MILLET

Post-harvest Operations

INPhO - Post-harvest Compendium

Food and Agriculture Organization
of the United Nations

MILLET: Post-harvest Operations

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Preface

Millets represent a collective term referring to a number of small-seeded annual grasses that are cultivated as grain crops, primarily on marginal lands in dry areas of temperate, subtropical and tropical regions. They are regarded as a subsistence product and generally looked upon as a famine crop for the poor.

The statistical documentation for millet is generally poorer and more fragmented than that for rice and wheat despite its nutritional superiority. It may not come as a surprise to note that some scientists may not differentiate millets from sorghum. Some may be even astonished to learn how vast and variable are the millet species and varieties.

Postharvest operations, such as threshing, drying, cleaning, packaging, storage, processing and transportation are as significant. This comprises the second half of activities following pre-harvest operations. Therefore, these are crucial processes in the whole food chain for millet production.

As stated before, documentation of the post-harvest operations for millet is not as rich in content as other cereals. The purpose of this chapter is to add to the scanty information on millets with the eventual aim of providing facts on this often neglected yet consequential cereal crop.

1. Introduction

Millet is a cereal crop plant belonging to the grass family, Graminae (FAO, 1972). The term "millet" is used loosely to refer to several types of small seeded annual grasses (FAO and ICRISAT, 1996), belonging to species under the five genera in the tribe *Paniceae*, namely *Panicum*, *Setaria*, *Echinochloa*, *Pennisetum* and *Paspalum*, and one genus, *Eleusine*, in the tribe *Chlorideae* (FAO, 1972). Most of the genera are widely distributed throughout the tropics and subtropics of the world (de Wet, 1987). The genus *Pennisetum* for example, includes about 140 species, some of which are domesticated and some are growing in the wilderness.

Millets are small grained cereals, the smallest of which include kodo, foxtail, proso (common millet), little and barnyard millets (Rao, 1989). They are the staple food of the millions inhabiting the arid and semi-arid tropics of the world, and are distributed in most of the Asian and African countries and parts of Europe.

According to Dendy (1995) the most important millets are **pearl millet** (*Pennisetum glaucum*), **finger millet** (*Eleusine coracona*), **proso millet** (*Panicum miliaceum*) and **foxtail millet** (*Stalia italica*). But according to FAO (1972) and Hulse *et al*., (1980), the most important cultivated millet species are: **pearl Millet** *(Pennisetum typhoides)*, also known as bulrush millet; **proso millet** (*Panicum miliaceum)*, also known as common millet; **foxtail millet** (*Setaria italica*); **Japanese barnyard millet** *(Echinochloa crusgalli* var. *Frumentacea or E. colona* (Sawa)); **finger millet** (*Eleusine coracona*) also known as birds food millet or African millet; and **kodo millet** of India (*Paspalum scorbiculatum*).

Other millets include **little millet** (*Panicum sumatrense*), **tef millet** (Eargrostis *tef*) and **Fonio millet** (*Digitaria exilis* and *D. iburua*) (Dogget, 1989). The various types of millets, their food values and comparison are shown in Tables 1 and 2.

Table 1. Various types of millets and their food values (%) compared to rice

Name of millet	Moisture	Protein	Carbohy-drate	Fat	Fibre	Mineral	Calcium	Phosph orus	Calorific value (100g)
1. Finger millet (Eleucine coracona)	13.0	8.0	72.0	1.3	3.0	2.70	0.3	0.3	332
2. Common millet *(Panicum milliaceum)*	11.1	13.71	72.26	1.76	0.10	1.07	0.01	0.2	341
3. Foxtail millet (Setaria italica)	11.9	9.7	72.4	3.5	1.0	1.5	0.04	0.3	353
4. Little millet *(Panicum miliare)*	11.1	13.4	72.3	1.8	0.10	1.1	0.02	0.3	360
5. Kodo millet (Paspalum scrobiculatu m)	11.6	10.6	59.2	4.2	10.2	4.4	0.04	0.3	346
6. Tef (Eragrostis tef)	11.2	9.1	74.3	2.2	-	-	-	-	-
7. Japanese Barnyard Millet (Echnochloa frumentacea)	11.9	6.2	65.5	2.2	9.8	4.4	-	-	-
8. Hungry rice (Digitalis exilis)	6.0	8.7	81.0	1.1	1.1	2.1	-	-	-
9. Polished Rice (Oryza sativa)	13.2	7.5	76.7	1.0	0.3	1.6	0.01	0.17	348

Source: Ponnuthurai, 1989.

Table 2. Structural comparison of some millets

Attribute/ millet	**Pearl**	**Finger**	**Foxtail**	**Proso**	**Japanese**	**Fonio**	**Kodo**	**Tef**
Seed type	Caryopsis	Utrical	Caryopsis	Utrical	&	Caryopsis	& ..	Caryopsis
Kernel wt 1 000 kernels	7.8	2.3	2.0	6.1	& ..	0.5	& ..	0.8
Testa (layers) Pigmented Thickness	1 Sometimes 0.4	5 Yes 10.8X24.2	Remnant & .. & .	1 No 0.2-0.4	& .. & .. & .	1 No 0.5-1.5	& .. & . & ..	1 No 1.5-2.0
Aleurone (layers)	1	1	1	1	1	1	None	1
Starch granules	6.4-12.0	8.0-21.0	5-25	1.3-17	2.5-20	6.5-7.8	7-15	5.6-22.4
Starch type granule	Simple	Compound simple	Simple	Simple	& .	Simple	Simple	Compound simple
Waxy type	No	No	Yes	Yes	No	No	No	No
Protein body size (mm)	0.6-1.2	2.0	1-2	0.5-2.5	& .	1.2-1.4	& .	1.2-1.4
Germ size (LXW)	1420 X 620	980X270	& ...	1100X 977	& .	517X977	& .	160X725
Endorsperm-germ ratio	2.5:1	11:1	& .	12:1	& .	6:1	& .	3:1

Source: Compiled by Saldivar and Rooney (1995) from various sources.

Table 3. Chemical composition of pearl millet and its anatomical parts.

Component	Whole grain (%)	Endosperm (%)	Germ (%)	Pericarp (%)
Whole kernel	100	75.1	16.5	8.4
Protein	13.3	10.9	24.5	17.1
Fat	6.3	0.5	32.2	5.0
Ash	1.7	0.3	7.2	3.2
Essential				
Phe	5.5	5.5	4.4	4.3
Ile	3.1	3.1	2.1	2.4
Leu	9.6	11.2	6.5	7.1
Lys	3.0	1.4	5.2	4.4
Met	2.3	2.6	1.8	1.6
Thr	3.6	3.3	3.9	4.7
Val	3.9	3.9	3.6	3.5
Non-essential				
Asp	8.8	8.1	11.4	11.4
Glu	19.6	22.8	15.1	13.5
Ala	8.2	9.4	8.0	8.7
Arg	4.8	2.0	9.0	5.0
Gly	3.3	1.9	6.1	7.3
Pro	6.4	8.0	5.0	6.8
Ser	5.2	5.2	5.7	5.6
Tyr	3.8	3.6	4.0	4.7

Source: Saldivar and Rooney, 1995.

Pearl millet

The development and structure of pearl millet is similar to that of sorghum, with some exceptions. Pearl millet is an erect, short-day (Dave, 1987) annual grass that tillers more profusely than sorghum. Tillering is primarily from basal nodes, and the number of tillers varies considerably in different varieties. Branches may also arise from other nodes, each branch terminating in to an inflorescence. The inflorescence of pearl millet is a panicle, cylindrical in nature, broadest at the middle and slightly tapering towards both apex and base. The length as well as thickness of the panicle varies between 0.20 to 0.45 m long.

The leaves of pearl millet are generally smaller than those of sorghum, 90 to 100 cm in length, and 5 to 8 cm in width. The stem, on the average is thinner than that of sorghum (1 to 3 cm in diameter). The panicles are long and cylindrical, ranging from 15 cm to 1 m in length and 2 to 5 cm in width. At maturity, the stem tends to be woodier than that of sorghum (House *et al*., 1995).

Plant heights range from 1.2 to 3.5 m, depending on dwarfing genes (House *et al*., 1995) and on the environmental factors (such as climate, soil type, etc). Roots are fibrous with the main root being thin, small and quickly replaced in function by adventitious roots. The stem is round to oval, with flat, cordate leaf blades, of 0.75 m or more in length and 0.05 to 0.07 m wide (FAO, 1972).

Pearl millet is adapted to hot climates, and is even more resistant to drought than sorghum (Dave, 1987). No other cereal crop grows so well in hot dry regions like pearl millet. It yields reasonably well on poor sandy soils on which most other crops fail.

Pearl millet takes about 80 to 100 days to mature, but some varieties may mature earlier. It is primarily cross-pollinating, as stigmas emerge one to three days before the anthers (protogynous) and therefore have opportunity to be cross-pollinated. The seeds are one third to one half the size of that of sorghum, and tend to be more elongated and tear shaped. Spikelets can be bristled (awned) but in most varieties, there are no awns (House *et al*., 1995).

Pearl millet is the most widely grown of all the millet species (FAO, 1972). It is grown on an estimated 27 million hectares, followed by finger millet (Singh *et al*., 1987, quoted by Saldivar and Rooney1995). World production of millets has been stable during the last "decade", because it is mainly cultivated as a subsistence crop. In 1991, 37.1 million ha were sown, with an average yield of 781 kg/ha, totalling 28.9 million metric tonnes (FAO, 1992, quoted by Saldivar and Rooney, 1995). Thirty percent of the production was harvested in Africa, 56 percent in Asia and 13 percent in the former USSR. Major producers were India (31.1 percent), China (15.8) percent and the former USSR (12.4 percent) (Saldivar and Rooney, 1995)

Pearl millet is the major millet grown in Africa (Spencer and Sivakumar, 1987) and it is the fourth most important cereal food crop grown in India (Harinarayana, 1987).

Table 4. Synonyms of pearl millet as known in different countries of the world.

COUNTRY	SYNONYMS GIVEN
USA	Pearl millet, cattail millet, Pencillaria, Mands forage plant
INDIA	Bajra, bajri, sajje, cumbu
AFRICA	Sanio, gero, babala, nyoloti, burlush millet, dukhn, souna.
EUROPE	Candle millet, dark millet.

Source: FAO, 1972.

It is believed that pearl millet was first domesticated in India and then moved to Africa, but most of the earlier scientists believed that Africa is the centre of origin of pearl millet and that it was introduced to India from Africa (Vavilov, 1951 quoted by FAO, 1972).
In India, pearl millet is the fourth most important food crop (Harinarayana, 1986)
Pearl millet is the most important cereal crop in arid and semi-arid regions of the world, and is grown most widely in India (Dave, 1987). As a semi-arid and arid crop, pearl millet is traditionally a component of the dryland system, usually grown in soils with depleted fertility which receive 150 - 750 mm of rainfall per year (Harinarayana, 1987).
Nutritionally superior to rice and wheat (Harinarayana, 1987, Seetharam *et al*., 1989) pearl millet is commonly used to make unleavened bread, thin or thick porridge or may be cooked like rice. The chemical composition of pearl millet and its anatomical parts are shown in Table 3.
The major factors that restrict the production potential of pearl millet are low hybrid coverage, slow varietal spread, poor plant establishment, no fertilizer, weeds (such as *Striga spp*) and diseases (such as downy mildew) and pests (such as grain-eating birds) (Harinarayana, 1987).
Pearl millet has been given different names in various countries of the world (Table 4).
Constituents of pearl millet grain
The structure of a mature caryopsis of pearl millet is shown in Figure 1. It is very small, weighing between 3-15 g/1 000 kernels (as compared to 5-80 g/1 000 kernels in sorghum).

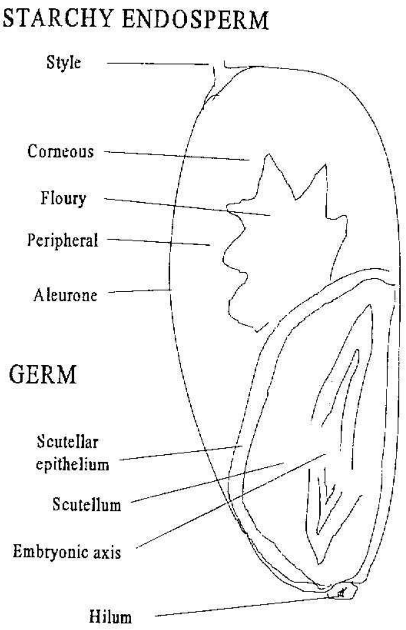

Figure 1: Schema of Pearl Millet Seed Structure.
(Source: Rooney and McDonough, 1987)

The typical seed (kernel) of pearl millet is a caryopsis similar in structural components to sorghum. Kernel shape, size and appearance (colour) vary significantly among pearl millet varieties, and within a sample, kernels vary significantly in size and shape (Rooney and McDonough, 1987). They are 3-4 mm long and 2.25 mm wide, usually yellowish-grey or steel-grey in colour, but varieties are known which have pearly-white or yellow grains (FAO, 1972) The appearance of pearl millet inflorescence is shown in Figure 2.

Figure 2: Pearl millet inflorescence.***Finger millet***

Among the millets of the world, finger millet (*Eleusine coracona*) ranks fourth, after pearl millet (*Pennisetum americanum* L.), foxtail millet (*Setaria italica*), and proso millet (*Panicum miliaceum*) (Gupta, *et al*., 1989). Finger millet is the most widely grown small millet in the world (see definition of small millets under Section 2.8.3).

Finger millet, also known as *ragi* in India (Hulse *et al*., 1980) is a highly tillering annual grass, whose average height is a little over 1.0 m, but can reach as high as 1.6 m. Tillers come from the base of the plant and axillary buds along the stem (House *et al*., 1995). Each tiller produces a panicle. Leaves are generally 30 to 40 cm long, but can reach 70 cm and are narrow (1.5 to 3 cm). Panicle branches commonly come from the same place giving a finger like appearance (Figure 3). The number of branches ranges from 4 to 19; they can be straight (3 to 10 cm long) or they can be curved like a hand with fingers partially closed (hence the name finger millet). Seeds are formed in florets generally arranged in two rows along the panicle branch. The seeds are generally dark brown, red brown or purple, although light brown and cream coloured seeds are found. Seeds are hard and very small, up to 2 mm in diameter.

There are two groups of cultivars of finger millet, namely (a) the African highland types with grains enclosed within the florets and (b) Afro-Asiatic types with mature grains exposed out of the florets (Hulse *et al*., 1980). The cultivars vary in many characters, including height, ranging from dwarf-types (40 cm) to tall types of about 1 m. The colour of the vegetative organs varies from green to purple. The inflorescence may have straight and open spikes, incurved or closed spikes and branched spikes, resembling a cock. s comb. The length of spikes may range from 3 to 13 cm, the colour of grains may vary from white through orange red, deep brown, purple to almost black.

Finger millet is generally grown in higher rainfall areas (600-1200 mm) and is one of the better crops for acid soils. It matures within 100 to 130 days. Finger millet is an important staple food in East and Central Africa and in India (Hulse *et al*., 1980).

In Uganda, Finger millet is the second most important cereal after maize (Esele, 1989). Uganda is regarded as the centre of its origin, and was probably taken to India some 3000 years back (Hulse, 1980).

Figure 3: Finger millet *Foxtail millet*

Foxtail, Figure 4, is an annual grass that is variable in its morphology (House *et al*., 1995). It is an important crop grow for food and feed in China. It is one of the main cereal crops grown in Northern China, where the other important crops are wheat and corn (Jiaju, 1989).
Plants range from single-stemmed to highly tillered. The highly tillering types range from 30 cm to almost 1 m, each tiller having a panicle pretty well described by its name - foxtail. Panicles are frequently small, 10 to 15 cm in length and 1.5 to 3 cm in diameter. The central rachis is frequently lax, so the panicle droops. By contrast, some varieties, especially those common in China, are single-stemmed, and range from 60-70 cm up to 150 cm high. Leaves are 30 to 35 cm long and 1.5 to 3 cm wide. The panicles have short branches, the central rachis is frequently stiff, but heads on some varieties droop. Seeds are small (2 to 3 mm) and are generally light cream in colour. Foxtail is adapted to temperate regions although found in the tropics. It has a broad range of maturity, from 70 to 120 days.

Foxtail millet

Proso millet (Common millet)

Proso, also known as common millet (Figure 5), is an annual grass adapted to temperate parts of the world. It is suited to a dry continental climate, and grows further north than most other millets (Hulse *et al*., 1980). It is mainly cultivated in Eastern Asia, including Mongolia, Manchuria, Japan, India, Eastern and Central Russia. It is also found in Arabia, Syria, Iran, Iraq, and Afghanistan. Common millet is reported to be the largest millet crop in USA, and one of the most popular cereals in Northern China, commanding a price equal to that of wheat (Hulse et al., 1980)

Proso is a shallow-rooted plant, which is highly variable in morphology, ranging from as short as 25 cm to 230 cm. Many tillers are formed, each with an open panicle with drooping branches. Panicle branches range from 4-5 cm up to 15 cm in length. Individual seeds weigh from 5 to 9 mg. Its inflorescence consists of a slender panicle up to 45 cm long, which may be open or compact. The caryopsis is generally white, oval and smooth.
Common millet displays possibly the lowest water requirement of any cereal. It matures in 60 to 90 days and may be grown where the climate is too hot, the rainy season too short or the soil too poor for any other cereal (Hulse *et al*., 1980).

Figure 5: Proso millet

Kodo millet

Kodo millet (Figure 6) is grown commercially in India (House *et al*., 1995), although the wild grass is a widespread tropical weed (Dogget, 1989). It is an annual millet that varies in height from 30 to 90 cm and has many basal tillers, between 10 and 48. The inflorescence is small, 2 to 12 cm. It matures late compared to other small millets. It is self-pollinating, florets generally remain closed during the flowering period. The grain occurs in a hard husk, making de-branning difficult. The crop is drought resistant, hardy and frequently grown on poor soils. Kodo millet is reported to be poisonous after the rain, perhaps due to fungal infection (Dogget, 1989), but clean healthy grain seems to pose no health problem.

Figure 6:**Kodo millet**

Japanese barnyard millet

Japanese barnyard millet (*Echinochloa frumentacea*), Figure 7, is a short plant, frequently grown in Egypt as a reclamation crop on land, which is too saline for rice (Arnon, 1972, quoted by Hulse *et al*., 1980). It is the fastest growing of all the millets, and, under favourable moisture and temperature conditions, the grains would mature in 45 days after sowing (Hulse *et al*., 1980). However, Rachie, 1975, quoted by Hulse et al., (1980) reported that *Echinocloa* millets grow well in different seasons and at high elevations, but may require 3 - 4 months to mature.

Others (Pursegrove, 1972, quoted by Hulse *et al*., 1980) also reported that Japanese barnyard millet is a fast growing crop, and may take only 6 weeks to mature. Though not of importance, it is grown in the Orient and India, and as a forage crop in USA where it is reported to produce eight harvests per year.

The height of Japanese barnyard millet varies between 50 and 100 cm, the inflorescence consists of a panicle frequently tinged with purple, bearing up to 15 lateral branches. It is normally grown as a rainfed crop, but may be cultivated in waterlogged conditions and survive submersion. It may yield between 700 and 800 kg of grain per ha.

Figure 7: Japanese barnyard millet

Little millet

There are two races of little millet (*Panicum miliare*), namely, *nana* and *robusta* (House *et al*., 1995). Plants in race *nana* vary from 60 to 170 cm in height. The inflorescence is 14 to 15 cm long, erect, open, and highly branched. These branches sometimes droop at maturity. Plants in the race *robusta* are 120 to 190 cm tall. The inflorescence is 20 to 45 cm long, open or compact, and highly branched. It is primarily a self-pollinated crop, with up to 3.5 percent cross pollination.

Little millet (Figure 8) is grown throughout India up to altitudes of 2100 m, but is of little importance elsewhere (Hulse *et al*., 1980). Although little millet has received comparatively little attention from plant breeders, it appears to thrive under conditions where no other edible plant will survive. It matures between 2.5 to 5 months. The yields are generally less than 0.5 tonnes/ ha, but under favourable conditions, may reach close to 1 t / ha. Little millet tends be confused with common millet, but it is generally shorter, and has smaller panicles and seeds than common millets.

Figure 8:**Little millet**

Other millets

Tef

Tef in the most important cereal crop in Ethiopia, particularly in the poor drained heavy soils that predominate in the central plateau. Nevertheless, the crop has not become important outside Ethiopia (Dogget, 1989)

Fonio

Fonio, also known as *hungry rice*, is grown as a cereal crop throughout the savanna zone of West Africa. In parts of Guinea and Nigeria, it is the staple crop. It is considered to be the oldest West African cereal, and its cultivation is thought to date back to 5000 BC. The crop can grow on poor soils, but it is not grown outside Africa (Dogget, 1989).

Small millets

Small millets (also referred to as minor millets) may be defined as millets cultivated for their grains which are borne on short, slender grassy plants, but pearl millets (*Pennisetum*) are excluded (Doggett, 1989). Small millets include Finger millet, Proso millet, foxtail millet, little millet, Baranyard (Sawa) millet, kodo millet, Tef millet and Fonio millet. The grains of small millets are nutritionally superior to rice and wheat, providing minerals and vitamins (Rao, 1989).

In India, small millets occupy 4.5 percent of the cultivated area and are confined to vast stretches of dryland and hilly tracks (Rao, 1989). The productivity of finger millet in India is the highest among the small millets, at 1 150 kg/ha during 1983-84. The productivity of other small millets remained at 450 kg/ha (Rao, 1989).

A structural comparison of the most important millets has already been presented in Table 2.

1.1 Economic and social impact of millets

Millets, in most cases, have been grown in difficult conditions, and it is scarcely surprising that they involve high production risks (Dogget, 1989). They have always been crops for situation where there is a risk of famine, as well as offering a low but more reliable harvest relative to other crops.

Although it is found in other countries, finger millet has gained little importance outside Africa and India. Equally important to note is that, common millet has received little attention from plant breeders (Hulse *et al*., 1980).
In most parts of the world, millet is grown as a subsistence crop for local consumption. Commercial millet production is risky, especially in Africa because the absence of large market outlets means that fluctuations in output cause significant price fluctuations, particularly in areas where millet is the main food crop (FAO and ICRISAT, 1996). Apart from grain production, millet is also cultivated for grazing, green fodder or silage.

1.2 World trade

According to Spencer and Sivakumar (1987) world production of all millets is about 29 million tonnes, of which 35 percent is produced in Africa (Tables 5 and 6). This represents about one third of all the world millets, 70 percent of which is grown in West Africa. According to FAO and ICRISAT (1996), developing countries, mainly Asia and Africa, account for about 94 percent of global output of millet, estimated at some 28 million tonnes (according to the 1992-1994 average) (Table 7).

Table 5. World distribution of sorghum and major types of millets.

Scientific name	Common names	Cytogenic origin	Location grown
Sorghum bicolour	Sorghum, milo, jowar, kafir, Guinea-corn, cholam	Equatorial Africa	Worldwide, Africa, India, China, United States.
Pennisetum glaucum P. americanum P. typhoides	Pearl, bajra, cattail, burlush, Candlestick, sanyo, munga, seno	West Africa	Africa, India.
Eleucine coracona	Finger, ragi, African, bird. s foot, rapoko, Hansa	Originated in Africa and domesticated in India	East and Central Africa, India, China.
Setaria italica	Foxtail, Italian, kangni, navane, German, Siberian, Hungarian	Eastern Asia	Asia (Russian Federation, China, India, Japan) North Africa, Southeast Europe, Near East
Panicum miliaceum	Proso, Common, Hershey, Panivarigu, broomcorn, hog, Samai, Russian	China	Eastern Asia, Russian Federation, China, Mongolia, Middle East, Main millet in USA
Echnochloa frumentacea E. crus-galli E. utilis	Japanese, barnyard, sanwa, kweichou, kudiraivali, sawan, Korean	Java / Malaysia	East Asia, India, Egypt
Paspalum scrobiculatum P. commersoni	Kodo, varagu, bastard, ditch, naraka	Africa or India	India
Eragrostis tef	Tef	Ethiopia	East Africa (Ethiopia)
Digitalia exilis D. iburua	Fonio, fundi, hungry rice, acha, Crabgrass, raishan	Domesticated in Nigeria	West Africa (savanna)

Source: Saldivar and Rooney, 1995.

Table 6. Average Annual Area, production and Yield of millets and Percentage of Total Cereal Production by Major Producing Countries in Africa plus Major Regions of the World, in 1974-76 and 1980-82.

Region (country)	Area (. 000 ha) 1974-76 1980-82		Cereal production (%) 1974-76 1980-82		Production (. 000 mt) 1974-76 1980-82		Yield (kg per ha) 1974-76 1980-82	
Africa	15 218	16 247	13.9	13.8	9 630	10 249	633	619
Burkina Faso	857	870	31.7	32.1	364	387	425	441
Chad [1]	959	1 160	87.8	88.0	520	593	542	510
Mali [1]	1 212	1 425	70.1	76.9	852	868	702	615
Niger	2 150	3 060	74.0	76.5	828	1 321	385	432
Nigeria	4 800	5 230	34.5	32.4	2 843	3 220	592	636
Senegal [1]	1 004	938	79.7	80.7	658	642	655	705
Sudan	1 126	1 120	15.8	12.3	416	393	370	345
Uganda	498	303	38.2	42.1	613	489	1 232	1 615
Asia	25 212	23 450	3.0	2.5	16 718	16 445	663	701
India	18 338	18 096	7.6	6.7	9 042	9 426	493	521
South America	211	167	0.4	0.3	241	193	1 141	1 157
USSR	2 914	2 807	1.4	1.1	2 410	1 791	827	637
WORLD	43 610	43 050	2.1	1.8	29 062	28 733	666	668

[1] Includes sorghum
Source: Spencer and Sivakumar, 1987.

Table 7. Millet area, yield and production by region [1].

	Area (million ha) 1979-81 1989-91 1992-94			Yield (tonnes / ha) 1979-81 1989-91 1992-94			Production (million tonnes) 1979-81 1989-91 1992-94		
Developing countries	34.7	37.4	35.6	0.68	0.73	0.75	23.67	25.0	26.6
Africa	11.5	15.8	18.5	0.67	0.66	0.61	7.68	10.46	11.36
Northern Africa	1.10	1.05	1.96	0.40	0.18	0.28	0.44	0.19	0.55
Sudan	1.10	1.05	1.95	0.40	0.18	0.28	0.44	0.19	0.55
Western Africa	8.30	12.6	14.0	0.67	0.68	0.64	5.52	8.55	9.00
Burkina Faso	0.80	1.21	1.24	0.49	0.54	0.64	0.39	0.65	0.79
Ghana	0.18	0.19	0.20	0.64	0.64	0.82	0.12	0.12	0.17
Côte d. Ivoire	0.06	0.08	0.08	0.58	0.61	0.84	0.04	0.05	0.07
Mali	0.64	1.19	1.20	0.72	0.69	0.61	0.46	0.82	0.73
Niger	3.01	4.19	4.87	0.44	0.34	0.38	1.31	1.43	1.86
Nigeria	2.40	4.50	5.20	1.04	1.04	0.89	2.50	4.67	4.62
Senegal	0.93	0.90	0.89	0.60	0.64	0.61	0.56	0.58	0.55
Togo	0.12	0.13	0.13	0.36	0.51	0.50	0.04	0.07	0.06
Central Africa	0.63	0.79	0.93	0.59	0.51	0.48	0.37	0.40	0.45
Cameroon	0.13	0.06	0.05	0.75	1.06	1.01	0.10	0.06	0.06
Chad	0.36	0.54	0.59	0.50	0.40	0.47	0.18	0.22	0.28
Eastern Africa	1.46	1.33	1.46	0.89	0.97	0.91	1.31	1.29	1.33

	Area (million ha) 1979-81 1989-91 1992-94			Yield (tonnes / ha) 1979-81 1989-91 1992-94			Production (million tonnes) 1979-81 1989-91 1992-94		
Ethiopia	0.23	0.25	0.25	0.90	0.95	1.05	0.20	0.24	0.27
Kenya	0.08	0.10	0.09	1.05	0.67	0.65	0.08	0.07	0.06
Tanzania	0.45	0.23	0.32	0.80	0.94	0.71	0.36	0.22	0.23
Uganda	0.30	0.38	0.41	1.59	1.53	1.57	0.47	0.58	0.63
Zimbabwe	0.35	0.27	0.25	0.43	0.50	0.27	0.15	0.14	0.07
Southern Africa	0.09	0.11	0.21	0.41	0.49	0.18	0.04	0.06	0.04
Asia	22.98	18.29	16.99	0.69	0.79	0.89	15.75	14.45	15.17
Near East	0.19	0.18	0.15	1.02	0.58	0.78	0.19	0.10	0.12
Far East	22.79	18.41	16.84	0.68	0.78	0.89	15.56	14.35	15.05
China	3.98	2.25	1.90	1.45	1.74	1.93	5.79	3.92	3.67
India	17.84	15.19	13.95	0.51	0.64	0.77	9.19	9.76	10.70
Myanmar	0.18	0.17	0.20	0.45	0.69	0.66	0.08	0.12	0.13
Nepal	0.12	0.20	0.21	0.99	1.16	1.14	0.12	0.23	0.24
Pakistan	0.51	0.44	0.43	0.50	0.41	0.44	0.25	0.18	0.19
Central America and Caribbean	0	0	0	0	0	0	0	0	0
South America	0.20	0.04	0.04	1.21	1.19	1.53	0.25	0.06	0.06
Argentina	0.20	0.04	0.04	1.21	1.19	1.53	0.25	0.06	0.06
Developed Countries	2.94	4.13	2.49	0.65	0.88	0.72	1.93	3.64	1.79
Australia	0.03	0.03	0.03	1.0	0.88	1.05	0.03	0.03	0.03

	Area (million ha) 1979-81 1989-91 1992-94			Yield (tonnes / ha) 1979-81 1989-91 1992-94			Production (million tonnes) 1979-81 1989-91 1992-94		
United States	0.09	0.15	0.15	1.2	1.20	1.20	0.11	0.18	0.18
Russian Federation[2]	2.79	3.92	2.27	0.63	0.87	0.68	1.76	3.40	1.54
World	37.60	38.60	38.10	0.68	0.74	0.74	25.70	28.65	28.38

1. Each figure is a 3-year average for the respective period e.g. 1979-81
2.Until 1991, area of the former USSR
Source: FAO and ICRISAT (1996)
NB: Many of the statistics are only estimates, therefore analyses derived from these data should be treated with caution (FAO and ICRISAT (1996).

Table 8. Millet recorded international trade: exports [1]

Exports	**1979-81 (. 000 tonnes)**	**1989-91 (. 000 tonnes)**	**1992-94 (. 000 tonnes)**
Africa	57.9	26.4	20.2
Mali	0.0[2]	15.0	18.0
Niger	36.7	0.1	0.0
Sudan	2.1	1.3	0.0
Asia	12.0	16.8	84.6
China	8.7	4.6	21.6
India	0.0	7.0	58.5
North, Central and South America +Caribbean	145.9	119.1	90.3
Argentina	112.9	41.0	42.9
United States	33.0	75.5	45.5
Europe	20.5	33.0	43.7
EC (12 countries)[3]	15.6	22.6	28.3

Exports	**1979-81 (. 000 tonnes)**	**1989-91 (. 000 tonnes)**	**1992-94 (. 000 tonnes)**
Hungary	4.4	6.9	13.0
Oceania	14.6	13.6	16.3
Australia	14.6	13.6	16.3
World	250.9	208.7	255.0
Developing countries	181.9	84.0	147.4
Developed countries	69.0	124.7	107.6

1. Each figure is a 3-year average for the respective period, e.g. 1979-81
2. Shown as zero for trade less that 50 tonnes
3. Including intra-trade among member countries
Source: FAO & ICRISAT, 1996

Table 9. Millet recorded international trade: imports [1]

Imports	1979-81 (. 000 tonnes)	1989-91 (. 000 tonnes)	1992-94 (. 000 tonnes)
Africa	82.0	7.9	40.9
Angola	0.0[2]	0.0	21.7
Côte d. Ivoire	0.0	2.6	1.2
Gabon	0.0	0.0	0.1
Mauritania	1.0	0.0	0.0
Mali	40.0	0.0	0.5
Niger	8.0	2.4	0.5
Nigeria	26.7	0.5	0.0
Senegal	0.0	2.1	15.0
Sudan	0.0	0.0	0.3
Zimbabwe	0.2	0.0	0.3
Asia	58.9	40.3	44.3

Imports	1979-81 (. 000 tonnes)	1989-91 (. 000 tonnes)	1992-94 (. 000 tonnes)
Japan	53.1	23.7	20.3
Kuwait	1.1	0.3	0.5
Malaysia	0.7	2.1	2.4
Saudi Arabia	1.4	1.5	2.8
Singapore	0.4	1.1	0.7
Thailand	0.8	1.7	1.8
North, Central and South America + Caribbean	4.0	26.2	18.1
Brazil	3.8	3.7	5.8
Canada	0.0	5.9	8.2
Europe	145.7	145.5	155.4
Austria	2.3	1.2	0.8
EC (12 countries)[3]	114.9	131.5	145.2
Switzerland	26.0	9.2	8.2
Oceania	0.8	0.8	5.7
World	291.9	220.8	264.3
Developing countries	90.5	43.8	75.4
Developed countries	201.0	177.0	188.8

1. Each figure is a 3-year average for the respective period, e.g. 1979-81
2. Shown as zero for trade less that 50 tonnes
3. Including intra-trade among member countries
Note: The discrepancies between imports and exports are largely because some exporting counties do not report millet sales at all, or include them under "other cereals".
Source: FAO & ICRISAT, 1996

Table 10. Average annual export prices for millet in selected countries.

Year	Argentina (US$ / tonne)	United States (US$ / tonne)	Australia (US $ / tonne)
1979-81 (Average)	129	186	224
1983	147	175	251
1984	166	176	254
1985	107	171	210
1986	139	151	195
1987	108	154	162
1988	123	173	110
1989	190	177	249
1990	143	188	318
1991	107	156	249
1992	114	170	249
1993	156	223	245
1994	228	254	325

Source: FAO & ICRISAT, 1996.

Of the 28 million tonnes, pearl millet accounts for about 15 million tonnes, foxtail millet accounts for about 5 million tonnes, proso millet for about 4 million tonnes and finger millet for over 3 million tonnes (FAO and ICRISAT, 1996).

Small-scale farmers produce almost all millets for household consumption and localized trade. Very limited quantities of millet are produced in the developed countries. Correspondingly, only small quantities of millet are recorded in the international trade (FAO and ICRISAT, 1996).

The major African producers are Nigeria and Niger, both in West Africa. Other major producers are Burkina Faso, Chad, Mali, and Senegal in West Africa, and Sudan and Uganda in East Africa (Spencer and Sivakumar, 1987; FAO and ICRISAT, 1996). Pearl millet is the major millet grown in Africa. Apart from Uganda, which grows mainly finger millet, all the major African producers listed in Table 7 produce mainly pearl millet.

In all the major African millet producing countries, the crop is of considerable importance in the agricultural system, and accounts for over one third of the total cereal output. This contrasts with the other areas of the world, where large quantities of millets are produced, but in which they usually account for less than 10 percent of the total cereal output. For example, India grows one third of the world. s millet (Table 7), but the crop only represents about 7 percent of the total cereal production (Spencer and Sivakumar, 1987). In relative terms, pearl millet is more important to the agricultural systems and economies of Africa than other regions of the world.

In Africa, South of the Sahara, finger millet occupies the largest area under small millets in the Eastern part of the continent, but there is a substantial area of tef in Ethiopia (Doggett, 1989). In West Africa, fonio millet occupies a similar ecological niche to finger millet. There is also a small area of *Brachiaria deflexa* millet there. Area and production figures for these millets separately are not readily available. Data collected on the small millets are often combined with pearl millet and sometimes with sorghum (Doggett, 1989). Finger millet is grown abundantly in the Lake Victoria region, namely Uganda, Kenya, Tanzania, Zaire, Rwanda and Burundi. The crop is also important in Northern Zambia and the southern highlands of Tanzania. Significant amounts are also grown in Zimbabwe, Malawi and Mozambique. It is possible to get an approximate picture for the situation of finger millet in Uganda, because very little of any other millet is grown (Doggett, 1989)

In India, during the period 1970-71 to 1980-81, finger millet production increased at a rate of 3.37 percent per year, which exceeded the rate of population growth (Doggett, 1989). In India, grain price is clearly very important, but a crop such as finger millet is probably most influenced by very local demands. Finger millet shows a higher probability of failure than pearl millet, rice, or sorghum (Doggett, 1989). In India, out of the total area of 126.67 million ha in 1984-85 under food grain, the small millets area was just 5.78 million ha, or 4.56 percent (Sampath *et al*., 1989). In production, their contribution was 3.85 million tonnes or 2.63 percent of the total 146.22 million tonnes of food grain in the country. However, the contribution of small millets to total cereal is 14.76 percent in area and 12. 36 percent in production (Sampath *et al*., 1989).

There are two regions of the world where finger millet is most intensively grown, namely, the area immediately surrounding Lake Victoria in East Africa, and the south eastern parts of Karnataka and parts of Tamil Nadu and Andhra Pradesh in Southern India (Gupta, 1989). These regions account for nearly 75 percent of the world. s production of this cereal (Gupta, 1989). In Africa, finger millet is produced principally in Uganda, Tanzania, Rwanda, Burundi, Eastern Zaire, Kenya and to a lesser extent in Ethiopia, Sudan, and Somalia (Gupta, 1989). It is also grown in Zimbabwe, Malawi, Zambia, Botswana and Madagascar. In central and Western Africa, it is grown to a limited extent in central Africa, southern Chad and northeastern Nigeria. In Uganda, finger millet is the most important cereal, equalling all other cereals combines (Gupta, 1989). In fact, finger millet is the only other millet of consequence after pearl millet throughout Africa (Gupta, 1989). More information on world distribution of millets is shown in Table 5.

According to FAO and ICRISAT, (1996) the total world production of millet in the period 1979 to the period 1994 has been relatively stable (with minor fluctuations) between 25 and slightly over 30 million tonnes Table 7.

From Table 7, it can be seen that, based on 1979-81 and 1992-94 records respectively, the world. s five major producers of millet, in million tonnes, are, in that order, India (10.7 and 9.2), China (3.7 and 5.8) Nigeria (4.6 and 2.5), Russian Federation/USSR (1.5 and 1.8) and Niger (1.9 and 2.3).

Global trade in millet is estimated to range between 200 000 and 300 000 tonnes, representing roughly 0.1 percent of world trade in cereal, or 1.0 percent of world millet production (FAO and ICRISAT, 1996). The major exporters are India, the United States, Argentina and China, which together supplies about two-thirds of all recorded, exports (Table 8).

The recorded international imports of millets are tabulated in Table 9. The European community accounts for more than 50 percent of the global imports (FAO and ICRISAT, 1996).

Besides this official trade, a substantial unrecorded quantity of millet is traded within subregion in Africa, with grain moving from surplus to deficit areas. In West Africa for example, there is movement of millet during good years from surplus producing areas along the southern boundary of the Sahara both southward to higher-rainfall but millet deficient areas and northward to supply nomadic populations (FAO and ICRISAT, 1996).
Millet marketing channels in many developing countries are not well developed. There are three main reasons for this: scattered and irregular supplies, large distances between producing areas and the main urban centres and limited demand in urban areas (FAO and ICRISAT, 1996).
International trade in millet is controlled by a few specialized trading companies and generally conducted on a sample basis. Only Argentina is reported to have established official export quality standards (FAO and ICRISAT, 1996). The average annual millet export prices for selected countries are shown in Table 10.

1.3 Primary products

Traditional methods are usually applied to decorticate millet grains partially or completely before further processing and consumption. Whole grains may as well be directly dry-milled to give a range of products: broken or cracked grains, grits, coarse meal and fine flour. The flour thus obtained is used in the preparation of an extensive variety of simple to complex food products. They can also be mixed with other flours to form composite flours for soft and stiff porridges (Bangu *et al*., 2000)

1.4 Secondary and derived products

It is unusual, in any human society, for cereals to be eaten as uncooked whole seeds (Hulse *et al*., 1980). For human food, the millet grains are customarily milled before being cooked. Dry milling embraces a wide range of technologies from simple grinding of the whole seed between stones or in a pestle and mortar to the complex continuous system of precision rollers.
Common millet (proso) contains a comparatively high percentage of indigestible fibre because the seeds are enclosed in the hulls, and difficult to remove by conventional milling processes (Matz, 1969 quoted by Hulse, *et al*., 1980).

Figure 9: Traditional dehulling equipment.

1.4.1 Traditional milling equipment

Almost without exception, women do traditional milling and decorticating of millet. Munck (1995) reports that care is taken to prepare the milling products and cook them freshly every day, because keeping quality of flour is low in the tropics. However, flour may keep for some days (even up to two weeks after it has been prepared). The simplest type of processing is to grind the whole grain in a stone hand mill, a village stone mill, or a hammer mill driven by diesel engine.

Many consumers decorticate (dehull) the kernel before grinding it in to various particle sizes for use in different products. In most of Africa, a significant portion of the millet is decorticated (Witcombe and Berkerman, 1984).

Pearl millet is usually decorticated by washing the clean grain in water. The water is removed and the grain is crushed using a stone mortar and wooden pestle. The bran is removed by washing or winnowing the sun-dried crushed material.

In rural Africa, a wooden mortar and pestle is used to thresh, decorticate and grind flour or meals (Rooney and McDonough, 1987). Figure 10 shows the pounding process in order to dehull millet grains.

Pearl millet is usually milled daily in quantities of 2-3 kg. Water is added to moisten the pericarp, and facilitate bran removal. The moisture often promotes fermentation and microorganism growth, both of which affect the keeping properties of the products (Rooney and McDonough, 1987). In addition, the high oil content of the of pearl millet can lead to rancidity problems.

Decortication of 2.5 kg of pearl millet takes two women about 1.5 h, including winnowing. Processing into flour with a mortar and pestle requires an additional 2.0-2.5 h. Size, shape and hardness of the kernel and thickness of the pericarp affect the milling yields and time. The extraction rate is lower for pearl millet (74 percent) than that for sorghum (79 percent) (Rooney and McDonough, 1987)

In some countries, such as Rhodesia, Finger millet is ground by pestle and mortar without water, and winnowed, sifted winnowed and reground (Carr, 1961 quoted by Hulse *et al*., 1980). The ground millet yield is meal 80 percent, offals 18 percent and waste 2 percent. In Rhodesia, Finger millet is used mainly for brewing and less commonly as a meal to make porridge. Peal millet is ground with 20 percent of its weight of water added. After stamping, the grain is winnowed, light roasted and ground on a quern without sieving. The extraction rate of pearl millet is about 75 percent.

Grains can be de-husked either fresh or after parboiling. It is cooked solo or with rice and consumed like rice with vegetables or pulses. It is also consumed in the form of *chapati* or bread prepared from flour. Whole fried grain or its flour is consumed after mixing with Gur (molasses) and salt. Various types of delicious cakes are prepared from flours of millets. Palatable sweet dishes like *Payesh* or *Firney* are made from dehusked foxtail millet mixed with milk and sugar.

Small millets are well protected in glume encasements and, therefore, the processing of the grain to usable form is not only time consuming, but also labour intensive. There is therefore need to develop postharvest processing technology in order to reduce human drudgery (Ra, 1989).

Moistened millet grains are pound in mortar with a pestle to remove the pericarp (Figure 10). The decorticated grain is later crushed to grits, flour etc. In India, women use mortars made of stone and pestles made from wood to decorticate the millets. The stone mortar is sometimes fixed in the ground, and appears as a pit or hole in the ground. Millet grains require more time to pound than sorghum grains. Usually, an amount of grain less than 1kg is washed and placed in mortar, and moistened to soften the bran. Sorghum grains are pounded vigorously for 5 minutes, but millet grains may be pounded for a longer period. The bran obtained after

pounding is washed, and the clean endosperm recovered is left for sundrying. The washes contain the bran and a major portion of the germ, which gets broken and removed from the kernel during the pounding process.
In some parts of the world, such as Africa, the pestle and mortar are curved from wood. The mortar is about 60 to 70 cm high, with a diameter of about 30 cm. The pestle weighs about 3 kg, and is about 1.2 m long 6 cm in diameter with bulbous ends (Figure 10). Approximately 2-3 kg of clean grain is placed in the mortar, and about 250 ml of water added (Murty and Kumar, 1995). The water is mixed with the grain and pounded vigorously by one, two or three women, each working at about 60 strokes per minute. When grinding of millet grains in to flour is done by pounding in a mortar and pestle, Hulse *et al*., (1980) reported that it takes one woman four hours to pound the grains in to flour.

Figure 10: Pounding grains using a mortar and pestle.

1.4.2 Improved milling equipment

Some machines equipped with Carborundum stones are used to polish the grains. Decortication is sometimes accomplished by using rice dehullers or other abrasive dehullers. A hammer mill may be used for milling of millet in to flour.
The key raw material characters for grain milling quality are the size, form and structure of the seed, including the development of its outer (bran) layers and the endosperm hardness (Muck, 1995). Due to their small grain size, milling is often more complex with millet that it is with sorghum (Muck, 1995).

When finger millet, for example, is ground by pestle and mortar in to flour (without addition of water) and winnowed, sifted, winnowed and reground, and sieved through a 100-mesh sieve, the yield of various ingredients is as follows: meal 80 percent, offals 18 percent and waste 2 percent (Hulse *et al*., 1980). Figure 11 shows a flowchart for milling millets in to flour.

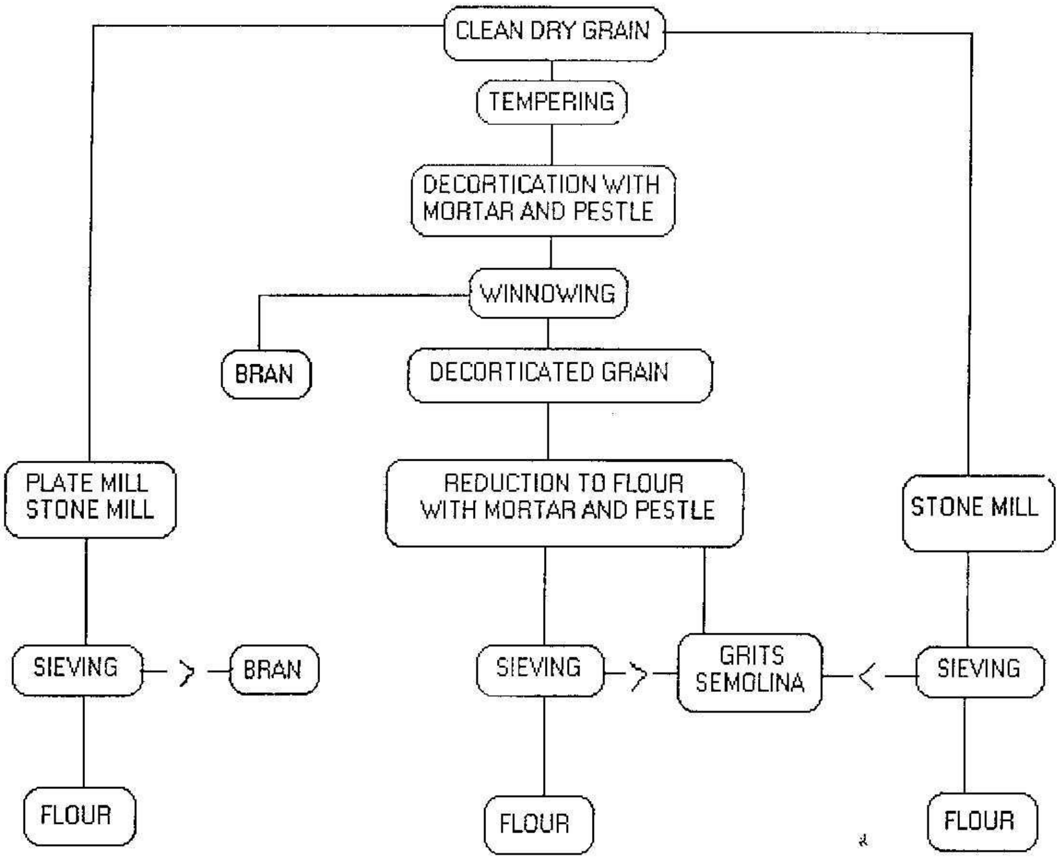

Figure 11: Flowchart for traditional milling methods of millets into flour.

Once millet has been processed (milled) in to flour, the latter can further be processed in to various secondary products. The details are of the various secondary millet prod**ucts are as shown below:**

1.4.3 Thick porridges

The most common and simple food prepared from millets is porridge. Stiff (thick) porridges are consumed in almost all countries where sorghum and millets are cultivated (Murty and Kumar, 1995). Soft (thin) porridges are also a simple food product from millets. The basic difference between thick and thin porridges is the concentration of flour. Generally, thick porridges are solid, and can be eaten with the hand, while thin porridges are fluid and can be drunk from a cup, or eaten by a spoon. The preparation of stiff porridge entails adding flour to boiling water in increments accompanied by vigorous stirring. The flour is cooked until it forms a thick, homogeneous and well gelatinized mass devoid of lumps.

In some countries, the pH of the resulting stiff porridge will vary greatly depending on the ingredients added (Dendy, 1985). In Burkina Faso, for example, the pH of thick porridge

called ***tô*** is prepare by cooking flour in water to which tamarind extract or lemon juice is added to produce an acidic medium (Murty and Kumar, 1995).
In some parts, such as Nigeria, Ghana, Zimbabwe, Tanzania, Kenya, Uganda and some parts of south India, plain water without any additives is used for making stiff porridge, which results in a neutral pH medium.
In Botswana and Sudan, the flour is soured and fermented for at least 18 hours before cooking, resulting in a fermented porridge. The different types of stiff porridges prepared from millets and sorghum are shown in Table 11.

Table 11. Traditional stiff porridges prepared from sorghum and millets.

Common name	**Country or Region**	**Description and variations**
Sankati, kali	Southern India	Coarse flour from dehulled/whole millet
Mudde	Southern India	Coarse flour made into a stiff porridge and later moulded/shaped
Nsima	Zambia, Malawi	Neutral pH stiff porridge made from dehulled sorghum or millet flour.
Mafo	Somalia	Neutral pH stiff porridge
Sadza	Zimbabwe	Neutral pH stiff porridge
Ugali	Kenya, Uganda, Tanzania	Neutral pH stiff porridge
Mosokwane (bogobe)	Botswana	Neutral pH stiff porridge
Tuwo	Nigeria	Neutral pH stiff porridge
Tuo	Ghana	Neutral pH stiff porridge
Boule	Mauritania, Chad	Neutral pH stiff porridge
Bita	Niger	Neutral pH stiff porridge
Tõ	Burkina Faso	Acid pH, stiff porridge
Tõ	Mali	Alkaline pH, stiff porridge (Wood ash leachate added)
Dalaki	Nigeria	Wet-milled fermented grains used
Aceda	Sudan	Fermented batter cooked in to stiff porridge

Ting (bogobe)	Botswana	Fermented batter cooked in to stiff porridge
Umqo	South Africa	Sour, fermented stiff porridge
Umphokoqo, phutu	South Africa	Sour, fermented stiff porridge

Source: Murty and Kumar, 1995.

1.4.3.1 Tõ

Tõ is the principal cereal recipe consumed by millions of people in the 400-900 mm rainfall zone of West Africa. Sorghum ***t***ô is more commonly consumed in the wetter areas, while millet ***t***õ is used in the drier areas. The traditional procedure to prepare ***t***ô begins with decortication followed by grinding of the decorticated grains to flour. In Mali, for example, it is prepared by first boiling four litres of water. Ten grams of wood ash extract is mixed with about 650 ml of cold water in a calabash, and about 750 g of flour is added. The mixture is stirred until it is homogeneous, and then swirled in to the boiling water in the pot. The boiling gravy is stirred for about 8 min and at this point, a thin solution, called *bouillie,* is obtained. Heat is then reduced, and about 1 125 g of flour is added, a handful at time. With each addition of flour, the contents are vigorously stirred with a paddle.

1.4.3.2 Ugali

The stiff porridge prepared from any cereal flour (or yam, cassava, potato flour) is known as *ugali* in Eastern and some parts of Southern Africa (Kajuna, 1995). The most popular *ugali* in the region is made from maize flour, but other cereals such as millets, sorghum, and such roots and tubers as yams, potatoes and cassava may be used (Bangu *et al*., 2000).

Figure 12: Housewife preparing stiff porridge (ugali) from millet flour.

In millets (such as finger millet), white grain types are preferred for *ugali* preparation. The flour is generally obtained by the traditional decorticating and grinding methods. Soft and brown grains are usually pounded dry and winnowed before grinding in to flour. In urban areas, hammer mills may be used. The cooking procedure of *ugali* entails boiling a predetermined amount of water in a pan. Flour (from millet or any other source) is mixed with boiling water and vigorously stirred and kneaded by a paddle for about 10 minutes, until a thick consistent mixture is obtained. Other types of thick porridges are as shown in Table 2. The traditional processes for production of various stiff porridges are shown in a flow chart in Figure 13.

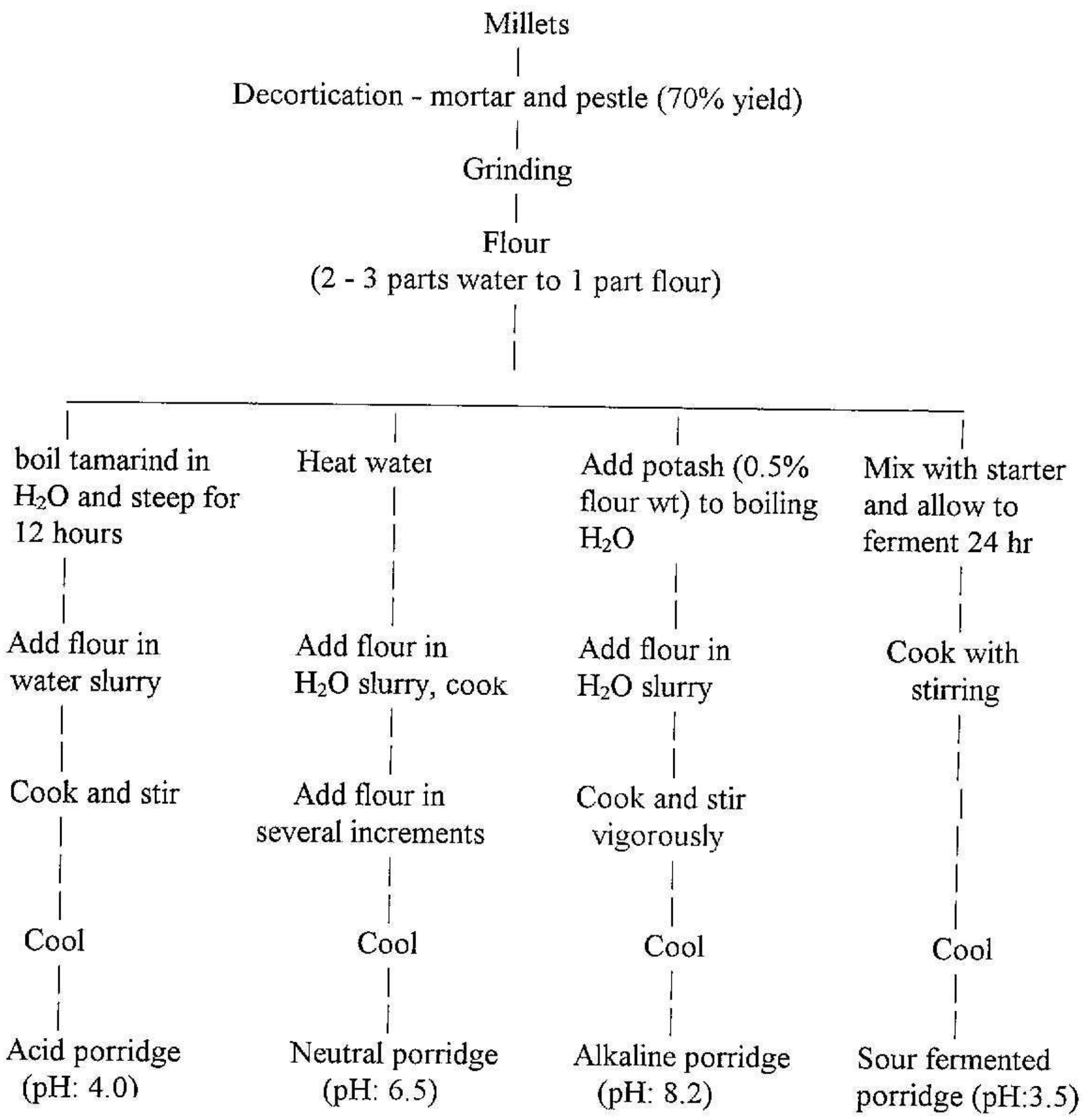

Figure 13: Flow chart for producing stiff porridge from millets.

1.4.4. Soft porridges

Soft porridges (sometimes known as thin porridges) may be prepared from millet flour (or other flours) as fermented or unfermented food product (Marty and Kumar, 1995). They may be prepared from dry-milled flour, from whole de-hulled grains, soaked grains, and germinated or malted grains. Composite flours of millets, sorghum, rice, cassava etc may be used (Bangu *et al.*, 2000). A simple unfermented soft porridge, called *uji* in Tanzania, Kenya and Uganda, may be prepared by making a thick flour suspension and adding it to boiling water. The thin boiling solution is stirred with a ladle for about 5 minutes when complete gelatinization is achieved. The initial suspension of flour can be left aside overnight for fermentation and used next day to make a fermented *uji*. The purpose of fermentation is to produce some acceptable flavours and mask the undesirable ones, as well improve storability. Much of the bulrush millet is made in to soft porridge, (*uji*), or into stiff porridge (*ugali*) (Acland, 1971; Kajuna, 1995). Bulrush millet is sometimes used for brewing, where the grain is germinated, dried and ground in to flour and this is boiled and allowed to ferment for a bout a week (Acland, 1971).

1.4.4.1 Ogi

This is the most important fermented soft porridge consumed in Nigeria and some parts of Ghana. It may be prepared from either millets or sorghum (Murty and Kumar, 1995). It is the most extensively consumed traditional break fast food. It is prepared by soaking whole grain in water at room temperature for two or three days, and the steeped grain is washed and crushed in a slurry of water and sieved through a thin cloth to remove bran. The stuff that passes through contains the endosperm and chunks are allowed to ferment for several hours. Most of the water is decanted, and the sediment that settles at the bottom is called *ogi*. The *ogi* is cooked in fresh water, or sometimes the same decanted water to produce *ogi* porridge, which is free flowing, with a creamy consistency. Traditionally, *ogi* is consumed the same day it is prepared, but if stored overnight, it solidifies in to a gel. The gel products are called *kafa* or *agidi* in Nigeria.

Although millets are used for producing *ogi*, maize and sorghum have been shown to produce more superior *ogi* (Banigo and Muller, 1972 quoted by Murty and Kumar, 1995).

1.4.4.2 Obushera

This is a traditional name found in Northern parts of Tanzania (Kagera region) used to refer to thin (soft) porridge prepared from flour obtained from finger millet. The dried grains are ground by women on manual traditional stone mills.

Flour is mixed with cold water to obtain a freely flowing consistency, which is brought to boiling, and cooked for a further 6 to 8 minutes. The resulting non-f**reely flowing thin porridge is found to be a nutritious food for breakfast for adults and especially infants (personal experience). In some parts of Uganda, soft porridge prepared from sorghum flour is also termed** *obushera* (Murty and Kumar, 1995).

1.4.5 Steam cooked products

1.4.5.1. Kudumu

In India, fermented sorghum-millet flour is cooked over steam to make a product called *kudumu*. Wet milled sorghum-millet batter can be mixed with wet milled black gram batter, fermented overnight and poured into small cakes or moulds which are steam cooked to give a product called *idli*. *Idli* is soft, moist and spongy with a slightly sour taste (Murty and Kumar, 1995)

1.4.5.2 Furah

In Northern Nigeria and Niger, a traditional pearl millet product called *furah*, is popular and commonly sold in the markets. Slightly fermented and humid flour from millet is shaped into balls which are placed in a small quantity of water and steam-cooked for about one hour, after which they are pounded in morta**r to give a highly viscous paste. The paste is then rolled in fine millet flour and sold as** *furah* (Murty and Kumar, 1995).

1.4.5.3 Couscous

In Northern Africa, a steamed granulated product, called *couscous* is made from cereals such as pearl millet. It is however produced from such other cereals as sorghum and maize although pearl millet is preferred. *Couscous* is a nice travelling food, preferred in West Africa.

1.4.6 Breads

1.4.6.1 Fermented breads

In India, millet flours are fermented and used to make a wide range of pancakes (Murty and Kumar, 1995). Such traditional fermented breads as *injera, kisra, dosa, massa* and *galettes* do exist.

Injera

Injera is a traditional cereal bread prepared from Tef millet, and is popular in Ethiopia It can also be prepared from Finger millet. *Injera* preparation starts by fermenting the flour for about 48 hours. A fresh batch of flour is gelatinized by adding boiling water, and the gelatinized flour is added to the fermented batter to hasten secondary fermentation. The fermented batter is baked on a hot clay griddle, called *metad*. Usually, 0.5 l of batter is poured on to hot *metad* in a centrifugal manner from the edge of the griddle to the centre. When holes start to form on top of the *injera*, it is covered with a lid and let to bake 2-3 min, after which a circular pancake of about 60 cm in diameter and 6 mm thick, called *injera*, is obtained.

Kisra

In Sudan, a staple diet prepared from millet, called kisra, is very popular. Millet flour, is made into thick paste (*ajin*) by mixing two parts flour and one part water, and allowing to ferment over night (Murty and Kumar, 1995). The resulting batter is diluted with water to the desired consistency, and baked on a griddle for about 30 to 40 seconds to produce a kisra with a pH of about 3.5 which is usually preferred. Kisra is normally consumed with stew and sauce.

Dosa

In Southern India and Sri Lanka, fermented batter is mixed with legume batter and baked into a thin pancake called *dosa*. Rice is preferable to other cereals, but millets may also be used. De-hulled millet grains are soaked, wet milled and fermented overnight. The batter is poured in small quantities onto a hot metal plate with some oil, and baked for about one minute. The resulting crispy but flexible 2-4 mm thick and 20-25 mm diameter pancake is called *dos*a, and is consumed with curd, vegetables, chillies or other sauces.

Massa and Galettes

In West Africa, pancakes such as *massa* and *galettes* are prepared from millets and sorghum, but these are only consumed occasionally (Faure and Muchnik, 1989, quoted by Murty and Kumar, 1995)

1.4.7 Unfermented bread

1.4.7.1 Roti

In India, an unfermented pancake, called *roti*, is produced from pearl millet, small millets, sorghum or maize flour. *Roti* is also known as chapati in other parts of India and East Africa, such as Tanzania. It can be consumed with vegetables, dal, meat, milk, curd, sour milk, pickles and other sauces.

The preparation of *roti* entails taking about 50 g of flour, which is mixed with about 45 ml of warm water. The flour-water mixture is kneaded on a wooden board to obtain cohesive dough. The dough is made into a ball, which is pressed by a wooden rod into a thin (about 1.3 to 3 mm thick) circular sheet, which is then baked for about one minute on an earthen or iron pan.

1.4.8 Beverages

Malted millet grains have been widely used in Africa for centuries to make alcoholic and non-alcoholic fermented beverages (Murty and Kumar, 1995).

1.4.8.1 Alcoholic

Two major kinds of beer are produced in millet consuming areas, namely (a) a soured alcoholic, effervescent, brown, viscous opaque beverage which is consumed while undergoing active fermentation, and (b) a sweet, relatively non-sour type of beer (Rooney and McDonough, 1987). The soured beer is made from malted millet or sorghum or both, and several different starch materials, e.g. corn grits are used as adjuncts. The traditional production of beer is an art, usually practised by women.
A fairly high proportion of millet produced in Africa is utilized in the making of traditional beers. In west Africa, for example, use of millets in beer production is more prevalent in the higher rainfall zones and is not common in areas where Islam is widely practised.

1.4.8.2 Non-alcoholic

In Africa, several non-alcoholic beverages are prepared from millets (Murty and Kumar, 1995). A great majority of these non-alcoholic fermentations are sourings. Lack of precise microbiological control under local conditions make it difficult to conduct pure alcoholic or non-alcoholic fermentation. Nevertheless, some degree of control is exercised in certain processing techniques, and many of the soured beverages produced have negligible or very low amounts of alcohol in them.

1.4.9 Snack foods

There is a numerous number of snack foods, which can be derived from millet flour. These are found in plenty in such countries as India, Sudan, Nigeria and other countries (Vogela and Graham, 1979, quoted by Murty and Kumar, 1995). Different types of snack foods may be prepared by deep frying in the dough in fat. Thick porridges of fermented dough can be extruded or moulded and then deep-fried or sun-dried and then deep fried. Sugar, salt and other spices may be added to improve both the flavour and the nutritional status of the snack. However, these snack foods make up a small proportion of the total millet production.

1.5 Requirements for export and quality assurance

1.5.1 Inspection and certification of millet seed crop

Certification of a seed crop such as millet seeks to maintain genetic purity and identity and make available to the public, through certification, high quality seeds and propagating materials of superior crop plants and varieties so grown and distributed as to ensure genetic identity and genetic purity. Seed certification is also designed to maintain reasonable standards of seed condition and quality prescribed for the crop. This can be obtained by (a) verification of seed sources, field inspection to verify conformity to prescribed standards and seed analysis to verify conformity to seed standard.

1.5.2 Pre-harvesting inspection

This inspection should be made after the seed has matured and before harvesting of the millet is carried out. The purpose is to check that disease affected plants are removed, and off-type plants are other volunteers are rogued out. The inspection is carried out mainly to observe the prescribed standards for seed born diseases, which should be met as laid down. The inspection considers the colour of grain, shape and size of earhead, compactness, etc (FAO, 1972).

1.5.3 Quality seed availability

Many farmers keep their own millet seed which is invariably a mixture of local cultivars (Esele, 1989). They exercise care and select uniform ears and preserve them as seed for the next season. Farmers select the best heads in the field, cut them, dry and store them separately in long strawed bundles. This exercise helps farmers to carry forward varieties of millet that they feel to be superior and of higher quality.

2. Post-production Operations

2.1 Pre-Harvest Operations

One of the major pre-harvest operations is the field inspection to ensure uniform ripening of the crop. If ripening is not uniform in the field, selective harvesting, may be done to pick the ripe heads that may start shattering, leaving the unripe heads for the next round of harvesting. Pre-harvest inspection (as mentioned in section 6) also ensures maintenance of quality of the crop.

2.2 Harvesting

Harvesting of many varieties of millets is done by removing the individual heads with sickles or small hand knives. This is sometimes preceded by breaking the stems (Aucland, 1921). Esele (1989) reported that, in Uganda, finger millet is harvested by a sharp hand or finger knife. The ears are cut with about 2 cm of stalk. The harvested ears are kept in a pile for a few days to ripen the grain further and to give the desirable taste. They are then sun-dried.
Hulse *et al*., (1980) reported that harvesting of proso (common) millet is by pulling up the entire plant by the roots as soon as the grain is ripe in order to avoid excessive shattering, and is threshed immediately.
Although the literature surveyed does not show any evidence of mechanized harvesting of millets, it is envisaged that combine-harvesting of millets is possible. It may be particularly so for millet varieties which have uniform heights. However, the screen to retain good seed in the combine harvester would have to be very small, much smaller than that of maize and rice.

2.3. Transport

Transportation of millet starts immediately after harvesting within the farm. For farmers who do not prefer drying their crop in the field, they transport the millet in bags to their homestead where the heads are spread out on the sun to dry. Some farmers in central parts of Tanzania transport their millet by wrapping the crop in a piece of cloth which is loaded on to donkeys and transported to the homestead (Figure 14 a). Alternatively, whole crop may be tied up by rope and transported using donkeys (Figure 14 b).

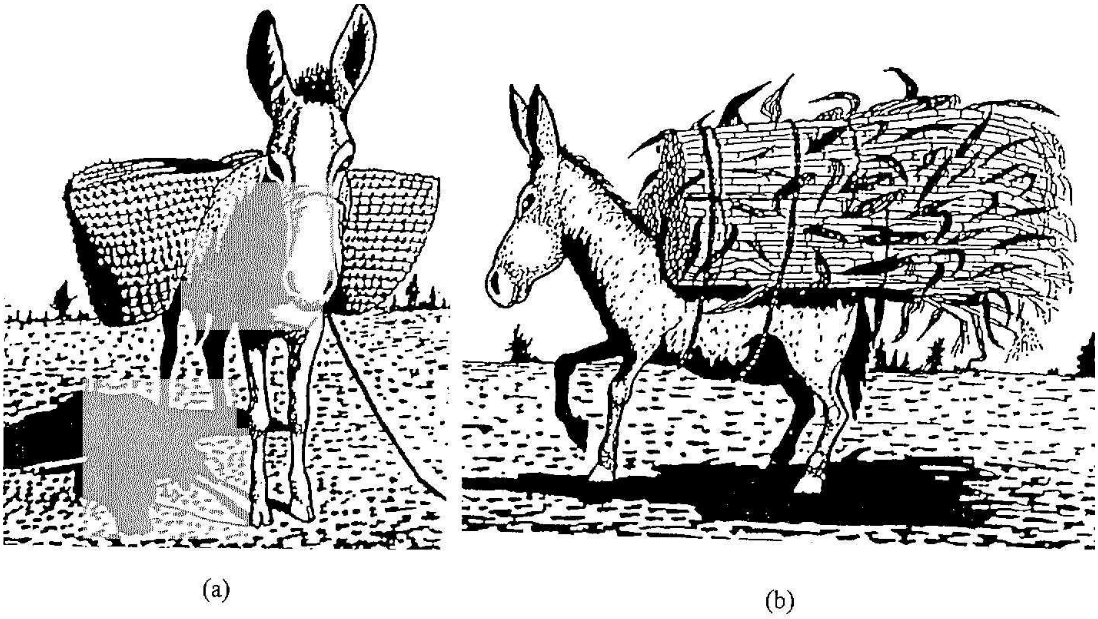

Figure 14: Transportation of millet (or other grains) using donkeys (a) bag or basket transportation (b) Transport of whole crop on the plant.

Animal-drawn carts are also used for transportation of the crop from the field but these can only be afforded by medium scale farmers (personal experience) (Figure 15). If drying is done in the field, threshing must also be done in the field to avoid grain loss because the grains will fall off the heads very easily during transportation.

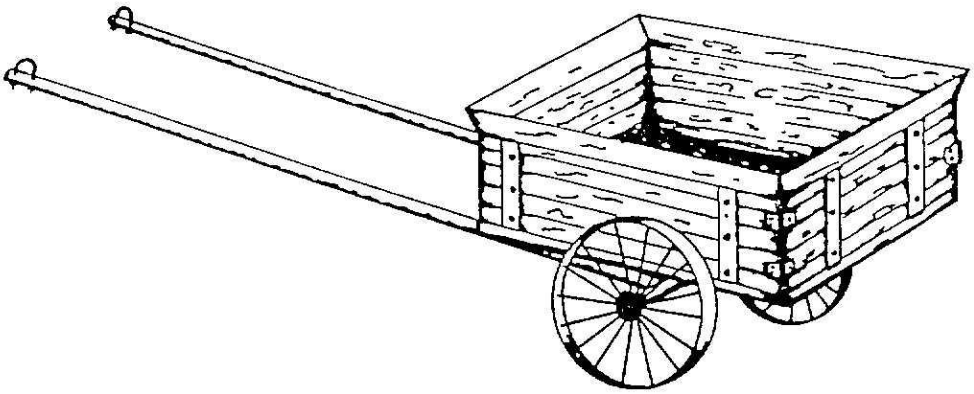

Figure 15: **Pull carts for transportation of millet from farm using donkeys. (Source: Odogola and Henrikson, 1991)**

The shelled millet is usually packed in sisal bags (or other types of bags) and transported to the market. The bags may be stacked on sledges, which are pulled by animals (Figure 16). Individual farmers stack their bags along the road and await transportation. Trucks are the most common means of transporting millet from the rural areas to urban centres.

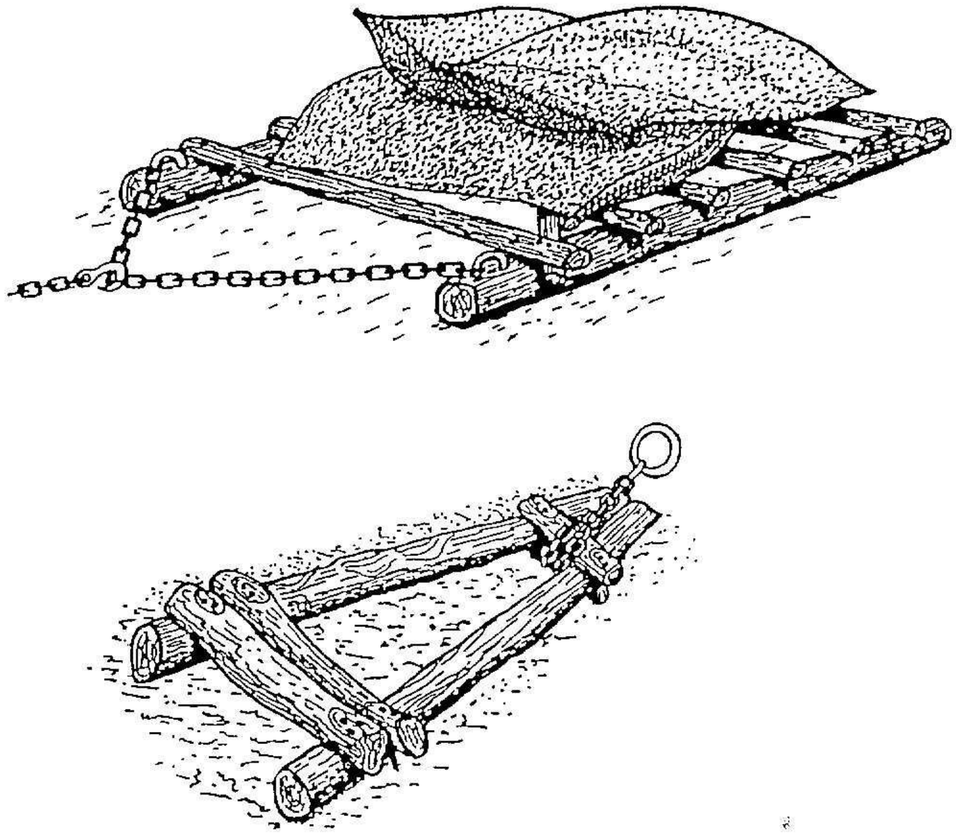

Figure 16: Traditional on farm transportation by using sledges.

2.4 Threshing

Threshing is the removal of grain from harvested plant or plant part (Acland, 1921). Threshing of millet is done manually by women and men. It entails beating the millet heads with sticks or clubs repeatedly until almost all the grains are detached from the heads. Figure 17 (a) shows the process of threshing millet by beating. The beating action may be done either on a mat, canvas or bare ground. In order to ease grain collection after beating, sometimes the heads of millets may be stuffed in to bags, prior to beating. This practice is common in Tanzania, Kenya, Malawi, Mozambique, Zimbabwe, and Uganda.
The straw that remains after threshing may be used as a source of fuel. Straw is used as thatching material for traditional houses (Seetharam *et al*., 1989), or used as mulch as well as animal feed.

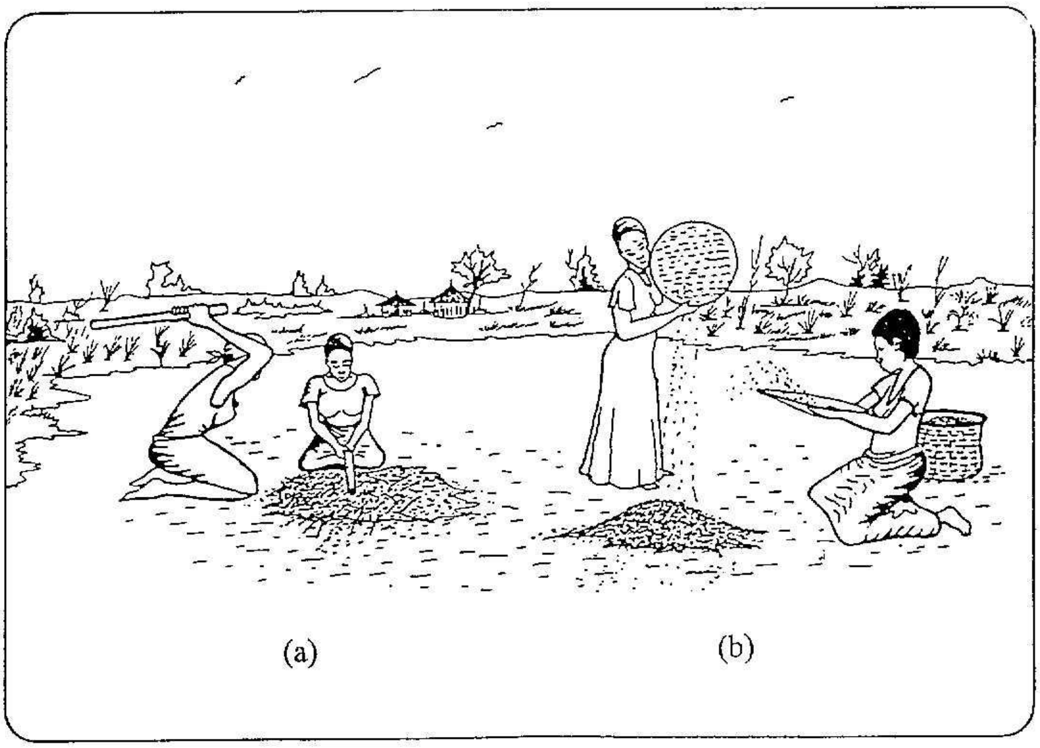

Figure 17: (a) Women threshing millet by beating with clubs on bare ground (b) Women cleaning millet by aspiration and winnowing (Source: Odogola and Henrikson, 1991).

2.5 Drying

Information on the drying of millet is meagre (McFarlane *et al*., 1995). Millet grains harvested during rainy season may be left to dry in the field for up to two weeks. Further drying if required is completed after threshing on mats laid down on the sun, or plastic sheets (Figure 18a). Many Africans consider that foods prepared from rain-beaten grains have improved quality and palatability (Vogel and Graham, 1928; quoted by McFarlane *et al*., 1995). Mechanical drying may be employed to dry the millet grains, but this is expensive, and therefore, must only be recommended where returns are economical.

Apart from the traditional sun drying, unheated air drying could be employed. This is a simple method to operate, and requires minimum attention to achieve uniform drying (McFarlane *et al*., 1995). However, unheated air drying is weather dependent, and in case of prolonged wet conditions with high relative humidity, the drying process may take a long time. In such circumstances, one may therefore, have to select the airflow rate very carefully to optimize the drying process. The recommended air flow rates for drying sorghum are 0.02 m^3/s per m^3 of sorghum at 14 percent moisture content (wb) up to 0.04 m^3/s per m^3 of sorghum at 20 percent moisture content (wb). McFarlane *et al*., (1995) recommend the same rates for millets.

Supplementary heaters could be used to improve the performance of unheated air-drying in areas where weather is not in favour of the drying process. Oil, gas or electric burners may be used as a source of heat.

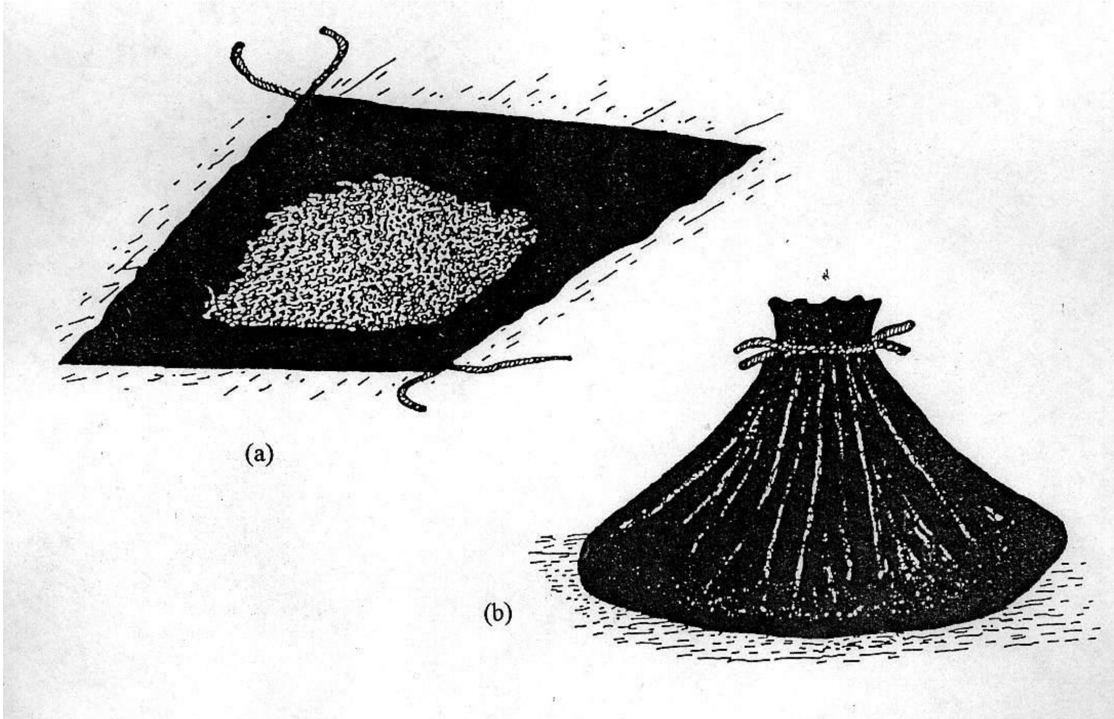

Figure 18: (a) Grains spread out to dry on a plastic sheet (b) grains wrapped up in a plastic sheet for rain protection. (Source: Odogola and Henrikson, 1991)

2.6 Cleaning

Cleaning refers to separation of contaminants from produce, and complete removal of the contaminants so that the cleaned produce is free from re-contamination. The contaminants for millets may be sand (soil), small stones, leaves, shrivelled seeds, off-type seeds, broken seeds, glumes, sticks, chaff, parts of stems, insects, animal hair, animal excreta (e.g. rat and insect faeces) and more annoyingly, metal pieces. Metal pieces, if not removed, may damage the sieves of the milling machines if mechanized grinding is used. Sand and soil if not removed, will make the secondary products such as *ugali*, porridge and other products to taste gritty. Contamination by small stones, sand, off-type seeds, etc may arise from the drying ground, where the farmers in rural areas spread the millet heads on bare ground in the sun to dry. Sometimes, even the threshed grains are spread out on bare ground for drying.
Cleaning is traditionally done by two techniques namely:
winnowing: This is a process of millet cleaning whereby approximately 2 to 3 kg of threshed millet grains are placed on a flat reed- or raffia-woven basket (known as *ungo* in Tanzania, Kenya and Uganda) and winnowed by up and down strokes (known *as kupepeta* is Swahili). In this process, the basket is jerked up and down so that the grains are thrown up in the air and allowed to fall back onto the basket (right hand side of Figure 17.(b)). The sand and other light contaminants are separated to the front of the basket from where they are thrown off by a jerky motion, or are removed by hand. Often, the light contaminants are blown off by the mouth. Women in both rural and urban areas are usually the experts. The process is labourious, and time consuming, and may take up to 1 hr to clean 1 bag of 100 kg.
aspiration: This is a traditional cleaning process whereby the difference in densities between the good millet grains and contaminants is exploited to separate the contaminants from millet grains (left hand side of Figure 17 (b)). The separation effect is best obtained when it is

slightly windy, so that the wind current blows the light contaminants from the relatively heavy grains (personal experience). About 10 kg of threshed millet grains are placed in a tin or basket and poured from above the head to fall on to the ground usually lined with either a carpet or canvas. The wind blows off the chaff leaving a heap of clean grains. This method is much faster than the traditional winnowing, and up to 4 or 5 bags may be winnowed in 1 hour. However the method is not effective in separating sand, stone and metal contaminants which are as heavy as (or even heavier than) the millet grains.
Other techniques of cleaning include screening, where a set of sieves is used to separate abnormally small grains from the good ones. Screening also removes sand particles and broken pieces of millet grains.

2.7 Packaging

After threshing, drying and cleaning, millets are usually bagged in to 100 kg hessian/sisal bags and sealed ready for transportation to distant markets (personal experience). Sometimes millet grains may be packed in bags sewn from artificial polythene bags for either transportation or storage.

2.8. Storage

Storage of crops is an essential component of the whole production system. It facilitates several farmer objectives, namely, availing food for the future and avoiding food shortage, providing seed during the next growing season, allows the farmer to sell at a time when the price is good.
Scientific attention to the storage of sorghum, and especially millets has been considerably less than that for other cereals (McFarlane, *et al*., 1995). The main reason is that sorghum and millets are regarded as minor grain crops despite their relative importance as food staple in many growing countries. The other notable reason is that farmers in the arid and semi-arid countries where millets are grown achieve quite impressive performance in grain storage by employing relatively simple traditional methods.
Most millets have excellent storage properties and can be kept for up to 4-5 years in simple storage facilities such as traditional granaries. This is because the seeds are protected from insect attack by the hard hull covering the endosperm, and because grain is usually harvested and stored in dry weather conditions (FAO and ICRISAT, 1996). Thus, although there may be large year to year variations in production, stock can be easily built up over the years.
Millets may be stored, after drying and threshing, as loose grain in bags or loose containers (McFarlane *et al*., 1995). They are commonly left on the field, prior to threshing, in stacks or piles of harvested plants. The detached heads may also be stored away from the field, in exposed stack or in traditional storage containers. However, the essential pre-requisites for storage of millets are the same as those for other grains.
Esele (1989) reports that, in Uganda, storage of finger millet is done in granaries made out of reeds and mud walls. Other traditional storage structures, which can be used to store millet, include sealed storage drum (Figure 19), mud straw bins (Figure 20) And earthenware pot and jar (Figure 21).
Underground storage of grains such as millet, sorghum and maize has been reported in different countries such as Somalia and Sudan (Figure 22).

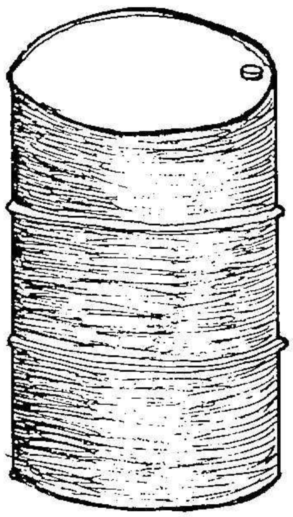

Figure 19. Storage drum for air-tight storage of millet
(Source: Odogola and Henrikson, 1991)

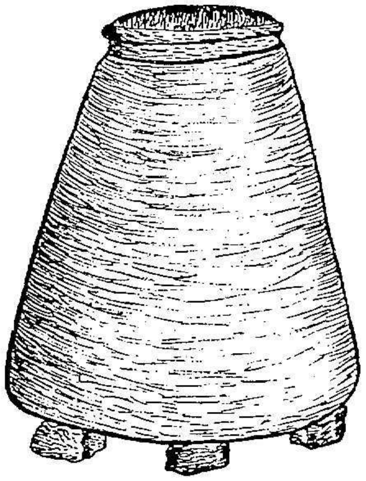

Figure 20: Mud straw bins for storage of millet.
(Source: Odogola and Henrikson, 1991)

Figure 21: **Earthenware pot and jar for traditional storage of millet.**
(Source: Odogola and Henrikson, 1991)

Storage life in millets is inversely related to temperature and relative humidity in storage. Quality can be maintained by reducing storage temperature and humidity or moisture content (or all the three factors) (McFarlane, 1995). Mould growth and intrinsic deterioration of millet in storage are negligible when the grains are sufficiently dry. The relative humidity of 20 percent is marginally acceptable for storage, and 60-65 percent is preferable for storage.
Less commonly, storage of millets may be by admixture with beans (e.g. in Botswana) which reduces the intergranular spaces between the beans, thereby impeding infestation of the beans by braccate beetles and optimizing the use of storage space (McFarlane, 1995).

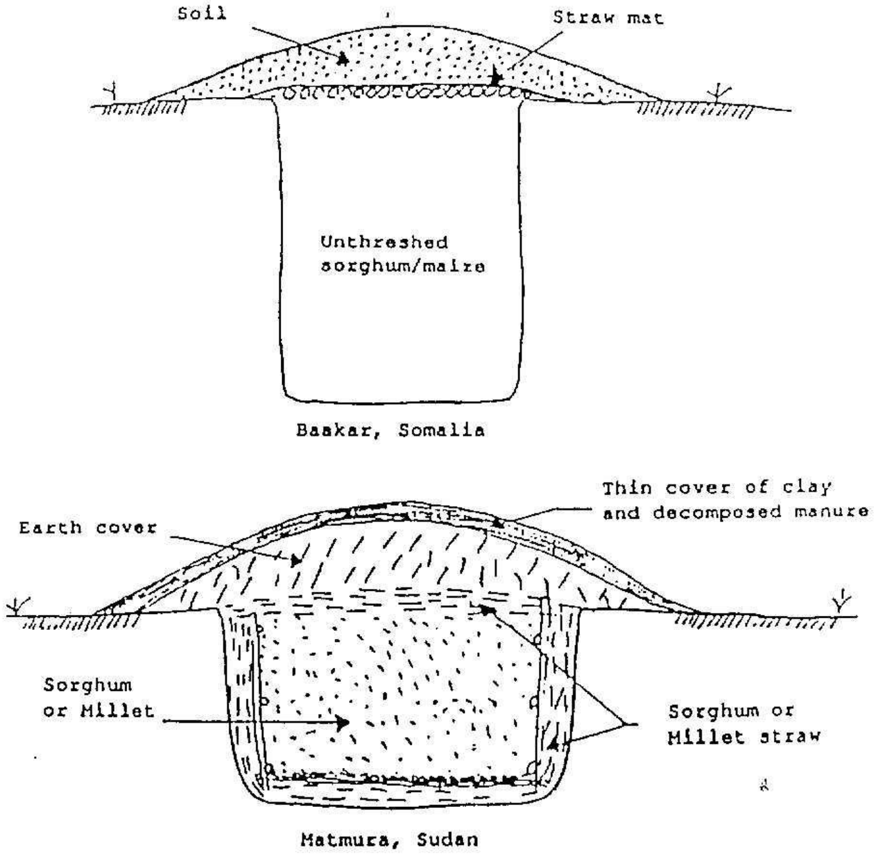

Figure 22: Traditional underground storage of millet and other grains.
(Source: Odogola and Henrikson, 1991)

3. Overall losses

3.1. Crop Loss Assessment Techniques

There are several approaches for estimating damage and yield losses in millets. One method, which has been successfully used in West Africa, involves the caging of individual panicles or whole plant stands into which a known number of insects are introduced (Krall *et al*., 1995). Apart from providing direct quantitative information on pest damage, this method can also be used to study pest activity. However, field trials and extensive surveys are necessary to obtain data on the extent of crop damage and yield losses. The crop loss assessment techniques can be classified as follows (Nwanze, 1988, quoted by Krall *et al*., 1995):
(a) Incidence ratio
(b) Visual score paired analysis

(c) Damage density loss ratio
(d) Quantitative assessment (insecticide trials).
Grain size for many millets is relatively very small compared to other grains, and this tends to reduce susceptibility to infestation by storage insects, but to increase the likelihood of loss by spillage and seepage from sacks, and also by contamination by sand or other foreign matter. Therefore, there are possibilities of difficulties of assessing percentage grain damage and consequent weight loss (McFarlane, 1995). Grain cleaning by sieving and winnowing may also be less efficient and more wasteful.
Damage to millet heads caused by the developing head miner larvae is very typical and is characterized by the presence of spiral miners developed by larvae during feeding. In mines caused by full grown larvae, there is a typical presence of white faecal pellets. Damage due to young larvae results from their feeding in the florets (floral glumes) initially, and this type of damage in not easy to detect unless the developing panicle is very carefully examined. The damage due to late instars can be easily detected because they feed on the base of the flowers or florets, which fall out, leaving the mines open. The early phase of this damage ca be detected by the uneven surface of the millet head as the developing larvae push florets/seeds from the rachis. (Youm, 1995).
In contrast, the bio-ecology of the scarab beetle *Rhinyptia infuscata* until recently is usually poorly documented due to the nocturnal feeding habits of this insect. Although *Rhinyptia infuscata* has been reported to attack millet in Niger (Guevremont, 1981 quoted by Youm, 1995) and in Senegal (Gahukar and Pierrard, 1983, quoted by Youm, 1995), it was not, until recently, that its pest status was recognized. Its population density has been reported to be about 500 000 adults per ha. The damage due to *R. infuscata* is more difficult to describe due to its nocturnal feeding habits and similarities with damages caused by other panicle feeding insects. The beetle is reported to feed on the stigmas of millet, resulting in empty spikelet (ICRISAT, 1990, quoted by Youm, 1995). It also feeds on flowers, often resulting in empty glumes.

4. Pest control

4.1 Pest species

The number of insect pests known to attack pearl millet is variable, and in West Africa, the number of species is estimated to range between 81 and over 150. Despite the list of many species reported as pests or potential pests, the number of species classified as major pests of economic importance is apparently less than a dozen (Mwanze and Harris, 1992 quoted by Youm, 1995) with the millet head miner (*Heliocheilus albipunctella*) ranking second to non in all insect pests (Youm, 1995).
The main pest of millet panicles found in Mali in the period 1985-1990 were:
The millet head miner, *Heliocheilus albipunctella* de Joannis (Lepidoptera, Noctuidae). Six major grasshopper species (Orthoptera, Acridae): *Oedaleus senegalensis* Krauss, *Kraussaria angulifera* Krauss, *Hieroglyphus daganensis* Kraus, *Cataloipus cymbiferus* Krauss, *Diabolocantatops axillaris* Thunberg, and *Kraussella amabile* Krauss. The control of pests which millet panicles can be achieved by spraying the crop with 50 percent (w.p) carbaryl at 3 kg/ha in 600 litres of water (FAO, 1972).
Two major genera of flower-feeding beetles (Coleoptera): *Pachnoda interrupta* Olivier (Scarabaeidae), chafer beetles, and three species of *Psalydolytta* (Meloidae), blister or oil beetles often referred to as "cantharides" in Francophone West Africa.
Pachnoda interrupta and *K. Amabile* are diurnally active and not attracted to light. Their populations were in the fields during daylight (Ago, 1995).

The grains of pearl millet are sufficiently large for the destructive attack by the major pests such as *Rhyzopertha dominica* and *Trogoderma granarium* (McFarlane *et al*., 1995). For this reason, the popular concept that millets are hardly susceptible to damage by storage insect pests is erroneous, except for the very small grained millets such as tef and fonio. Another factor contributing to a general myth that millets are immune to susceptibility to insect pest attack is the fact that millets are grown in semi-arid climates, where stored grain is typically very dry, with moisture contents often in equilibrium with humidities below 40 percent. In such conditions, the warehouse moths and most secondary beetle pests do not thrive. However, the major pests *R. dominica* and *T. granarium* are relatively well adapted to extremely dry conditions and will cause serious damages (McFarlane, 1995).
The control of such pests as *Rhyzopertha dominica* (Lesser grain borer) and *Trogoderma granarium* (Khapra beetle) may be achieved through sealed storage e.g. in drums or underground storage. In Sudan for example, an underground storage may carry up to 30 tonnes of grains.
Alternatively, Khapra beetle may be controlled by dusting the grains with Pirimiphos Methyl (Actellic) which has a wide spectrum of activity against beetles, bruchids, moths and mites (Odogola and Henriksson, 1991).
Population control of *Rhyzopertha dominica* and *Trogoderma granarium* during drying of millet can be achieved by lowering the drying temperature. For example, the optimum reproduction temperature for *Rhyzopertha dominica* is 30-35 ^{o}C. Therefore, a temperature around 21 ^{o}C could check reproduction and therefore control the pest (Odogola and Henriksson, 1991). Likewise, *Trogoderma granarium* reproduces well in temperature range of between 33 and 32 ^{o}C. Lowering this temperature to around 22-25 ^{o}C during drying would check the reproduction.

4.2 Relative status of major pests species

A comprehensive table of the pests, their scientific names and remarks is given in Table 12. According to a study conducted in Bangladesh on small millets, Majid *et al*., (1989) reported that stem-fly (*Atherigona miliaceae*) was the major pest, but its damage was greater on Proso than on Fox tail millet. They reported that the extent of damage might vary from 15-25 percent depending on the year, location and genotype. The other minor insect pests that they reported in the millet fields are stripe borer, pink borer flea beetle, aphid and pentatomid bug. Commonly found diseases on millets, which they reported were: Foot rot (*Sclerotium rolfsii*), leaf blast (*Pyricularia setariae*) leaf spot (*Helmithosporium sp*.), leaf and sheet blight (*Drechslera* sp.) And grain spot (*Phoma* sp., *Fusarium* sp. and *Curvularia* sp.)
Foot rot caused by Sclerotium rolfsii was reported to be an important disease and mortality is high on millet. The cultivars Bpm-52, Islampur and Telipara of Proso millet and Parameshpur and Shibnagar of Foxtail millet were found to be resistant to this disease in screening tests. Small millets are vulnerable to different spectra of field pests and diseases (Rao, 1989). Finger millet is more vulnerable to diseases like blast and viruses and barnyard millet to smuts (Rao, 1989). Little and proso millets are more susceptible to pests like shoot fly while bores occur on finger and barnyard millet. The incorporation of genetic resistance offers the best choice in low
input crops like small millets. Cultural controls like early planting and appropriate cropping systems could also reduce the pest and disease incidence.
The insect problems on pearl millet are of less importance than on sorghum. The major problems are from stem borers; this is also true for finger millet. There is a head girdler that produces a spiral - like effect moving length-wise up the pearl millet head. Ins some conditions, army-worms and aphids can be a problem. The species are essentially the same as

on sorghum, and are similar. Soft grain pearl millet is more subject to attack than hard grain (House *et al*., 1995).

Rodents like rats and mice are also an important pest of millet. They pose a keen threat especially in storage. For modern storage structures with plastered and sealed walls, rodents may not be too much of a problem. Also underground storage of sealed drum storage may keep away rodent attack. For most of the traditional storage structures, rodent attack is serious problem. They bore holes in bags and destroy the millet grains during storage. In addition to destroying the grains, rodents contaminate the grains with their excreta, thereby reducing the quality. In some parts of developing countries, such as Tanzania, Uganda, Kenya and Malawi, farmers use rat guards on mud-and-straw structures in order to check the infestation of rodents (Figure 23).

Weed pests

Striga hermonthica is an important weed pest of finger millet in East Africa. Control measures involve uprooting before seedling, crop rotation and the possible use of chemicals (Gupta *et al*., 1989). Insect and animal pests include: locusts and grasshoppers stem borers and foliage caterpillars.

Mycotoxins in millets

Compared to other grains such as sorghum, relatively few studies have been made on the mycotoxin content in millets (McFarlane *et al*., 1995). *Aspergillus terreus*, a producer of patulin, has been isolated from pearl millet. A lot of other toxigenic fungi have also been isolated. *Claviceps fusiformis* Loveless, which produces alkaloids, is widely distributed on pearl millet, and causes major reductions in crop yield and quality.

Table 12. Major and minor pests of pearl millet

Common name	**Scientific name**	**Remarks**
Soil insects		
White grubs	Lachnasterna longipennis Holotrichia consanguinea	Grubs feed on roots and kill the plants
Seedling pests:	Anomala sp.	
Shoot fly	1. Atherigona approximata Mall.	Serious pest in sandy areas. Cause dead hearts in central shoots.
Flea beetles	2. Chiloba acuta	Feed on tender leaves and stems.
Leaf feeding insects		
Cut-worms	Agrostis epsilon rotted *A. flammatra* Schiff.	Cut seedlings near the soil surface. Occasionally serious.
Army worms	Pseudaletia separata (Walk.) Leucania loreyi (Dup.)	These polyphagus insects damage a number of crops

Common name	**Scientific name**	**Remarks**
	Laphygma exigua (Hbn.)	generally feed at night. Occur in a number of countries.
Grasshopper Phadka	Hieroglyphus nigrorepletus Bo.	Polyphagus pest. Defoliate plants completely when serious.
Deccan wingless grasshopper	Colemania sphenareoides Bol	
Surface grasshopper	Chrotogonus sp.	
Hairy catterpillars	`	Emerge after rains, may cause severe loss by defoliation.
Red	Amsacta moorei	
Black	Estigmene lacinea Cram.	
Leaf roller weevils	Marasmia trapezalis Guen. Myrocerus granulosus Tanymecus indicus	Green active larvae feed on chlorophyll inside rolled leaf near tip.
Stem bores	Chillo zonellus (Swin.) Sesamia inferens (Walk.)	Very minor pest. Occasionally serious.
Sucking insects		
Aphids	Rhopalosiphum maydis Fitch. Aphis sacchari Zehnt.	Infest undersurfaces of leaves. Suck plant sap. Exude honeydew on which mould develops.
Shoot bug	Perigrinus maydis Ashm.	Remains near the base of leaves in colonies, sucks sap.
Mites	Oligonychus indicus (Hirst.)	Feed on underside of leaves, cause dark-brown spots.
Earhead pests:		
Midge	Geromvia penniseti (Harris)	Larvae damage developing seeds by feeding on ovaries.
Blister beetles	Lytta tenuicollis Pall. Gnathospstoides rouxi Cast Zonabris pustulata Th.	Adults feed on pollen and flowers.

Common name	Scientific name	Remarks
	Cantharis rufficollis Oliv.	
Flower beetles	Oxycetonia versicolor	Adults feed on flowers.
Earhead caterpillars	Eublemma silicula S. Stenachroia elongella	Caterpillars feed on soft maturing grains.
Birds		
House sparrow	Passer domesticus (Linn.)	Feed on maturing grains.
Yellow throated sparrow	Petronia xanthocollis (Burt.)	

Source: FAO, 1972.

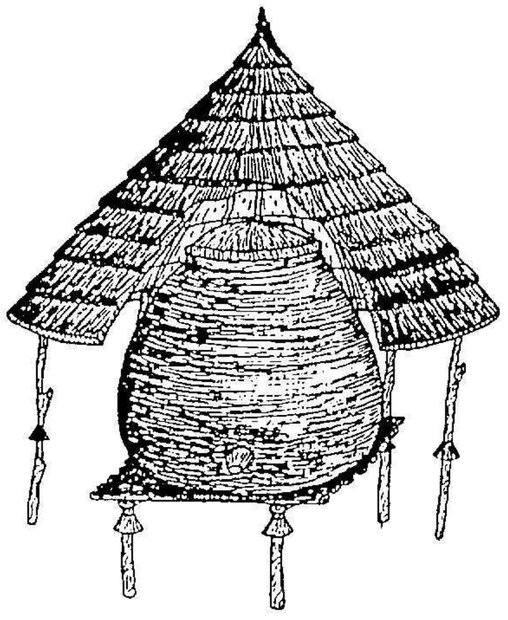

Figure 23: Traditional underground storage of millet and other grains.
(Source: Odogola and Henrikson, 1991)

5. Economic analysis and social considerations

Future world trade in millet is very difficult to project because of its small size, the unknown volume of unrecorded trade and uncertainties regarding supply and demand. If large surpluses of millet become available in come countries (for example Western Africa), trading opportunities in those regions would increase. However, in view of the huge distances and the high transportation costs, and the large variability of tradable volumes, any significant trade expansion is unlikely. Most international trade in millet up to the year 2005, therefore, is envisaged to remain largely restricted to border transaction among developing countries and limited but regular purchases by the developed countries as in the past (FAO and ICRISAT, 1996).

5.1 Other

5.1.1 Gender participation in production and processing of millet

It has been reported that women make 51 percent of the agricultural labour force of the world. A study of the household division of labour in Bangladeshi villages found that women worked 12 hours a day compared to 10 hours a day worked by men in the same villages. In Africa and Asia, women work 13 hours more than men do each week. The women duties involve, among others, all the agricultural activities such as land preparation, sowing, weeding, harvesting, threshing, drying, pounding, food preparation for the family, fetching water and firewood and water, looking after animals, taking care of the children, to name but a few.

In an endeavour to relieve women of the tedious and time-consuming exercises of pounding in order to dehull and grind millet (and other cereal) grains, some machines were manufactured and introduced in rural areas of some developing countries. One such example was the introduction, in the rural areas of Arusha, Tanzania, of the TDRI Bicycle and Pedal mill (TDRI stands for Tropical Development Research Institute based in England) (UNIFEM, 1998). The TDRI mill was originally intended to be used on a bicycle, which the villager already owned. Thus, if a villager had no bicycle, he or she could not use the mill. The performance of the TDRI mill was unsatisfactory because the men in the villages considered grinding cereals to be a waste of a good bicycle, and they took off the bicycle and used it for other "meaningful" purposes. They viewed pounding as women's work, and could not see any value in using the bicycle to help women to do that job (UNIFEM, 1998). Again, women were not prepared to use bicycles for milling, because, traditionally, it is men who ride bicycles, and village women found it embarrassing to do so. Sometimes, women got down on to their knees and turned the pedals with their hands, rather than ride (UNIFEM, 1998).

Another endeavour that was undertaken in Tanzania, by the Community Development Trust Fund (CDTF) with an attempt to lessen women burden of pounding grains, was the introduction of diesel mills in rural areas. These were popular, but required a big component of initial capital investment. As such, many broke down, and only a handful remained operational. Women found themselves either spending a lot of time and energy walking to and from (and invariably waiting at) the nearest diesel mill, or continuing to use the slow and difficult methods which have not been improved upon for generations (UNIFEM, 1998).

In an endeavour to solve this problem, there was an introduction of hand-grinding mills project. A principle objective of the project was to encourage and facilitate the participation of women. The CDTF wanted to prevent the introduction of hand mills from having a negative effect on women. For example, in the vast majority of the diesel mill projects, women were reduced to passive recipients of a service, which was entirely controlled by men. However, the idea of treating the project as a "women only" activity was rejected because of the fear that this would isolate women from the mainstream of village (and national development).

Another case study involving gender participation in processing of millet and other cereals was carried out in Senegal (UNIFEM, 1998). The study reported that traditional threshing of large amounts of grains was done by a work group or "*santanee*". The village women respond to an invitation to help thresh one woman's grain and bring a full tub or two of their own millet to be threshed at the same time. The *santanee* usually takes the whole day, with some women coming and going, as their other responsibilities require. Payment to the threshers includes a day's meal, with an assurance that they will also be able to recruit help when they have a large threshing task.

With the arrival of the thresher, dehuller and mill project in the village, the threshing of the family. s grain became the financial responsibility of the men. This was probably due to the heavy work involved in bringing bundles of grain heads to be threshed, and subsequent handling of the large quantities of threshed grain. The women were the immediate beneficiaries in this case, being freed from both the manual threshing and the expense of employing the machine. It was hard to tell why the men took the threshing activity upon themselves with the advent of the machines. Yet for the they did not feel their responsibility extended as far as mechanical dehulling and milling of small amounts of millet for daily consumption as a task worth of their attention, although they would pay for millet processing destined for sale.

Users of the mechanical grinder for millet fell into two general categories: regular and irregular users. Paying for the services of the grinder was, in many households, the wife's responsibility. If she had some cash, she would have that day's millet ground by machine, and, if not, she would pound. These women were the irregular users. Those women whose husbands paid for the use of the grinder were the regular users and pounded only on days, which the mill was not in operation. Many women brought their grain to the centrally located mill on their way to perform some other tasks such as drawing water or fetching fire wood, and returned later to pick up the flour.

In case of dehulling, very few women used the dehuller because they found it expensive. Most women could afford either dehulling or milling (not both). They preferred to pay for machine milling rather than dehulling because milling by hand was much more time consuming and tiring a task than dehulling by hand. Machine dehulling and milling resulted in a product of lower quality, containing more bran, than the flour produced by hand dehulling and subsequent machine (or hand) milling.