.0	62.0	-	9.8	4.80	1 780	1 540	2000	-
Kodo millet	24.0	57.0	68.0	-	12.0	5.50	300a	270	390	-
Finger millet	16.0	64.3	68.3	-	11.4	6.50	1 633	1 286	1 796	-

a Peak viscosity achieved at 83.5C.

***Sources*: Rooney and Serna-Saldivar. 1991: Leach. 1965: Horan and Heider. 1946: Subramanian et al. . 1982; Beleia. Varriano-Marston and Hoseney, 1980: Yanez and Walker. 1986: Lorenz and Hinze. 1976: Wankhede. Shehnaj and Raghavendra Rao. 1979b: Paramahans and Taranathan. 1980.**

TABLE 20: Soluble sugar composition of sorghum and millets (g per 100 g, dry-matter basis)

Grain	Number of cultivars	Total sugar	Sucrose	Glucose + fructose	Raffinose	Stachyose
Sorghum, normal (a)	10	2.25	1.68	0.25	0.23	0.10
		(1.3-5.2)	(0.9-3.9)	(0.06-0.74)	(0.10-0.39)	(0.04-0.21)
Sorghum, normal (b)	-	1.34	0.61	0.52	0.15	0.06
Sorghum, sugary	-	2.21	0.81	0.95	0.39	0.06
Sorghum, high lysine	-	2.57	0.94	1.13	0.39	0.11
Pearl millet	9	2.56	1.64	0.11	0.71	0.09
		(2.16-2.78)	(1.32-1.82)	(0.08-0.16)	(0.65-0.84)	(0.06-0.13)
Finger millet	3	0.65	0.22	0.16	0.07	-
		(0.59-0.69)	(0.20-0.24)	(0.14-0.19)	(0.06-0.08)	
Foxtail millet	1	0.46	0.15	0.10	0.04	-

Proso millet	6	-	0.66	-	0.08	-

Sources: Subramanian. Jambunathan and Suryaprakash. 1980: Murty et al . 1985: Subramanian. Jambunathan and Suryaprakash, 1981: Wankhede, Shehnaj and Raghavendra Rao. 1979a: Becker and Lorenz. 1978.

Sorghum

With values ranging from 56 to 73 percent, the average starch content of sorghum is 69.5 percent (Jambunathan and Subramanian, 1988). About 70 to 80 percent of the sorghum starch is amylopectin and the remaining 20 to 30 percent is amylose (Deatherage, McMasters and Rist, 1955). Both genetic and environmental factors affect the amylose content of sorghum (Ring, Akingbala and Rooney, 1982). Waxy or glutenous sorghum varieties are very low in amylose; their starch is practically 100 percent amylopectin (Ring, Akingbala and Rooney, 1982; Deatherage, McMasters and Rist, 1955). But in sugary sorghum the amylose content of the starch is about 5 to 15 percent higher than in normal sorghum (Singh and Axtell, 1973b). The total carbohydrate content of sugary sorghum is normal, however, since it contains exceptionally high levels of water-soluble polysaccharides (29.1 percent)

The digestibility of isolated starch of sorghum cultivars ranged from 33 to 48 percent as against 53 to 58 percent for corn starches (Sikabbubba, 1989). The texture of the grain endosperm, the particle size of the flour and starch digestibility were found to be strongly correlated with each other. Starch in floury sorghum was found to be more digestible than that in corneous sorghum. Particles of ground floury sorghum were smaller than those of similarly ground corneous sorghum. The smaller particle size and correspondingly greater surface area facilitate the enzyme action and thus improve starch digestibility.

The chemical nature of the starch, particularly the amylose and amylopectin content, is yet another factor that affects its digestibility. The starch digestibility was reported to be higher in low-amylose, i.e. waxy,

sorghum than in normal sorghum, corn and pearl millet grains (Hibberd et al., 1982). Feeding trials in rats (Elmalik et al., 1986) and other animal species (Sherrod, Albin and Furr, 1969; Nishimuta, Sherrod and Furr, 1969) have confirmed the superiority of waxy sorghum over normal grain types in terms of dry matter and gross energy digestibility.

The presence of tannins in the grain contributes to the poor digestibility of starch in some varieties of sorghum (Dreher, Dreher and Berry, 1984). Tannins isolated from sorghum grain were shown to inhibit the enzyme X-amylose, and they also bind to grain starches to varying degrees (Davis and Hoseney, 1979).

The gelatinization temperature of isolated sorghum starch and that of finely ground flour of the corresponding endosperm has been reported to be the same. On the other hand the pasting temperature, i.e. the temperature at which starch attains peak viscosity when heated with water to form a paste, was found to be about 10C higher for the sorghum flour than for the isolated starch.

The quality of cooked sorghum has been strongly associated with the total and soluble amylose content of the grain and also the soluble protein content (Cagampang and Kirleis, 1984). The swelling power of starch and its solubility significantly influenced the cooking quality of sorghum (Subramanian et al., 1982). The percentage weight increase of cooked grain was negatively correlated with starch solubility at 60C, a temperature at which most of the starch granules will have reached gelatinization stage. The swelling power of starch at 60 and 90C and solubility at 25 and 50C were inversely correlated with gruel solid content, which directly depended on the starch content of the grain. The starch gelatinization temperature did not show any significant effect on the cooking quality of sorghum.

Plasticity of sorghum flour dough mostly arises from the gelatinization of starch when the dough is prepared in hot or boiling water. The stickiness of the cooked flour is a function of the starch gelatinization. Porridge prepared from hard endosperm of sorghum is less sticky than that prepared from grains with a larger proportion of floury endosperm (Cagampang, Griffith and Kirleis, 1982).

Dough prepared with cold water has poor adhesiveness and is difficult to roll thin. Thus heat modification of the starch when the dough is prepared with hot water determines its rolling properties (Desikachar and Chandrashekar, 1982). Higher water uptake' low gelatinization temperature, high peak paste viscosity and high setback are the starch properties that have been shown to be associated with good quality of roti, the unleavened bread that is the most common form in which sorghum and pearl millet are consumed on the Indian subcontinent. On the other hand, for stiff porridges such as Indian mudde or sankhati and African t, the desirable characteristics of the grain starch are high gelatinization temperature, low peak paste viscosity and low retrogradation tendency. In other words, the starch characteristics for goodquality roti were found to be exactly opposite to those desirable for goodquality porridge. Thus sorghum varieties that are not suitable for roti may be suitable for porridge. Almeida-Dominguez, Serna-Saldivar and Rooney (1991) found that low-amylose or waxy sorghum produced sticky dough (masa) and was not suitable for preparation of tortillas.

Pearl millet

In different pearl millet genotypes the starch content of the grain varied from 62.8 to 70.5 percent, soluble sugar from 1.2 to 2.6 percent and amylose from 21.9 to 28.8 percent (Jambunathan and Subramanian, 1988). Lower values for starch (56.3 to 63.7 percent) and amylose (18.3 to 24.6 percent) have been found in some high-yielding Indian pearl millet varieties (Singh and Popli, 1973). Subramanian, Jambunathan and Suryaprakash (1981) found that the predominant component of total soluble sugar (2.16 to 2.78 percent) was sucrose (66 percent), followed by raffinose (28 percent). Other sugars detected in measurable amounts were stachyose, glucose and fructose. The proportion of sucrose in total sugar was lower in pearl millet than in sorghum.

Pasting properties of pearl millet starch were generally similar to those of sorghum except when it was held for one hour at 95C (Bad), Hoseney and Finney, 1976). Beleia, Varriano-Marston and Hoseney (1980)

considered inherent molecular dissimilarities the primary factor in physico-chemical differences among five pearl millet starches examined. The amylose content of these starches varied within a narrow range (22 to 24 percent). Variation in the water-binding capacity (83.6 to 99.5 percent) was probably due to differences in the proportions of amorphous and crystalline starch in the granule; amorphous starch has greater water absorption capacity than crystalline starch. In the five starches, the initial gelatinization temperature ranged from 59 to 63C, the mid-point from 65 to 67.5C and the final gelatinization temperature from 68 to 70C. The gelatinization of pearl millet starch occurred at a lower temperature than that of sorghum starch (Table 19). In general it was observed that starches having low solubility and swelling below 75C showed greater solubility and swelling at and above 80C. The peak pasting temperature of the five starches was the same, 76.5C. Differences in paste viscosity were larger in magnitude after one hour's holding at 95C and during the cooling cycle. This showed that some starches tended to retrograde more than others.

The peak paste viscosity of pearl millet flour starch was much lower than that of sorghum starch (Bad), Hoseney and Finney, 1976). Pearl millet was shown to have very high amylase activity, about ten times higher than that of wheat grain (Sheorain and Wagle, 1973), and this was probably responsible for the low peak viscosity observed. It is of interest that amylase of pearl millet was observed to be more active against wheat starch than against the starch from pearl millet grain itself (Beleia and Varriano-Marston, 1981 a,b). This observation is of great practical importance. Bread prepared from wheat flour blended with 10 percent pearl millet flour had better loaf volume than standard bread prepared from wheat flour containing malt and sugar (Bad), Hoseney and Finney, 1976). Thus pearl millet flour used in partial replacement of wheat flour can be successfully substituted for malt and sugar in the preparation of bakery products such as bread, biscuits and pasta. Subramanian, Jambunathan and Ramaiah (1986) observed that the quality of unleavened bread (roti) prepared from pearl millet flours was influenced by swelling capacity, water-soluble flour fraction, water-soluble protein and amylose content of the flour. The swelling capacity of the flour was highly and positively correlated with all the sensory dualities of roti, namely colour, texture, odour, taste and acceptability. On the other hand, the amylose content and water-soluble flour fraction were negatively correlated with all these

characteristics.

Finger millet

In high-yielding varieties of finger millet analyzed by Wankhede, Shehnaj and Raghavendra Rao (1979a), mean starch content was 60.3 (59.5 to 61.25) percent; pentosan 6.6 (6.2 to 7.2) percent; cellulose 1.6 (1.4 to 1.8) percent, lignin 0.28 (0.04 to 0.6) percent; and free sugar 0.65 (0.59 to 0.69) percent. Sucrose (33 percent) glucose and fructose (each 12 percent) and maltose and raffinose (10 percent each) were the major components of the free sugar of finger millet. The amylose content of the starch in finger millet was 16 percent (Wankhede, Shehnaj and Raghavendra Rao, 1979b), which is lower than the values in normal sorghum and other millets. The swelling capacity and solubility in water at 90C of the isolated starch of finger millet were lower than for sorghum and similar to those of other millet starches. The high peak viscosity and the increase in viscosity on cooling suggested a strong tendency of the starch to undergo retrogradation. The paste viscosity is reduced and the nutrient density, particularly energy density, is enhanced after malting of the grain, and on this basis weaning food containing 70 parts of malted finger millet and 30 parts of dehulled green gram has been developed (Malleshi and Desikachar, 1982).

Other millets

Foxtail and prove millet have been reported to have both glutenous and nonglutenous endosperm types, while only the non-glutenous type of endosperm is reported to be present in finger and barnyard millets (Tomita et al., 1981). The starch in two foxtail millet varieties was 100 percent amylopectin. Starches of foxtail, prove and barnyard millets were more digestible than maize starch in terms of in vitro amylolysis by pancreatic amylase. The glutenous starches were more digestible than non-glutenous types as in other cereal grains.

The increase in paste viscosity on cooling to 35C and the further rise after one hour's holding at that

temperature indicated the strong tendency of these millet starches to undergo retrogradation. One of the prove varieties, namely Big red prove, was exceptional in that its starch had higher water-binding capacity and gelatinization temperature than that of five other varieties.

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Protein content and quality

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The second major component of sorghum and millet grains is protein. Both genetic and environmental factors affect the protein content of sorghum and millets. In sorghum the variability is large, probably because the crop is grown under diverse agroclimatic conditions which affect the grain composition (Burleson, Cowley and Otey, 1956; Waggle, Deyoe and Smith 1967; Deosthale, Nagarajan and Visweswar Rao, 1972). Fluctuations in the protein content of the grain are generally accompanied by changes in the amino acid composition of the protein (Waggle and Deyoe, 1966).

The quality of a protein is primarily a function of its essential amino acid composition. To assess the protein quality, Block and Mitchell (1946) introduced the concept of an amino acid or chemical score, in which the amount of the essential amino acid that is in greatest deficit is expressed as a percentage of the amount present in a standard or reference protein. Egg and human milk proteins, for their very high biological value, have been considered as reference standards. Sorghum and millet proteins differed in their essential amino acid profile (Table 21). However, the most common feature was that lysine was always found to be the most

limiting amino acid. The highest deficit of lysine was in the protein of barnyard millet (chemical score 31), closely followed by little millet (chemical score 33). Sorghum protein, with a chemical score of 37, did not differ very much in quality from the proteins of barnyard and little millet.

The primary function of dietary protein is to satisfy the body's needs for nitrogen and essential amino acids. According to the World Health Organization (1985), the chemical score of a protein if calculated in relation to the essential amino acid requirement pattern as reference would be more realistic and indicative of the capacity of the protein to meet human requirements. Such data on chemical score relative to amino acid requirement for different age groups (Table 22) suggested that the inherent capacity of the existing varieties commonly consumed was not adequate to meet the growth requirements of infants and young children, though all of them except sorghum may be able to meet the maintenance requirements in adults.

Grain proteins are broadly classified into four fractions according to their solubility characteristics: albumin (water soluble), globulin (soluble in dilute salt solution), prolamin (soluble in alcohol) and glutelin (extractable in dilute alkali or acid solutions). In solubility fractionation studies with sorghum and pearl, finger and foxtail millets, five protein fractions were obtained (Table 23). The levels of albumin plus globulin were higher in pearl millet varieties than in sorghum, while amounts of the cross-linked prolamin, -prolamin, were higher in sorghum than in pearl millet.

TABLE 21: Essential amino acid composition (mg/g) and chemical score of sorghum and millet proteins

Grain	**Isoleucine**	**Leucine**	**Lysine**	**Methionine**	**Cystine**	**Phenylalanina**	**Tyrosine**	**Threonine**	**Tryptophan**	**Valine**	**Chemical score**
Sorghum	245	832	126	87	94	306	167	189	63	313	37
Pearl millet	256	598	214	154	148	301	203	241	122	345	63

Finger millet	275	594	181	194	163	325	-	263	191	413	52
Foxtail millet	475	1 044	138	175	-	419	-	194	61	431	41
Common millet	405	762	189	160	-	307	-	147	49	407	56
Little millet	416	679	114	142	-	297	-	212	35	379	33
Barnyard millet	288	725	106	133	175	362	150	231	63	388	31
Kodo millet	188	419	188	94	-	375	213	194	38	238	55

***Sources*: FAO. 1970a; Indira and Naik. 1971.**

TABLE 22: Lysine amino acid scores for different age groups based on the 1985 WHO index

Grain	**Infant (<1 year)**	**Preschool child (2 - 5 years)**	**Schoolchile (10 - 12 years)**	**Adult**
Wheat	43	46	62	100+
Rice (hushed)	57	61	82	100+
Maize	41	43	58	100+
Sorghum	17-51	18-55	25-74	71-100+

Pearl millet	26-69	28-74	38-100+	100+
Foxtail millet	28-38	30-40	40-55	100+
Finger millet	39-63	41-68	56-91	100+
Kodo millet	46-52	48-55	65-74	100+
Barnyard millet	26	27	37	100+
Proso millet	23-72	24-74	32-98	93-100+

***Sources*: WHO, 1985; Hulse, Laing and Pearson, 1980.**

Apart from a favourable essential amino acid profile, easy digestibility is an important attribute of a good-quality protein. Chemical score does not take into account the digestibility of protein or availability of amino acids. Biological methods based on measurement of growth and nitrogen retention assess the overall nutritional quality of the protein. These methods include determination of protein efficiency ratio (PER), net protein utilization (NPU), biological value (BV) and true protein digestibility (TDP).

Sorghum

Wide variability has been observed in the essential amino acid composition of sorghum protein (Hulse, Laing and Pearson, 1980; Jambunathan, Singh and Subramanian, 1984). Lysine content was reported to vary from 71 to 212 mg per gram of nitrogen and the corresponding chemical score varied from 21 to 62.

Singh and Axtell (I 973a) identified two high-lysine Ethiopian sorghum varieties, IS 11758 and IS 11167. The average lysine content of the whole kernel of IS 11758 was 3.13 g per 100 g protein and the total protein content of the kernel was 17.2 percent. IS 11167 contained 3.33 g lysine per 100 g protein and 15.7 percent protein. Normal sorghum grown under similar conditions contained 12 percent protein and 2.1 g lysine per

100 g protein. Feeding trials in rats have shown higher PER values for high-lysine varieties (1.78 and 2.05 for IS 11758 and IS 11167, respectively) than for normal sorghum (PER 0.74 and 1.24).

TABLE 23: Distribution of protein fractions in sorghum and millet grains (percentage of total protein)

Fraction	**Sorghum**		**Pearl millet**		**Finger millet**		**Foxtail millet**	
	Range	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**
Albumin+globulin	17.1-17.8	17.4	22.6-26.6	25.0	17.3-27.6	22.4	11.6-29.6	17.1
Prolamin	5.2-8.4	6.4	22.8-31.7	28.4	24.6-36.2	32.3	47.6-63.4	56.1
Cross-linked prolamin	18.2-19 5	18.8	1.8-3.4	2.7	2.5-3.3	2.78	6.4-17.6	8.9
Glutelin-like	3.4-4.4	4.0	4.7-7.2	5.5	-	-	5.2-11.9	9.2
Glutelin	33.7-38.3	35.7	16.4-19.2	18.4	12.4-28.2	21.2	-	6.7
Residue	10.4-10.7	10.6	3.3-5.1	3.9	16.1-25.3	21.3	-	2.0
Total	91.2-94.0	92.9	78.6-87.5	83.9	74.7-83.9	78.7	-	98.0

***Sources*: Jambunathan,Singh and Subramanian. 1984 (sorghum and pearl millet); Virupaksha. Ramachandra and Nagarajut. 1975 (finger millet): Monteiro. Virupaksha and Rajagopol Rao. 1982 (foxtail millet).**

Another high-lysine mutant, P721, was reported to have 60 percent more lysine than normal sorghum. Van Scoyoc, Ejeta and Axtell (1988) have demonstrated that the high lysine of P721 resulted primarily from unusually high amounts of lysine-rich glutelin and low lysine-poor prolamin.

Ejeta and Axtell (1987) observed that in all three of these high-lysine sorghum varieties the lysine content of the germ was normal but the lysine content of the endosperm was higher than in normal sorghum.

Naik (1968), using a modified extraction procedure, observed wide variations in the distribution pattern of protein fractions in the sorghum varieties. Albumin ranged from 2 to 9 percent of total protein, while globulin ranged from 12.9 to 16 percent, prolamin from 27 to 43.1 percent and glutelin from 26.1 to 39.6 percent. Seasonal differences in the distribution pattern of protein fractions were reported (Virupaksha and Sastry, 1968): sorghum varieties grown in the Rabi (dry) season had less prolamin than when grown in other seasons.

Studies on amino acid composition of the protein tractions (Ahuja, Singh and Naik, 1970) showed that the albumin and globulin fractions contained high amounts of lysine and tryptophan and in general were well balanced in their essential amino acid composition. On the other hand, the prolamin fraction was extremely poor in lysine, arginine, histidine and tryptophan and contained high amounts of proline, glutamic acid and leucine. Present in the form of protein bodies, prolamin was found to be a predominant protein fraction directly associated with the protein content of the grain. Glutelin, the second major protein traction, is a structural component, the protein matrix in the peripheral and inner endosperm of the sorghum kernel.

Both in vitro and in vivo studies have demonstrated wide variability in protein digestibility of sorghum varieties (Axtell et al., 1981). Values ranging from 49.5 to 70 percent (Nawar et al., 1970) and from 30 to 70 percent (Silano, 1977) have been reported. Elmalik et al. (1986) observed that in rats digestibility of protein of sorghum varieties with intermediate and corneous endosperm texture was 70.3 and 74.5 percent, respectively. These values were lower than that observed for corn protein (78.5 percent). In certain sorghum

varieties the presence of condensed polyphenols or tannins in the grains is another factor that adversely affects protein digestibility and amino acid availability (Bach Knudsen et al., 1988; Bach Knudsen, Munck and Eggum, 1988; Whitaker and Tanner, 1989).

In tannin-free sorghum varieties, Sikabbubba (1989) observed that the protein digestibility was inversely correlated with total protein in the grain ($r = -0.548$, $p < 0.1$), total prolamin ($r = -0.627$, $p < 0.25$), cross-linked or -prolamin ($r = 0.647$, $p < 0.05$) and digestibility of -prolamin ($r = -0.727$, $p < 0.01$). In studies in boys aged 10 to 11 years (Kurien et al., 1960), progressive substitution of sorghum for rice in a predominantly vegetarian diet resulted in progressive decrease in protein digestibility from 75 to 55 percent and in apparent nitrogen retention from 4.5 to 2.1 percent. Similar observations were also made in 10- to 11-year-old girls fed sorghum proteins. In nitrogen balance studies conducted with 6- to 30-month-old children recovering from protein energy malnutrition, MacLean et al. (1981) observed that for whole-grain gruels prepared from four sorghum varieties including two high-lysine varieties, P721 opaque and IS 11758, the average protein digestibility was 46 percent. The protein digestibility of sorghum grain was thus found to be extremely poor as compared to that previously observed for wheat (81 percent), maize (73 percent) and rice (66 percent). However, in a study with decorticated and extruded sorghum product fed to young children (Maclean et al., 1983), the protein digestibility, 81 percent, was much higher than for the whole grain (46 percent). Nitrogen retention, which had been 14 percent in the whole-grain study, was also enhanced, to 21 percent. In vitro studies conducted on extruded sorghum (Mertz et al., 1984) also showed that extrusion processing of sorghum grain improved the protein digestibility and hence the nutritive value. Digestibility of sorghum protein was also improved after processing of the grain into nasha, a thin fermented porridge used as baby food in the Sudan (Graham et al., 1986). Nitrogen retention was improved in normal Nigerian men fed home-pounded and winnowed sorghum with reduced fibre content (Nicol and Phillips, 1978). These observations emphasize the importance of grain processing to improve the nutritive value of sorghum. A decrease in the protein digestibility of sorghum on cooking was attributed to reduced solubility of prolamin and its reduced digestibility by pepsin (Hamaker et al., 1986).

Pearl millet

Pearl millet, like sorghum, is generally 9 to 13 percent protein, but large variations in protein content, from 6 to 21 percent, have been observed (SernaSaldivar, McDonough and Rooney, 1991). Lysine is the first limiting amino acid of pearl millet protein. A significant inverse correlation has been reported between the level of protein in the grain and the lysine content of the protein (Deosthale et al.,1971). In high-protein varieties of pearl millet with protein content ranging from 14.4 to 27.1 percent, significant inverse correlations have also been observed between protein and threonine, methionine and tryptophan. The essential amino acid profile shows more lysine, threonine, methionine and cystine in pearl millet protein than in proteins of sorghum and other millets. Its tryptophan content is also higher (Table 21).

Wide variation is observed in the lysine content of pearl millet protein, with values ranging from 1.59 to 3.8 g per 100 g protein. From chemical scores calculated in relation to amino acid requirements for different age groups it was apparent that pearl millet has greater potential to meet the lysine requirements of growing children than most other cereals (Table 22). Pushpamma, Parrish and Deyoe (1972) observed in rat feeding trials a PER of 1.84 for pearl millet as against 1.74 for finger millet, 1.46 for sorghum and 1.36 for maize. This has supported the view that the protein quality of pearl millet ranks quite high in comparison with that of other cereals. On fortification of a pearl millet diet with 0.3 percent lysine hydrochloride, the growth response of rats was enhanced and nearly equalled that of controls fed a casein diet (Howe and Gilfillan, 1970).

Protein quality is associated with the distribution pattern of protein fractions in the grain. Sawhney and Naik (1969) observed large variability in the protein fractions of pearl millet varieties. Albumin ranged from 6.1 to 26.5 percent (mean 15.1 percent), globulin from 3.5 to 14.7 percent (mean 8.7 percent), prolamin from 21.3 to 38.0 percent (mean 30.2 percent) and glutelin from 23.8 to 37.7 percent (mean 30.3 percent). As in other cereals, albumin and globulin are rich in lysine as well as the other basic amino acids arginine and histidine.

The globulin fraction appeared to be very rich in sulphur amino acids. The prolamin fraction is characterized by high glutamic acid proline and leucine and was also shown to be rich in tryptophan, whereas glutelin was found to contain more lysine and less tryptophan.

True protein digestibility in rats fed pearl millet varied little, from 94 to 97 percent (Singh et al., 1987), and it was not affected by the protein content of the grain (Table 24). The digestible energy content was lower in high-protein types because of their high prolamin content. In high-protein genotypes, the lysine content of the protein was low and this was reflected in low biological value and low net protein utilization. But the net utilizable protein (percent protein x NPU) from the high-protein genotypes was two to three times higher than that from normal millets. Rats fed raw pearl millet flour exhibited higher digestibility of protein and energy than rats fed raw wheat flour (Dassenko, 1980). However, the digestibility and PER were lower when the millet was fed as chapatti, probably because the longer cooking time required for millet chapatti resulted in heat damage to the protein. In nitrogen balance studies in 11 - to 12-year-old boys, the apparent protein digestibility of a pearl millet-based diet was 52.9 percent and the nitrogen balance was positive (Kurien, Swaminathan and Subrahmanyan, 1961).

TABLE 24: Protein quality and digestible energy in dehulled millets (%)

Grain	True digestibility	Biological value	Net protein utilization	Digestible energy
Pearl millet (low protein)	95.9	65.6	62.9	89.9
Pearl millet (high protein)	94.6	58.8	55.7	85.3
Foxtail millet	95.0	48.4	46.3	96.1

Common millet	99.3	52.4	52.0	96.6
Little millet	97.7	53.0	51.8	96.1
Barnyard millet	95.3	54.8	52.2	95.6
Kodo millet	96.6	56.5	54 5	95.7

***Sources*:: Singh et al . 1987 (pearl millet); Geervani and Eggum,1989 (other millets).**

Finger millet

Finger millet is poor in protein content compared with other common cereals (Table 17). Wide variability in the composition of the grain, including its protein content, was reported (Hulse, Laing and Pearson, 1980). Both genetic and environmental factors appear to have an important role in determining the protein content of finger millet (Pore and Magar, 1977; Virupaksha, Ramachandra and Nagaraju, 1975). Prolamin is the major protein fraction in finger millet (Table 23). The high protein of white-grain varieties was attributed to the higher prolamin content of the grain, while the lysine content and hence the protein quality of these varieties are low (Virupaksha, Ramachandra and Nagaraju, 1975). Differences in amino acid composition in different varieties of finger millet are large, and as in other cereals both the lysine content and the methionine content of the protein are inversely correlated with the protein content of the grain. The protein tractions also showed wide variation in their amino acid composition. While the albumin and globulin fraction was found to contain a good complement of essential amino acids, the prolamin fraction contained higher proportions of glutamic acid, proline, valine, isoleucine, leucine and phenylalanine but low lysine arginine and glycine. The amino acid composition of prolamin was almost the same as that of endosperm protein.

In vitro studies showed that proteins of finger millet and kodo millet were resistant to pepsin digestion unless the millet was first cooked in an autoclave for 15 minutes or boiled for at least two hours in water.

Digestibility of the protein was found to be adversely affected by tannin in the grain, which was as high as 3.42 percent in some of the finger millet varieties studied (Ramachandra, Virupaksha and Shadaksharaswamy, 1977). A finger millet diet was found to be adequate to maintain a positive nitrogen balance in adults (Subrahmanyan et al., 1955). The subjects also showed positive calcium and phosphorus balances, and the digestibility of finger millet protein was found to be 50 percent. Supplementation of a finger millet protein diet with lysine or with leaf protein in addition to lysine significantly improved nitrogen retention in young boys. They also showed greater increase in height and weight (Doraiswamy, Singh and Daniel, 1969). The use of finger millet in child and infant feeding, however, appeared to be limited because of its poor digestibility and the large quantity required to meet energy requirements. The growth performance of growing rats fed sprouted finger millet was better than that of animals fed raw grain. However, the protein quality as judged by PER was unaltered by sprouting (Hemanalini et al., 1980). Further processing of germinated finger millet grains by drying, roasting and filtering through a cloth gave a product low in fibre. Animals fed this product as a source of protein showed improved calcium retention, probably because of the low fibre content of the flour.

Malted grains of finger millet have a significantly higher saccharifying enzyme activity useful in brewing. This activity is higger than that of malted sorghum, pearl millet or maize (Rao and Mushonga, 1985). A weaning food with low hot paste viscosity and high energy density was developed in which malted finger millet from which the vegetative portion had been removed was combined with green gram. Amix of 70 parts malted finger millet grains and 30 parts green gram, combined with 10 percent skimmed milk powder, had a PER of 2.7 and NPU of 63 percent (Malleshi and Desikachar, 1982). An extruded cooked product prepared from a blend of rice (42.5 parts), finger millet (42.5 parts) and defatted soy flour (15 parts) exhibited a significant improvement in protein quality over the unprocessed blend (Dublish, Chauhan and Bains, 1988). The PER values after extrusion had increased from 1.92 to 2.41, while the trypsin inhibitory activity was reduced by about 70 to 100 percent, the tannin content was below measurable amounts and the phytin phosphorus as percentage of total phosphorus had decreased by about 4 to 13 percent. These changes obviously might have

contributed to the improved protein quality. A blend of finger millet and defatted soy flour (85:15) on extrusion had a PER of 1.81 before processing and 2.23 after extrusion.

Foxtail millet

The protein in foxtail millet is also deficient in lysine Its amino acid score (Table 22) is comparable to that of maize (Baghel, Netke and Bajpai, 1985). Monteiro, Virupaksha and Rajagopol Rao (1982) observed large variation in the grain protein content and in the distribution pattern of different solubility fractions. Prolamin constituted the major storage protein (Table 23) and showed a positive correlation with total protein in the grain. Evaluations of the amino acid composition of the protein fractions and of total protein in different varieties have confirmed that lysine is the first limiting amino acid, followed by tryptophan and sulphur amino acids.

With increase in grain protein, the lysine content of the protein decreased. The protein was found to be high in leucine. Naren and Virupaksha (1990) observed that the prolamin was relatively rich in the sulphur amino acid methionine and that the sulphur status of the soil affected the synthesis of prolamin in the grain. In studies on in vitro protein digestibility, 90.5 to 96.9 percent of the protein in foxtail millet was digestible by pepsin, and 89.7 to 95.6 percent by papain (Monteiro et al., 1988). Poor digestibility with trypsin (21.6 to 36.9 percent) was improved by prior treatment with acid. The protein quality of dehusked grain (Table 24) was the lowest among the minor millets tested (Geervani and Eggum, 1989). Heat treatment or lysine supplementation improved the protein quality (Geervani and Eggum, 1989). In growing rats fed 10 percent protein, the nitrogen balance improved from 19 to 31 percent when the foxtail millet diet was fortified with lysine protein digestibility and biological value were also enhanced (Ganapathy, Chitra and Gokhale, 1957). Supplementation of dehusked millet with chickpea raised the PER from 0.5 to 2.2.

Common millet

Though the range of protein content in common millet can be very wide, the values appear to lie most frequently in a narrow range of 11.3 to 12.7 percent, with a mean of 11.6 percent, on a dry-matter basis (Serna-Saldivar, McDonough and Rooney, 1991). The protein of common millet is deficient in lysine as well as threonine, and its tryptophan content is also marginal (Chung and Pomeranz, 1985). Studies on the protein solubility fractions of common millet showed that more than 50 percent of the grain protein was prolamin and the next predominant fraction was glutelin, about 28 percent. The prolamin fraction was very poor in lysine arginine and glycine compared to the albumin and globulin fraction and had more alanine, methionine and leucine (Jones et al., 1970). When ted as the sole source of protein (8.4 percent) in the diet, common millet had a PER of 0.95. According to data presented by Kuppuswamy, Srinivasan and Subramanian (1985), a common millet diet containing 9 to 11 percent protein had a PER of 1.2 and biological value of 56. A protein isolated (84.8 percent) by alkali extraction of common millet (Tashiro end Maki, 1977) was compared for its protein quality with casein and gluten. In a 21 -day feeding trial in young rats with 10 percent protein in the diet, the PER of the protein isolate of common millet was 3.1 while that of casein was 2.8. Animals fed whole millet flour as a source of protein failed to grow. In adult rats the biological value of millet flour was higher than that of the other protein sources. In in vitro studies, the isolated protein was digestible by pepsin and by pepsin-pancreatin but not by trypsin.

Other millets

Kodo, barnyard and little millets have been investigated less from the nutritional point of view. Kodo millet grains are enclosed in a hard, corneous husk which is difficult to remove. The fibre content of the whole grain is very high. Kodo millet has around 11 percent protein, and the nutritional value of the protein has been found to be slightly better than that of foxtail millet but comparable to that of other minor millets (Table 24). Apart from lysine the protein of kodo millet is deficient in tryptophan (Chung and Pomeranz, 1985). As with other foodgrains, the nutritive value of kodo millet protein was improved by supplementation with legume protein (Rajalakshmi and Mujumdar, 1966). The PER of kodo millet on supplementation with chickpea and

amaranth leaves was increased from 0.9 to 1.9 (Patwardhan, 1961b).

Barnyard and little millets are comparable to common millet in their protein and fat content (Geervani and Eggum, 1989), and both are very high in fibre. With lysine amino acid scores of 31 and 33, little millet and barnyard millet have the poorest quality proteins among the millets. Barnyard and little millets are comparable in their protein digestibility, biological value, net protein utilization and digestible energy content (Table 24) and therefore in their overall nutritive value.

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Lipid composition

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Sorghum

The crude fat content of sorghum is 3 percent, which is higher than that of wheat and rice but lower than that of maize. The germ and aleurone layers are the main contributors to the lipid fraction. The germ itself provides about 80 percent of the total fat (Rooney and Serna-Saldivar,1991). As the kernel tat is mostly located in the germ, in sorghum mutants with a large embryo fraction the fat content is higher (5.8 to 6.6 percent) than normal (Jambunathan, 1980). Variations in reported fat content of the grain can be attributed partly to the different solvent systems used for extraction of kernel fat. Price and Parson (1975) reported that the neutral lipid fraction was 86.2 percent, glycolipid 3.1 percent and phospholipid 10.7 percent in sorghum

fat.

No significant difference was reported in let content among several cultivated and wild sorghum races (Stemler et al., 1976). Fatty acid was significantly higher in kafir, caudatum and wild sorghum than in the bicolor, durra and guinea groups. On the other hand, caudatum types had the lowest linoleic acid and bicolor, durra and guinea varieties had more than wild and kafir sorghum. Oleic and linoleic acids were negatively correlated with each other. The fatty acid composition of sorghum fat (linoleic acid 49 percent, oleic 31 percent, palmitic 14 percent, linolenic 2.7 percent, stearic 2.1 percent) was similar to that of corn fat but was more unsaturated (Rooney, 1978).

Millets

Finger, foxtail and kodo millets appeared to contain less fat in the kernel than other millets (Table 17), while the fat content of common millet was similar to that of sorghum. The fat content of pearl millet is the highest among the millets.

Lai and Varriano-Marston (1980) observed significant differences in the fatty acid composition of four different bulk populations of pearl millet. Differences in lipid extraction procedures as well as genetic variability were shown to contribute to differences in the fatty acid content of pearl millet (Jellum and Powell,1971). The principal fatty acids in both free and bound tat were found to be linoleic, oleic and palmitic acids. Distinct differences in fatty acid composition were noted in the neutral lipid, phospholipid and glycolipid fractions (Osagie and Kates, 1984). Neutral lipid was highest in linoleic acid and lowest in palmitic acid; phospholipid was lowest in oleic acid and highest in palmitic acid; and glycolipid was highest in linolenic acid.

The fatty acid composition of common millet and foxtail millet did not differ from that of sorghum (Hulse, Laing and Pearson, 1980). Common millet was found to contain 1.8 to 3.9 percent lipids, and about 24

percent of the grain fat was in the embryo component. The fatty acid profile showed that saturated fatty acids totalled 17.9 to 21.6 percent while unsaturated fatty acids totalled 78 to 82 percent. The unrefined fat extracted from the kernel of common millet contained 8.3 to 10.5 mg vitamin A and 87 to 96 mg vitamin E per 100 g. On refining, all the vitamin A activity was lost and there was significant loss in vitamin E. Vitamin E is also present in the fat extracted from sorghum grain.

Minerals

The mineral composition of sorghum and millet grains (Table 25) is highly variable. More than genetic factors, the environmental conditions prevailing in the growing region affect the mineral content of these foodgrains.

Sorghum

In the sorghum kernel the mineral matter is unevenly distributed and is more concentrated in the germ and the seed-coat (Hubbard, Hall and Earle, 1950). Pedersen and Eggum (1983) have shown that in milled sorghum flours minerals such as phosphorus, iron, zinc and copper decreased with lower extraction rates. Similarly, pearling the grain to remove the fibrous seed-coat resulted in considerable reduction in the mineral contents of sorghum (Sankara Rao and Deosthale, 1980). However, these studies also showed that the in vitro availability of iron as judged by the ionizable iron as percentage of total iron was higher in pearled grain. Dehulling improves iron availability because the hull is rich in phytate, a compound that binds iron and certain other minerals and makes them biologically unavailable (see Chapter 6). Mbofung and Ndjouenkeu (1990) observed that the percentage of soluble and ionizable iron was higher in gruels prepared from mechanically dehulled sorghum than in those prepared from grain milled traditionally using mortar and pestle. The increase in iron availability was attributed partly to the efficient removal of the phytate-rich hull in mechanical milling and partly to the greater destruction of phytate during soaking of the grain prior to dehulling.

In studies in Indian women, absorption of iron was higher from tannin-free than from high-tannin sorghum cultivars (Gillooly et al., 1984). Pearling of the grain improved the absorption of iron from both high- and low-tannin cultivars. Radhakrishnan and Sivaprasad (1980) assessed the bioavailability of iron in normal and anaemic subjects fed diets based on two varieties of sorghum containing 20 and 136 mg of tannin respectively and 160 and 273 mg of phytin phosphorus respectively per 100 g. In normal subjects iron absorption from low- and high-tannin sorghum was essentially similar. However, in anaemic subjects it was significantly lower with high-tannin sorghum. On equalization of the phytate content of the two sorghum meals the difference in iron absorption disappeared. It was concluded that at the levels of tannins present in the two varieties of sorghum, tannins had a minor role in determining the iron bioavailability.

TABLE 25: Mineral composition of sorghum and millets (mg %) [a]

Grain	Number of cultivars	P	Mg	Ca	Fe	Zn	Cu	Mn	Mo	Cr
Sorghum	6	352	171	15	4.2	2.5	0.44	1.15	0.06	0.017
Pearl millet	9	379	137	46	8.0	3.1	1.06	1.15	0.07	0.023
Finger millet	6	320	137	398	3.9	2.3	0.47	5.49	0.10	0.028
Foxtail millet	5									
Whole		422	81	38	5.3	2.9	1.60	0.85	-	0.070
Dehulled		360	68	21	2.8	2.4	1.40	0.60	-	0.030
Common millet	5									

Whole		281	117	23	4.0	2.4	5.80	1.20	-	0.040
Dehulled		156	78	8	0.8	1.4	1.60	0.60	-	0.020
Little millet	5									
Whole		251	133	12	13.9	3.5	1.60	1.03	-	0.240
Dehulled		220	139	13	9.3	3.7	1.00	0.68	-	0.180
Barnyard millet	5									
Whole		340	82	21	9.2	2.6	1.30	1.33	-	0.140
Dehulled		267	39	28	5.0	3.0	0.60	0.96	-	0.090
Kodo millet	5									
Whole		215	166	31	3.6	1.5	5.80	2.90	-	0.080
Dehulled		161	82	20	0.5	0.7	1.60	1.10	-	0.020

a Expressed on a dry-weight basis.
***Sources*: Sankara Rao and Deosthale.1980 (sorghum) 1983 (pearl and finger millets), unpublished (other millets).**

Gillooly et al. (1984) found no difference in the iron absorption from porridges prepared from malted and unmelted sorghum. They observed that addition of ascorbic acid facilitated the iron absorption from both porridges, while consumption of tea adversely affected the iron absorption. Iron absorption varied in a narrow range of 72 to 83 percent in rats fed acidic, basic or neutral sorghum t, maize gruel or the fermented sorghum porridge aceda (Stuart et al., 1987). However, absorption of zinc was found to be significantly higher, 97 percent, in rats fed fermented sorghum aceda than in those fed maize gruel or any of the three types of sorghum t (67 to 78 percent).

Beers brewed with sorghum adjuncts and maize grits are very common in African countries. Derman et al. (1980) observed that the iron absorption from beer brewed from sorghum or maize was more than 12 times higher than that from gruel prepared from these two grains. Beer brewed with sorghum adjunct was found to be a concentrated source not only of vitamins such as thiamin and nicotinic acid but also of several minerals including copper, manganese, iron, magnesium, potassium and phosphorus (van Heerden, 1989). With appreciable amounts of protein and starch and no detectable phytate, sorghum beer could make an important contribution to the daily intake of vitamins and minerals in African populations.

Pearl millet

Wide variations have been reported in the mineral and trace-element composition of pearl millet, and as with sorghum the composition and nature of the soil was considered the main environmental factor determining the mineral content of the grain (Hoseney, Andrews and Clark, 1987; Jambunathan and Subramanian, 1988). Milling of pearl millet to a flour with an extraction rate of 75 percent reduced the calcium and iron content by about 66 percent (de Wit and Schweigart, 1970). Dassenko (1980) observed significant losses of calcium, magnesium and sodium but not of iron and potassium on milling pearl millet to a flour with 67 percent extraction rate.

In rat feeding studies, absorption of iron by anaemic animals fed pearl millet as a source of iron (2 mg per kilogram body weight) was 35.7 percent as against 29.7 percent with sorghum,37.5 percent with maize, 40 percent with soybean and 33.3 percent with bambara nuts (Ifon,1981). In bioavailability studies with chicks, the magnesium availability was higher from pearl millet than from sorghum (Nwokolo, 1987). However, the millet was found to be poor in available zinc, iron and manganese compared with sorghum.

Malting enhanced severalfold the ionizable iron content of pearl millet and finger millet grains and also significantly increased their soluble zinc content, indicating an improvement in in vitro availability of these two elements (Sankara Rao and Deosthale, 1983).

Klopfenstein, Hoseney and Leipold (1985) observed that rats fed pearl millet supplemented with calcium carbonate in the diet continued to grow well after seven weeks of feeding, while those fed unsupplemented millet in the diet ceased to grow after four weeks. It was concluded that calcium was more limiting than lysine or other nutrients in pearl millet when fed to growing rats.

Finger millet

Except for very high calcium and manganese content, the mineral and trace element composition of finger millet is comparable to that of sorghum. Some high-protein (8 to 12.1 percent) and high-yielding varieties of finger millet were also rich in calcium (294 to 390 mg per 100 g) (Babu, Ramana and Radhakrishnan, 1987). Studies conducted in nine- to ten-year-old girls showed that replacement of rice in a rice-based diet with finger millet not only maintained positive nitrogen balance but also improved calcium retention (Joseph et al., 1959). Thus finger millet could be used to overcome the calcium deficiency of a rice diet. In vitro studies showed that bioavailability of iron was poor in commonly cultivated and highly pigmented varieties of finger millet grain because of their tannin content. Removal or reduction of tannin either by extraction with solvent or by grain germination enhanced the ionizable iron content. These studies also showed that iron availability in terms of ionizable iron content was higher in white grain, no-tannin finger millet varieties (Udayasekhara Rao and Deosthale, 1988).

Other millets

The total mineral matter as ash content was higher in common, little, foxtail, kodo and barnyard millets than in most commonly consumed cereal grains including sorghum. These minor millets have a highly fibrous hull which is usually removed before consumption. Dehulling was found to result in considerable nutrient losses in all five millets. The extent of these losses was variable and depended upon the mineral content of the species (Sankara Rao and Deosthale, unpublished) (Table 25).

Lorenz (1983) observed that the phytate content of common millet varieties ranged from 170 to 470 mg per 100 g whole grain, and dehulling resulted in a 27 to 53 percent reduction in phytate content. On dehulling, phytin phosphorus decreased 12 percent in common millet, 39 percent in little millet, 25 percent in kodo millet and 23 percent in barnyard millet (Sankara Rao and Deosthale, unpublished).

Vitamins

Sorghum

Sorghum and millets in general are rich sources of B-complex vitamins. Some yellow-endosperm varieties of sorghum contain -carotene which can be converted to vitamin A by the human body. Blessin, VanEtten and Wiebe (1958) isolated carotenoids of sorghum and identified lutein, zeaxanthin and carotene. Suryanarayana Rao, Rukmini and Mohan (1968) analysed several varieties of sorghum for their -carotene content. The variations were very large, with values ranging from 0 to 0.097 mg per 100 g of grain sample. In view of the photosensitive nature of carotenes and variability due to environmental factors, yellow-endosperm varieties of sorghum are likely to be of little importance as a dietary source of vitamin A precursor.

Detectable amounts of other fat-soluble vitamins, namely D, E and K, have also been found in sorghum grain. Sorghum as it is generally consumed is not a source of vitamin C. On germination, some amount of vitamin C is synthesized in the grain and on fermentation there is a further rise in the vitamin content (Taur, Pawar and Ingle, 1984). In feeding trials in guinea pigs on diets based on wheat, rice, maize or pearl millet, the vitamin C requirement of the animals for optimal growth was five times higher than that of animals fed casein in their diets (Klopfenstein, Varriano-Marston and Hoseney, 1981 a,b: Klopfenstein, Hoseney and Varriano-Marston, 1981). Guinea pigs on isonitrogenous, isocaloric, nutritionally adequate diets based on sorghum required 40 mg vitamin C per day as against 2 mg on the casein-based diet. Higher levels of dietary ascorbic acid apparently had a niacin-sparing effect on the sorghum-based diet. Interestingly, the animals fed 40 mg

ascorbic acid had low levels of cholesterol in their blood and liver. The significance of these observations in relation to the nutrition of predominantly sorghum-eating populations needs further investigation.

Among B-group vitamins, concentrations of thiamin, riboflavin and niacin in sorghum were comparable to those in maize (Table 17). Wide variations have been observed in the values reported, particularly for niacin (Hulse, Laing and Pearson, 1980). The highest niacin content, 9.16 mg per 100 g sorghum, was reported by Tanner, Pfeiffer and Curtis (1947). Ethiopian high-lysine sorghum varieties were also very high in niacin; values per 100 g were 10.5 mg in IS 11167 and 11.5 mg in IS 11758, as against 2.9 to 4.9 mg in normal sorghum (Pant, 1975).

Niacin in cereal grains exists in a bound form which is alkali soluble but considered biologically unavailable to humans (Goldsmith et al., 1956). Ghosh, Sarkar and Guha (1963) observed that 80 to 90 percent of the niacin in sorghum grains was in bound form and was available for the growth of the microorganism used for niacin assay only after alkali treatment. Adrian, Murias de Queroz and Frangne (1970) followed different extraction procedures and found that in sorghum 20 to 28 percent of the niacin was cold-water extractable and thus biologically available, compared to about 45 percent in maize. Belavady and Gopalan (1966) in their studies in dogs observed that niacin in sorghum grain was completely cold-water soluble and thus available, an observation that was quite different from those of Ghosh, Sarkar and Guha (1963) and Adrian, Murias de Queroz and Frangne (1970). Other studies (Carter and Carpenter,1981,1982) showed that niacin in sorghum grain was present as a high-molecular-weight complex and was biologically available to rats after alkali treatment of the grain but not after boiling in water. In boiled grains total niacin per 100 g was 7.07 mg in rice, 5.73 mg in wheat, 4.53 mg in sorghum and 1.88 mg in maize. The proportion of total niacin available to rats was 41 percent in rice, 31 percent in wheat, 33 percent in sorghum and 37 percent in maize. Thus niacin bioavailability in cereal grains was found to be limited (Wall and Carpenter' 1988).

Other B-complex vitamins present in sorghum in significant amounts are vitamin B6 (0.5 mg per 100 g), folacin

(0.02 mg), pantothenic acid (1.25 ma) and biotin (0.042 ma) (United States National Research Council/National Academy of Sciences, 1982).

Millets

Available data are very meagre regarding the vitamin content of pearl millet, finger millet and minor millets. In thiamin and riboflavin content these millets differed little from sorghum (Table 17). Niacin content, however, was lower in some of them. Ghosh, Sarkar and Guha (1963) found that, as in sorghum, 80 to 90 percent of the niacin in pearl millet grains was biologically unavailable. Adrian, Murias de Queroz and Frangne (1970), however, found that 31 to 40 percent of the niacin in pearl millet was cold-water extractable and thus available. In little millet total niacin was very high (10.88 mg percent), about two to three times higher than in other cereals, but only 13 percent of it was cold-water extractable.

Khalil and Sawaya (1984) found that bread prepared from pearl millet flour by a traditional method was significantly lower in thiamin, pantothenic acid and folic acid than the flour itself. The millet flour was relatively high in pantothenic acid. In nine pearl millet varieties thiamin content varied from 0.29 to 0.4 mg per 100 g, with a mean of 0.34 mg (Chauhan, Suneja and Bhat, 1986). Germination of pearl, finger and foxtail millet grains for 48 hours increased ascorbic acid to 8, 5 and 6 mg per 100 g, respectively. There was also a small but significant increase in thiamin content (Malleshi and Desikachar, 1986a). Opoku, Ohenhen and Ejiofor (1981) observed increases in thiamin, riboflavin, ascorbic acid, vitamin A and tocopherol in pearl millet germinated for 48 hours and kilned at 45C. Niacin, however, decreased by about 30 percent. Aliya and Geervani (1981) observed increases in thiamin (to 90 percent) and riboflavin (to 85 percent) on fermentation of pearl millet batter. However, steaming the fermented batter decreased the thiamin (to 64 percent) and riboflavin (to 28 percent) below the initial values of unfermented batter. Similar vitamin losses on fermentation of pearl millet flour were observed by Dassenko (1980). On cooking there was no change in the vitamin content of the fermented product.

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Dietary fibre

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The term dietary fibre is used to describe a variety of indigestible plant polysaccharides including cellulose, hemicelluloses, pectins, oligosaccharides, gums and various lignified compounds. According to the modified definition of Trowell (1976), dietary fibre is defined as the sum of the lignin and polysaccharides that are not hydrolysed by the endogenous enzymes of the human digestive tract. Kamath and Belavady (1980) found that the major insoluble fibre component of sorghum was cellulose, which varied from 1.19 to 5.23 percent in sorghum varieties. In any seed material there are two sources of dietary fibre, namely the hull or the pericarp and the cell wall structural components. The plant cell walls contain many non-carbohydrate components in addition to lignin, such as protein, lipids and inorganic material, and they modify the properties of the polysaccharides. Several approaches have been suggested for the measurement of total dietary fibre in foods. Each of the methods has certain limitations which may contribute to the observed variations in dietary fibre content reported for various foodstuffs.

Sorghum

Bach Knudsen and Munck (1985) found that a commonly consumed lowtannin Sudanese sorghum variety, Dabar, had total dietary fibre content of 7.6 percent while a high-tannin Sudanese variety, Feterita, contained 9.2 percent. A major proportion of the total dietary fibre in both the varieties was water insoluble (6.5

percent in Dabar and 7.9 percent in Feterita). The acid detergent fibre in the two varieties was also different (2.9 percent in Dabar and 3.6 percent in Feterita). The contribution of polyphenols to the lignin fraction of the dietary fibre was responsible for the higher values of dietary fibre in the high-tannin variety. Cooking of the sorghum as whole-grain porridge decreased the availability of energy, mostly because of the formation of enzyme-resistant starch, therefore apparently increasing the dietary fibre content of both varieties. Fermentation at pH 3.9 helped overcome the formation of resistant starch and also prevented the formation of lignin during cooking. Compared to wheat, rye, barley or maize, the total dietary fibre in the two sorghum varieties was low. The amount of protein bound to total dietary fibre as well as to acid detergent fibre in the sorghum varieties was much higher than in wheat and other foodgrains, and this binding increased on cooking, especially in the high-tannin sorghum. Fermentation or acidification to pH 3.9 inhibited the protein binding. These observations indicate that the traditional Sudanese fermentation method has important nutritional advantages.

Dietary fibre has certain adverse effects on the availability of some nutrients. The concentration of zinc and iron in the tibia of rats on sorghum diets rich in fibre and phytate was significantly lower than in rats on a non-sorghum diet with low fibre content (All and Harland, 1991).

Decortication of the grain is one of the methods to remove fibre. Cornu and Delpeuch (1981) found that the apparent nitrogen digestibility in adult subjects on a diet of 80 percent sorghum decreased from 65.4 to 60.5 percent when the dehusked sorghum in the diet was replaced by whole-grain sorghum. The total faecal matter of subjects on the whole-grain sorghum diet was higher. The nitrogen and formic-acid insoluble material in the faeces also increased.

Karim and Rooney (1972) reported that the pentosan content of sorghum varied from 2.51 to 5.57 percent. Pentosans as they occur in the cell walls of cereal grains are a heterogeneous mixture of polysaccharides, many of which contain proteins.

Earp et al. (1983) identified the mixed linked -glucans in sorghum pericarp, aleurone and endosperm. These -glucans are water soluble and form viscous, sticky solutions. This property is important in the malting of sorghum and brewing of beer. Klopfenstein and Hoseney (1987) observed that rats fed bread prepared from white flour fortified with -glucan (7 percent by weight) had serum cholesterol significantly lower than those fed bread from unfortified flour. The cholesterol-lowering property was also shown by the glucans isolated from oat, barley, wheat and sorghum.

Millets

Kamath and Belavady (1980), using the method of Southgate, Hudson and Englyst (1978), found that the total dietary fibre in pearl millet (20.4 percent) and finger millet (18.6 percent) was higher than that in sorghum (14.2 percent), wheat (17.2 percent) and rice (8.3 percent). Singh et al. (1987), also using the Southgate method, found that the total dietary fibre content of pearl millet was 17 percent. There are not enough data available on the dietary fibre components of the millets. Bailey, Sumrell and Burton (1979) have isolated pentosan containing a mixture of heterogeneous polysaccharides from the cell wall of pearl millet grains. The pentosan of pearl millet extracted with different solvents including 80 percent ethanol, water and alkali was found to contain seven sugars, the most predominant being arabinose, xylose and galactose, followed by rhamnose and fucose. Emiola and de la Rosa (1981) also studied the water- and alkali-extractable pentosan of pearl millet, but their results were at variance with those of Bailey, Sumrell and Burton (1979), showing an identical pattern for the water- and alkali-soluble pentosan but with ribose rather than fucose as one of the sugars. Emiola and de la Rosa (198 1) found that in pearl millet water-soluble non-starch polysaccharides accounted for 0.66 percent of grain weight and water-insoluble non-starch polysaccharides for 3.88 percent. On further purification these values were reduced to 0.42 percent and 0.97 percent, respectively. Wankhede, Shehnaj and Raghavendra Rao (1979a) reported that in finger and foxtail millet the pentosan content was 6.6 and 5.5 percent, respectively. Muralikrishna, Paramahans and Tharanathan (I 982) found that the hemicellulose A in little, kodo and barnyard millets was a non-cellulosic -glucan and the hemicellulose B was

composed of hexose, pentose and uranic acid.

Chapter 5 - Nutritional quality of foods prepared from sorghum and millets

It stands to reason that when a grain is processed, some nutrients must be removed and also that the removal of any but an exactly proportionate part of any constituent of a seed will affect the nutritional quality of what is left. Consequently, the nutritional effect of milling probably depends as much on the amount of material removed as on the method used to remove it. It is therefore difficult to compare different reports involving different preparative techniques. Reichert and Youngs (1977) reported that traditionally decorticated sorghum and millets contained more oil and ash than abrasively decorticated grains but the protein content was similar. Pushpamma (1990) reported that decortication reduced total protein and lysine by about 9 and 21 percent respectively, but that it also Improved the utilization of the remaining protein. The loss of minerals was minimal. Decortication improved the biological availability of nutrients and consumer acceptability.

Whether the removal of nutrients (and antinutritional factors) is on balance beneficial is a question that must always be analysed carefully. Organoleptic factors must also be considered. What is actually done is not always nutritionally for the best, and what is best in one type of diet is not always what is best for another.

Germination leads to considerable changes in the nutritive quality of a grain. There will obviously be some changes because of the loss of dry matter, but far more important changes. such as increased enzyme activity

and the conversion of starch to sugars, result from the growing process. The toxicity of cyanide in germinated sorghum has already been mentioned. The danger of sickness or death from cyanide ingestion must always be borne in mind.

TABLE 26: Effect of time and temperature on nutritional quality of germinated sorghum seeds[a]

Time after germination(days)	Germination (%)	Coleoptile length (cm)	RNV (%)	PER[b]	Available amino acid (mg/g N)		
					Lysine	Tryptophan	Methionine
0[c]	-	-	54.6	1.5	13.5	6.8	8.5
25C							
2	10-15	0.2-0.4	48.6	1.4	24.0	4.8	8.4
3	15-20	0.5-1.0	54.0	1.5	33.0	7.6	11.5
4	25-35	2.5-5.5	67.8	1.8	45.0	15.2	18.6
5	25	2.5-8.5	68.9	1.8	28.0	15.0	15.3
30C							
2	10	0-1.0	52.4	1.4	15.0	7.2	7.2
3	10-15	2.4-4.5	62.1	1.7	21.0	8.8	7.5
4	20-30	2.5-7.0	58.0	1.6	33.0	12.0	13.8

5	30	3.5-7.5	62.4	1.7	33.0	15.2	14.3
6	30	5.0-10.0	78.3	2.0	69.0	18.6	19.5
35C							
2	15-20	2.0-3.0	54 7	1.5	30.0	9.4	14.0
3	10	3.5-5.5	62.4	1.7	26.3	8.0	10.2
4	10	4.0-7.0	63.0	1.7	24.0	12.0	10.0

a N = 1. Seeds were germinated in quart glass jars, dried at 50C and ground in a Wiley mill.
b PER = 0.286 + 0.022(RNV). Values rounded to nearest 0.1 PER.
c Non - germinated control.
***Source*: Wang and Fields, 1978.**

Wang and Fields (1978) found that germination of sorghum increased the relative nutritive value (RNV) from 54.6 to 63 percent and the protein efficiency ratio (PER) from 1.5 to 1.7. There were substantial increases in lysine, methionine and tryptophan (Table 26). Malleshi and Desikachar (1986b) reported that germination of finger, pearl and foxtail millets resulted in a slight decrease in total protein and moisture. The main advantage was a reduction in the level of phyate and an increase in the levels of ascorbic acid, lysine and tryptophan. Malleshi, Desikachar and Venkat Rao (1986) also found that germination substantially reduced the amount of phytate, thereby improving the absorption of iron. Sprouting, roasting and sieving reduced the protein content of finger millet from 7.7 to 3.9 percent (Hemanalini et al., 1980).

TABLE 27: Means of nutrient contents in sorghum meal[a]

Type of meal	Methionine (mg/g N)	Lysine (mg/g N)	Thiamin (g/g)	Riboflavin (g/g)	Niacin (g/g)	RNV (%)

Control	9.1a*	11.25a*	3.66ab**	1.34a**	68.39a**	45.57b**
Fermented, 25 C	33.2b	25.68b	3.18a	1.27a	70.88a	55.10a
Fermented, 35C	34.5b	26.79b	3.87b	1.38a	70.91a	56.17a

a n = 5. Means with different letters are significantly different. 'Significant at $P < 0.01$: "Significant at $P < 0.05$
Source **: Au and Fields, 1981.**

Changes that take place during fermentation include increases in amino nitrogen the breakdown of proteins and the destruction of any inhibitors that may be present. Significant increases in various amino acids (particularly methionine) and vitamins have been observed (Kazanas and Fields, 1981; Au and Fields, 1981) as a result of fermentation of sorghum (Table 27); an increase in the nutritive value was also reported. Axtell et al. (1981) found that fermented products of sorghum were more digestible than unfermented products. Fermentation or acidification inhibited the protein-binding effect of polyphenols (Bach Knudsen and Munck, 1985). Obizoba and Atii (1991) reported that fermentation reduced the level of cyanide in sprouted sorghum. It also reduced enzyme-resistant starch and decreased the concentration of the flatulence-causing sugars raffinose and stachyose (Odunfa and Adeyele, 1987). The starch and protein digestibility of rabadi, a product made from pearl millet, increased with longer fermentation (Dhankher and Chauhan, 1987).

MacLean et al. (1983) showed that decortication and extrusion can markedly improve the apparent digestibility of sorghum protein ted to young children. The addition of calcium hydroxide before extrusion also improved digestibility (Fapojuwo, Maga and Jansen, 1987).

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Culinary preparations

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Foods from sorghum and millets can be grouped in two categories, traditional products and non-traditional industrial products. Unprocessed or processed grain can be cooked whole or decorticated and if necessary ground to flour by any of the traditional or industrial methods described in Chapter 3. A detailed classification of traditional foods from sorghum and millets has been developed (Vogel and Graham, 1979; Rooney, Kirleis and Murty, 1986). They can be classified broadly into breads, porridges, steamed products, boiled products, beverages and snack foods (Rooney, Kirleis and Murty, 1986; Rooney and McDonough, 1987). The various uses of sorghum and millets in india are shown in Table 28 (Pushpammannd Chittemma Rao, 1981). Foods from pearl millet in different parts of the world are given in Table 29; the products are similar to those from sorghum. The following are a few of the many different ways sorghum and millet can be prepared for eating. (Spices and condiments may be added to suit individual tastes.)

Whole grains

Immature sorghum grains are sometimes roasted whole. Sorghum and to a lesser extent pearl millet and finger millet are popped (dry heated to make the grain explode) in villages in India (Subramanian and Jambunathan, 1980). The grains are usually popped on special hot plates or on sand baths heated over a fire. Popped sorghum is said to be more tender than popped corn, contains less hull, does not clog spaces between the teeth and makes less noise when eaten. In general, the desired characteristics of sorghum for popping are small grain size, a medium to thick pericarp, hard endosperm and a very low germ-to-endosperm ratio (Murty et al., 1982). Significant genotypic differences exist in sorghum for popping volume, expansion ratio and popping percentage (Thorat et al., 1988). In finger millet, wide varietal variations exist for popping quality. White-seeded types are preferred; brown-seeded varieties were found to be not particularly suitable

for popping (Malleshi and Desikachar, 1981; Shukla et al., 1986).

TABLE 28: Forms of utilization of sorghum and millets in India

Food	**Product type**	**Form of grain used**	**Consumers**	
			No.	**Percentage**[a]
Sorghum				
Roti	Unleavened flat bread	Flour	1 132	67
Sangati	Stiff porridge	Mixture of coarse particles and flour	811	48
Annam	Rice-like	Dehulled grain	586	35
Kudumulu	Steamed	Flour	295	18
Dosa	Pancake	Flour	213	13
Ambali	Thin porridge	Flour	167	10
Boorelu	Deep fried	Flour	164	10
Pelapindi	Popped whole grain and flour	Mixture of coarse particles and flour	94	6
Karappoosa	Deep fried	Flour	42	3
Thapala chakkalu	Shallow fried	Flour	24	1
Pearl millet				
Roti	Unleavened bread	Flour	706	88

Sangati	Stiff porridge	Mixture of coarse particles and flour	305	38
Annam	Rice-like	Dehulled grain	268	33
Kudumulu	Steamed	Flour	229	29
Boorelu	Deep fried	Flour	145	18
Dosa	Pancake	Flour	26	3
Thapala chakkalu	Shallow fried	Flour	24	3
Ambali	Thin porridge	Flour	22	3
Finger millet				
Sangati	Stiff porridge	Rice brokers and flour	308	63
Roti	Unleavened bread	Flour	151	31
Ambali	Thin porridge	Flour	149	31
Proso millet				
Annam	Rice-like	Dehulled grain	236	94
Muruku	Deep fried	Flour	96	38
Karappoosa	Deep fried	Flour	37	15
Ariselu	Deep fried	Flour	17	7
Foxtail millet				
Annam	Rice-like	Dehulled grain	517	96

Ariselu	Deep fried	Flour	21	4
Sangati	Stiff porridge	Flour	12	2
Roti	Unleavened bread	Flour	7	1
Kodo millet				
Annam	Rice-like	Dehulled grain	76	96

a Of surveyed consumers of each grain, percentage who consume the specified preparation. For example, 67 percent of sorghum consumers reported that they consume sorghum prepared as roti.
Source: Pushpumma and Chittemma Rao, 1981.

Grits

Decorticated millet grains are sometimes boiled in water and served like rice. Grits made from sorghum and pearl millet are also cooked like rice in many countries. Sorghum boiled like rice is called kichuri in Bangladesh, lehta wagen in Botswana, kaoliang mifan in China, nifro in Ethiopia and oka baba in Nigeria (Subramanian et al., 1982). Dehulled sorghum and pearl millet grains are also cooked like rice in India. A sorghum product similar to rice called sori has been developed in Mali. In China, grain with 80 percent extraction rate is used for boiled sorghum. Sometimes pearled sorghum, rice and beans are mixed and cooked. In some countries sorghum varieties with hard, small grains are specially grown for processing into food which can be used as a substitute for rice.

TABLE 29: Traditional foods made with pearl millet

Type of food	Common names	Countries
Unfermented bread	*Roti, rotii*	India

Fermented bread	*Kisra, dose, dosai, galletes, injera*	Africa, India
Thick porridge	*Ugali, tuwo, saino, dalaki, aceda, atap, bogobe, ting tutu kalo, karo, kwon, nshimba, nuchu, to, tuo, zaafi, asidah, mato, sadza, sangati*	Africa, India
Thin porridge	*Uji, ambali, edi, eko, kamo, nasha, bwa kal, obushera* *Ogi, oko, akamu, kafa, koko, akasa*	Africa,India Nigeria, Ghana
Steamed cooked products	*Couscous, degue*	West Africa
Boiled, rice like foods	*Annam, ache*	Africa, India
Snack foods		Africa, Asia
Sweet/sour opaque beers	*Burukutu, dolo, pito, talla*	West Africa
Sour opaque beers	*Marisa, busaa, merissa, urwaga, mwenge, munkoyo, utshwala, utywala, ikigage*	Sudan, southern Africa
Non-alcoholic beverages	*Mehewu, amaheu, marewa, magou, feting, abrey, huswa*	Africa

***Source*: Rooney and McDonough, 1987.**

Flaking is a process that is widely used for making foods from cereals, and both sorghum and millet can be flaked. Decorticated grits are moistened with water and steamed or cooked to gelatinize some of the starch, dried to a moisture content of about 17 percent and then either pounded in a special mortar (Desikachar,

1975)orrolledbetweenflakingrolls(RizleyandSuter, 1977) to produce a flat product. The flakes are further dried and can be stored for several months. Sorghum has been flaked in the United States to improve its digestibility for beef cattle. In India poha and avilakki are flaked foods based on sorghum and millet.

In many West African countries, sorghum and pearl millet grits are steamed to produce a coarse and uniformly gelatinized product called couscous. Sorghum with a pigmented testa produces reddish-brown couscous with an astringent taste. Couscous can be consumed fresh or can be dried; in its dried form it can be stored for more than six months (Galiba et al., 1987). The dried product can be reconstituted in water, milk or sauce. It is used as a convenience food in the Sahel.

Porridge

Porridges are the major foods in several African countries. They are either thick or thin in consistency. These porridges carry different local names. Thick porridges are called uguli (Kenya, United Republic of Tanzania, Uganda), to (Burkina Faso, the Niger), tuwo (Nigeria), aceda (the Sudan), bogobe, jwa ting (Botswana) and sadza (Zimbabwe). The nutritional value of whole and decorticated sorghum grains and dishes made from them is shown in Table 30. The biological value of sorghum ugali was superior to that of the raw grain, but the true digestibility of protein decreased when sorghum was processed into ugali (Table 31). In Mali, parts of Senegal and Guinea, to is alkali treated and has a pH of 8.2. In Burkina Faso, it is acid treated to a pH of about 4.6. In other regions of Africa, the to is neutral. These treatments have implications in the taste preferences and nutrition of the people.

Thin porridges are called uji (Kenya, United Republic of Tanzania), ogi or koko (Nigeria, Ghana), edi (Uganda), rouye (the Niger, Senegal), nasha (the Sudan), rabri (India), bota or mahewu (Zimbabwe) and motogo we tiny (Botswana). Sorghum flour, sorghum malt, pigeon pea and groundnut are mixed in different proportions to improve the nutritional value of traditional porridges (Nout et al., 1988).

In Uganda, a sour porridge called bushera is prepared by boiling ungerminated millet flour to produce a thick paste. Flour made from freshly germinated millet is then mixed into it. This sweetens the porridge and also lowers its viscosity. Bushera can be kept for three to four days before it starts to ferment. Ultimately it will become a strongly alcoholic drink.

TABLE 30: Chemical composition of whole and decorticated sorghum grains and dishes[a]

Variety and preparation	**Protein (N6.25)**	**Ash (% w/w)**	**Fat (%w/w)**	**Crude fibre (% w/w)**	**Such+sugar (% w/w)**
Tetron, whole grain	10.9	1.78	5.1	2.1	72.5
Dabar, whole grain	11.6	1.68	4.0	2.0	73.4
Feterita, whole grain	13.4	2.07	4.1	2.1	71.0
Dabar, decorticaded (79% extraction)	11,3	1.39	3.3	1.0	79.4
Feterita, decorticated (80% extraction)	14.9	0.87	2.7	0.8	74.3
Dabar, *ugali*, whole grain	11.3	1.56	4.1	2.2	69.9
Dabar, *ugali* (acid),whole grain	12.7	1.62	3.8	2.2	69.7
Feterita, *ugali*, whole grain	14.1	1.39	4.0	2.2	66.5
Tetron, *kisra*, whole	11.3	1.80	5.3	2.1	71.2

grain					
Feterita, *kisra*, whole grain	14.1	1.59	5.1	2.4	68.8
Dabar, *kisra*, decorticated (79% extraction)	12.6	1.23	4.2	1.1	74.8

a All data are expressed on a dry - matter basis.
***Source*: Eggum et al., 1983.**

Fermented porridge is made in several regions in Africa. Changes occur during fermentation that are the result of the activity of microorganisms bacteria, yeasts and moulds. Fermentation processes have evolved largely as a result of practical needs. The palatability and the texture of foods can be changed and their shelf-life can often be improved by fermenting them. In eastern Africa, a suspension of maize, millet, sorghum or cassava flour in water is fermented before or after cooking to make a thin porridge. Oniang'O and Alnwick (1988) described fermented porridge made in Africa from sorghum, finger millet and pearl millet. Fermented porridges are variously thought to promote lactation and to be unsuitable for young children. The shelf-life of fermented porridge is quite short, usually less than 30 hours. In the Sudan, a thin fermented porridge called nasha is prepared with sorghum. Tomkins, Alnwick and Haggerty (1988) identified some of the bacteria and moulds they found in nasha and also described a fermented porridge called ting from Botswana. Ogi, a popular fermented porridge in Nigeria, is prepared using sorghum, millet and maize in various proportions (Steinkraus, 1983; Tomkins, Alnwick and Haggerty, 1988). The predominant volatile and non-volatile acids in ogi are lactic and acetic acids, respectively. Traces of formic acid have also been detected. These give ogi its characteristic aroma and its sour taste. Light-coloured ogi with mild sourness is preferred. However, in Kenya, brown uji is preferred. Maize ogi contains more energy (calories) than sorghum ogi (Table 32). However, the

protein, fat and minerals on a dry-weight basis are higher in sorghum ogi than in maize ogi (Brown et al., 1988).

TABLE 31: Protein quality of whole and deconicated sorghum grains and dishes

Variety and preparation	**Amino acid (g/16 g N)**					**True protein digestibility (%)**	**Biological value (%)**	**Net protein utilization (%)**	**Utilizable protein (%)**
	Lysine	**Threonine**	**Methionine + cystine**	**Proline**	**Glutamic acid**				
Tetron, whore grain	2.3	3.3	3.8	8.0	21.2	94.5	57.0	53.8	5.9
Dabar, whole grain	2.1	3.1	3.6	8.2	22.1	95.4	54.9	52.4	6.1
Feterita, whole grain	1.9	3.1	3.5	8.2	22.7	95.8	48.6	46.6	6.2
Dabar, decorticated (79% extraction)	1.9	3 1	3.5	8.3	22.4	100.0	53.5	53.5	6.1
Feterita, decorticated (80%	1.6	3.0	3.5	8.6	23.5	99.6	43.9	43.7	6.5

extraction)									
Dabar, ugali, whole grain	2.1	3.0	3.5	7.9	21.6	87.5	60.8	53.2	6.0
Dabar, ugali (acid)whole grain	2.1	3.0	3.4	7.8	21.3	94.4	54.5	51.4	6.5
Feterita, ugali, whole grain	1.9	3.2	3.5	7.9	22.4	82.4	58.3	48.0	6.8
Tetron, kisra, whole grain	2.3	3.2	3.6	8.1	22.2	92.8	52.7	48.9	5.5
Feterita, kisra, whole grain	2.3	3.1	3.5	8.5	24.0	93.2	50.8	47.3	3.8
Dabar, kisra, decorticated (79% extraction)	2.3	3.0	3.7	8.9	25.3	96.9	55.3	53.4	6.7
LSD_{05}						1.2	1.2	1.3	0.2

Source: Eggum et al., 1983.

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