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CHAPTER VI WHEAT: Post-harvest Operations

2.2 Harvesting

2.3 Transport

2.4 Threshing

2.5 Drying

2.6 Cleaning

2.8 Storage

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2. Post-production Operations

Although post-production operations vary from country to country and region to region throughout the world, procedures are similar among the developing countries. However, operations diversify with farm size such as small landholders, medium scale farmers and progressive growers. Post-production operations will be dissimilar between the developed and developing countries. Functions like harvesting, transportation, threshing, cleaning, drying, storage, packaging and marketing are described below.

2.2 Harvesting

A major proportion of the crop in Asia is harvested manually using sickles (over 70 percentage in Pakistan, India and Bangladesh - Figure 2) or with types of knives leaving 3-6 cm wheat straw above the ground level. Methods and timing of harvesting are important factors to total crop yield. In South Asia wheat is harvested in the dry summer months from March to May. Farmers are conscious of the fact that the harvested wheat should be dry enough for threshing and storage. Artificial drying is uncommon. The manually harvested wheat crop is tied into small bundles and stacked in bunches of 10 - 15 bundles, which are left in the field for one to three days to dry (Figure 3). Combine or mechanical harvesters (Figure 4) yield a higher proportion of immature grains and pose a moisture hazard, leaving no time for the grain to dry.

Figure 2: Woman harvesting wheat manually 

Figure 3: Manually harvested crop left to dry on the field 

Figure 4: Mechanical harvester 

2.3 Transport

Labour-intensive systems of grain movement serve to minimise capital investment in countries where the cost of labour is low. Most wheat is manually loaded and unloaded from wagons, trucks, railroad cars, and barges between farm and mill. The greater the grain loss the higher the cost. In some situations, bagged wheat may be loaded on and off vehicles ten times manually before it is milled.

Highly efficient bulk handling systems exist in developed countries to load loose wheat into trucks. Using an auger, wheat is moved to the grain-processing centre in a single trip, dumped into a receiving bin, carried by a mechanical conveyor through the cleaning and drying processes and into storage. Next, it is moved out of storage into the flour mill at the same location, where the finished flour is mechanically bagged, loaded into trucks by elevator, and taken to a commercial bakery or retail market without once being handled manually. National policy regarding the appropriate degree of mechanical wheat handling is often based on the need to maximise employment for unskilled labour.

In South Asia post-harvest handling, transport and storage of grains at the farm level is done partially in bulk. The transportation of grain to primary markets by the farmers is also done in bulk using bullock carts, tractor trolleys or lorries. At the market yard, the grain is displayed in bulk, auctioned, cleaned, bagged, weighed and delivered to consumers in bags. The food grain trade depends upon labour. Therefore, handling, transport and storage of marketed grains in bags is common. Availability of cheaper jute bags in these countries also encourages handling, storage and marketing of grain in bags. Large quantities of food grain have to be moved through rail or road transport, another major factor promoting use of bags.

From farms in Pakistan, wheat is mainly transported in animal driven carts or carried on camelback. Large farmers use tractor driven trolleys and trucks. In each case bags are used for transportation. Problems arise when old torn bags are used which spill grain, causing loss. Mostly 100-kg bags are used which are cumbersome to carry. Other hazards for bags are hooks which tear the bags, the rough surface of the carts and trolleys and nails, which damage sacks when they are pulled. Transportation occurs from farm to market, market to consumer, market to temporary storage, temporary storage to long term storage and long term storage to consumers.

2.4 Threshing

The sheaves of wheat are carried to the threshing floor manually or on the backs of animals like camel donkeys and bullock (Figure 5). Tractor trolleys and bullock carts are mostly used for transporting harvested wheat crop to the threshing floor where they are spread out to dry in the sun and wind for a few days. The threshing and separation of the grain from the straw is done in a variety of ways. The wheat crop may be beaten with sticks or trampled by a bunch of animals. Animals may be used to draw a wheat bundle/stone roller over the thick layer of harvested wheat crop. Or, an implement consisting of a series of steel disks may be used. In some locales, a tractor may be repeatedly driven over the wheat stack spread on the threshing floor.

Figure 5: Animal transport to threshing floor 

The tractor-drawn thresher (Figure 6) and self-propelled harvester combine causes the least grain contamination, but are capital intensive solutions. Farmers, who cultivate only one or two hectares a season, hire small threshers, which are, light enough to be carried from one field to another by two people. Pedal or motor-driven mechanical threshers have been devised. One type has a revolving drum with projecting teeth that strip off the grain when a sheaf of wheat is held against the moving surface.

Figure 6: Tractor-drawn thresher 

After threshing, the straw (*bhoosa*) is stacked around the threshing floor (Figure 7), and used as animal feed, bedding, cooking fuel, to make sun-dried bricks, or compost. The wheat grain will be contaminated with pieces of straw chaff, broken grains, stones, and dirt when it is spread on the threshing floor for further drying.

Figure 7: Straw stacks around the threshing floor 

Labour saving schemes are employed in some farming communities. An old and simple improvement in threshing is to beat a sheaf of wheat and the grain heads against a low wall, an oil drum, or a wagon bed. This method is more efficient than trampling as the grains fall into a container or onto a woven mat. Small quantities are threshed but are less likely to become contaminated.

In many developing countries manpower is shifting from cereal production to cash crops or to industry causing a dearth of manpower in the urban areas. However, by tradition, the whole family participates in the harvesting and threshing process together with borrowed or hired labour. Women also join in these activities. In places where mechanical harvesters are used women do not participate. Labour prefers to be paid in kind than in cash. In typical communities, the farmers share resources of the village. Manpower reciprocates labour in the harvesting and threshing schedule. Whenever threshing is by bullocks, the community shares the threshing floor and animals.

Threshing is mainly mechanical (60-80 percentage) in Pakistan. Tractor-driven threshers and at times combine harvesters are used. The design and maintenance of the thresher are central to reducing the broken grain percentage. Threshing using animals is also common in many areas of Pakistan. Several animals continuously walk around a pole to crush the wheat straw and heads to separate the grains and convert the straw to *bhoosa*.

2.5 Drying

The most critical decision in harvesting is not the degree of mechanisation but the timing of the harvest. If the harvest starts late, the grain becomes too dry and rate of grain shattering is high. The longer a ripe crop is left in the field or on the threshing floor, the higher will be the loss from natural calamities including hailstorm, fire, birds, or rodents. The moisture content of the grain will be high, making drying difficult if the harvest start too early.

The moisture content of wheat grain is a crucial factor from harvest until milling. Moisture content of 25 percentage is not uncommon in newly harvested grain in humid areas but it must be dried immediately to protect it against mould. At 14 percentage moisture grain can be safely stored for 2 to 3 months. For longer periods of storage from 4-12 months, the moisture content must be reduced to 13 percentage or below.

Drying in many wheat-growing countries of Asia, Africa, and Latin America is done by spreading a thin layer of grain in the sun, on the threshing floor or on rooftops. Mechanical drying of wheat grain is not practised in most of the developing countries. It is mostly sun dried. Sun drying is risky because it depends on weather conditions leading to dirty grain, spillage loss and bird attack.

Each small farmer cannot afford mechanical equipment for cleaning and drying, but as a co-operative they could own such equipment. Some commercial grain buyers or government warehouses offer to accumulate the grain of small farmers, bulk, clean, and dry it with modern equipment. Unfortunately these services are rare in developing countries.

As the weather is quite warm at harvest, the moisture content of the grain (Pakistan) is below 10 percentage. During the rainy season moisture content slowly increases to 15 percentage. Deterioration of grain is closely related to the moisture content which is key to safe storage. Temperature and relative humidity influence moisture content of a stored product. The moisture content of wheat in Pakistan when first stored is usually low. In areas where there is heavy rainfall during summer, the relative humidity and grain moisture content increases.

The wheat delivered from the farm at harvest to the village market or to a government food corporation presents different challenges. Since mills need to be able to hold sufficient grain for 30 to 60 days of milling this wheat may be kept in sheds, large steel bins, concrete silos, or in the holding bins of a flour mill. Wheat may be temporarily stored in railroad cars or in open piles in market towns where protection is little better than on a village-threshing floor.

2.6 Cleaning

After threshing, the straw, chaff, immature grains, sand, stones, and other substances are separated from the grain by sieving, winnowing or hand picking. In traditional manual winnowing, a shallow basket containing grain is held overhead, and the grain is tossed during periods of fast winds. Lighter weight broken grain, straw, and weed seed are carried by the wind to one side, as the whole grain falls to the bottom of the winnowing device. The winnowing device may stand on a stool to give the falling grain longer exposure to the wind. Manual winnowing requires a continuous brisk wind and several repetitions. Even then, the results are erratic producing grain, which is far from satisfactory. Wheat cleaning is most often done manually by women, occasionally by professionals.

Simple, low-cost appliances that use hand-driven or motorised blowers have been developed that are more efficient and less time consuming than hand winnowing. A FAO publication on processing and storage of food grains by rural families describes grain mills, flourmills and sophisticated grain cleaners. Lending agencies that finance grain storage facilities can provide advice on appropriate cleaning equipment.

2.8 Storage

In South Asia and most of the developing countries, farmers for their own use for food, cattle feed and seed retain about 50-80 percentage of the grain produced. The farmers generally store their grain in simple granaries constructed from locally available materials like paddy straw, split bamboo, reeds, mud and bricks. A majority of wheat is stored in bags in a room, bin, drum or container for family consumption or is piled in farm buildings lacking proper flooring, closed doors and windows. Wheat is lost to moulds, birds, rodents, and insects. Storage varies in size and type including indoor, outdoor, above-ground, under-ground or airtight structures. Some conventional storage structures used by the farmers in Asia are:

1.Mud structures mostly bins or pots

2.Wood or Bamboo structures

3.Metallic drums, bins or containers

4.*Kothis* (small rooms)

5.*Bokharies* (straw structures)

It has been estimated that in Pakistan about 70 percentage of wheat is stored at farms in bags. The balance is stocked in the market and public sector storage partially in bulk. Wheat storage is primarily assigned to the public sector for food security.

Provincial Food Departments, Federal Food Directorate, Defence Department, National Logistic Cell and Pakistan Agricultural Supply Corporation are main public agencies, which are responsible for food security, using storage structures including house type sheds, *binnishells*, and silos. Some wheat is also stored in the open and covered with tarpaulin or polyethylene.

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CHAPTER VI WHEAT: Post-harvest Operations

3.1 Wheat loss factors

3.2 Public sector storage loss

3.3 Farm storage loss

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3. Overall losses

Depending on level of the self-sufficiency of the country the marketable surplus of food grain varies by factors comprising farm and family size, productivity and other parameters. In Pakistan, it is generally estimated that approximately 65 to 75 percentage of total wheat produced is stored at the farm. Smaller farms generally keep more grain for consumption. It is estimated that the quantity of wheat entering commercial channels from farms up to maximum 4.5 ha in size is negligible. Nationally, the 4.5 ha farm is worked by about 65 percentage of the farmers, who occupy 35 percentage of the cultivated land.

The major food grains are usually stored at the farm in specially constructed mud bins, protected by a cover, inside the house or in the open courtyard. Wheat may also be stored as a heap covered by straw, mud and dung plastered, loose in a room, or in bags, metal bins, baskets and pots. These widely contrasting storage practices may explain the range of storage loss in Asian countries.

The global emphasis on increased food production has been on the development of modern technologies relevant to the pre-harvest activities. The emphasis on achieving a significant reduction in post production food loss gained momentum from the World Food Conference in 1974 and the resolution passed at the 7th special session of the United Nations General Assembly in 1975.

Reports by a FAO Food Security Mission in 1980 and a World Bank Grain Storage Project Mission in 1981 in Pakistan, drew attention to the potential seriousness of farm storage loss, particularly for wheat. It was noted that considerable loss caused by insects, and to a lesser extent by rodents and fungi, occurs when grain is stored for three months or longer. Relatively low levels of insect damage may result in the rejection of a large amount of potential food material at the cleaning/food preparation stage. FAO, therefore, has been instrumental in developing action plans to reduce loss in grain after harvest through loss assessment, technology transfer and development of expertise via information dissemination.

3.1 Wheat loss factors

Loss is defined as a measurable decrease of the food quantity and quality. Loss should not be confused with superficial damage generally due to deterioration. Quantitative loss is physical and can be measured in weight or volume, while qualitative loss can only be assessed. Quantitative loss, qualitative loss, nutritional loss, seed viability loss and commercial loss may gauge this reduction.

The major biotic factors influencing wheat loss during storage are insects, moulds, birds and rats. The major insect species known to infect wheat include Khapra beetle, *Trogoderma granarium* Everts; Lesser grain borer, *Rhizopertha dominica* (F); Rice Weevil, *Stitophilus oryzae* (L.) and Red flour beetle, *Tribolium castaneum* (Hbst). All these insects may be found extensively in most developing countries to different extremes. Other insect species are recognised storage pests that also infest stored wheat like Angoumois grain moth, *Sitotroga cerealella* (Oliv.); Rice moth, *Corcyra cephalonica* Straint; Saw toothed grain beetle *Oryzaephilus surinamensis* (L.); Long headed flour beetle *Latheticus oryzae* Wat.; Flat grain beetle *Cryptolestes pusillus* (Schoen).

Biotic factors including temperature, humidity and type of storage all affect environmental conditions in storage. High temperature causes deterioration, while low temperature is good for storage. High temperature accelerates the respiration of grain, which produces carbon dioxide, heat and water, conditions favourable for spoilage. Humidity equally impacts grain storage. Increasing humidity increases spoilage, while decreasing humidity is good for storage.

The type of storage plays a fundamental role in storage efficiency. If a concrete or mud storage structure can absorb water or allow the water vapours to pass through, in the case of a jute bag, the bio-chemical changes and mould attack are minimal, but the risk of insect infestation increases. Sun drying or turning of food grain has many advantages as it provides an opportunity for inspection and precautionary measures to avoid spoilage. Aeration greatly minimises mould growth, insect activity, and respiration of the seed. Further aeration provides a cooling action and equalises the temperature throughout the mass of the grain stored. Bad odours developed by stored grains can be easily and effectively removed.

Climate conditions, grain conditions at storage (presence of infestation, moisture content, foreign matter content), the period of storage, grain and pest control practices all contribute to the rate of loss caused by insects and mould growth. As these factors interact, it is difficult to isolate them or identify one factor, which has a direct influence on loss. Average statistics for loss, whether for store types, areas, or quantities of grain stored are inconclusive. An average figure for loss for a region or a country holds no significance unless a decision regarding a new system of storage, or new pest control techniques is required. Nevertheless average loss figures are always sought. The loss figures consist of the following:

-The weight loss which occurred during storage = The difference between the condition of grain at the end of the storage period, compared to the condition at initial storage

-The weight loss, which happened before the grain was stored (Note: some of the grain under study had been stored elsewhere for an unspecified time).

3.2 Public sector storage loss

A preliminary review of public sector storage facilities in Pakistan by the author during 1984-85 confirmed the widely held view that loss due to insect infestation, mould growth and the activities of birds and rodents were often serious. The review also concluded that insect pests are most important. The survey of storage loss during 1984-85, therefore, focussed upon the measurement of weight loss caused by insects and mould growth (Table 5)

Table 5: Estimates of Storage Loss in various Provinces of Pakistan

Province	Average Storage Period (months)	Loss percentage			Total
		Insect		Moulds	
		Pre-storage	Storage		
Sindh	6.4	0.1	2.9	0.3	3.3
Punjab	6.3	0.1	1.8	0.3	2.2
NWFP	6.5	2.9	2.6	0.7	6.2

Baluchistan	2.6	0.5	1.2	0.5	2.2
Pakistan	**5.4**	**0.9**	**2.1**	**0.4**	**3.5**

Source: Baloch, U. K. et. al . *1994, Loss Assessment and Loss Prevention in Wheat Storage ... in Pakistan.*

in Stored Product Protection *ed. Ed Highley, CAB. International. Pp 906-10*

Loss due to insect infestation occurs in all regions, but is higher in grain stored at Karachi in Sindh and in Peshawar in NWFP. The higher loss at Karachi may be caused by generally favourable temperature and relative humidity, which are also conducive for insect growth combined with the difficulties in fumigating such large sheds. When the additional loss is taken into account from Peshawar (NWFP), the average loss due to insect pests during storage in two-year-old wheat was 8.9 percentage, with loss in individual cases as high as 15 percentage.

Mould damage is not a serious problem in countries like Pakistan, where wheat stored at procurement is usually dry at 10 percentage moisture content or less. During the rainy season the moisture content of stored grain may rise, but the average moisture content is rarely above 13.3 percentage. The loss figure due to mould measures the amount of grain, damaged so badly that it was regarded unfit for human consumption. Mould damage in tropical or humid countries is indicative of defects in storage structures and moisture migration due to insect activities.

Grain stored in the open covered with tarpaulin sheets, is always at risk and such stocks of grain suffer heavily. Some stacks of grain inside the shed are also damaged by mould because of rainwater. Occasionally rain enters through open or broken windows or through doors opened to allow ventilation and not closed in time. Wheat stored in bins is susceptible to localised mould damage, particularly in the surface layers. This results from condensation on the inner side of the metal manhole covering the top of the bin. Moisture migration following the activity of insects is common in bulk stored grain, but it is also noted in bag stacks.

3.3 Farm storage loss

A 1983 review by the author in Pakistan confirmed a broad variability in the reported estimates for wheat loss at the farm level and the need for quantitative data to base a loss reduction program. Following this was a preliminary survey, which provided an excellent record and understanding of the operation of post-harvest activities at the farm and village level. It also clearly demonstrated that farmers are concerned about the loss of grain occurring during long-term storage. While there was a need to establish reliable estimates of storage loss, there was already evidence to suggest that certain farm households were losing considerable quantities of grain to insects. The survey drew attention to the urgent need to formulate a suitable extension package on good storage management directed to both men and women.

Loss assessment surveys were conducted to determine the harvest loss from shattering of grain, loss of panicles and other effects, threshing loss and the amount of grain lost to rodents in the period between harvesting and storage. Based on the total quantity of wheat harvested, 0.35 percentage was lost during harvesting, 1.24 percentage was lost during threshing and 0.15 percentage was lost during temporary storage. Losses during harvesting are related to the degree of maturity of the crop at harvest and to delays in harvesting. Such losses are difficult to reduce. Although this represents a private loss to the owner, some of this grain will be recovered by those permitted to pick wheatears in the harvested field. Losses during threshing are operations-related and may be eliminated with a better adjustment of the thresher to limit the amount of grain lost with the straw.

3.3.1 Loss assessment survey

A socio-economic survey in Pakistan in 1984-85 confirmed that insect infestation was the most significant cause of loss in storage. Approximately 55 percentage of the households sampled regarded this as a major problem, while 15 percentage responded that it was a minor problem. There was inconsistent information provided when data from the farmers about perceived loss was compared with that provided by women. According to women respondents, the perceived storage loss due to insects in rain-fed and irrigated areas are about 4.0 percentage and 3.6 percentage, respectively, similar to the results obtained in the loss assessment survey. However, the actual food loss is likely to be far greater, since more than 80 percentage of the respondents admitted to discarding damaged grain. Of this group, approximately 30 percentage stated that the grain would be destroyed while others questioned would use the grain for animal feed.

The perception of losses by those directly concerned with storage management is a useful indicator to assess motivation for adopting new techniques for loss reduction. The results of the survey indicated that motivation is high. Most of the respondents felt that there was a need for additional advice on better pest control methods. Few suggestions were made for new types of storage containers; those who did referred to metal or concrete bins. Financial constraints limit the adoption of new storage structures.

While the traditional storage systems restrain loss to a low level, the introduction of new varieties of grains has placed an extra burden on those responsible for grain conservation, specifically the women members of the community.

3.3.2 Loss assessment studies

In Pakistan, wheat is commonly stored in jute bags, *bharolas* (containers of mud, plaster and straw), *kothis* (rectangular grain stores of mud, cow dung and straw) and open rooms. In the rain fed area, 90 percentage of farmers use jute bags, whereas, in the irrigated area, 42 percentage use jute bags and 44 percentage use mud bins. A small number of farmers in both areas use metal bins. The losses in the different storage types range from 0.1 percentage to over 10 percentage. Such wide variations are not unexpected, as the extent of loss will depend upon the quantity stored, the storage period, the consumption pattern, the condition of the grain at storage and the pest control methods used. The levels of insect infestation and of damaged grain were highest in jute bags. The average weight loss recorded in the different storage facilities is given in Tables 6 and 7.

Table: 6 Average weight loss (%) in different types of stores

Type of storage	Rain fed area	Irrigated area
Jute bag	3.1	6.6

Mud bin	2.3	6.1
Open Room	2.2	5.5
Metal bin	2.1	2.0

Source:Baloch, U. K. et. al . 1994, Loss Assessment and Loss Prevention

in Wheat Storage ... in Pakistan. In Stored Product Protection ed.

Ed Highley, CAB. International. Pp 906-10

Table: 7 Storage containers used by farmers (%)

Storage Container	1984-85		1985-86	
	Irrigated	Rain fed	Irrigated	Rain fed
1. Sacks	43.04	90.00	32.50	78.83

2. Metal Bin/Box*	3.37	4.59	4.08	13.75
3. Bharola/Mud bin	27.00	2.92	28.75	2.00
4. Other Storage	26.59	-	32.25	4.59

Source:Baloch, U. K. et. al . *1994, Loss Assessment and Loss Prevention in Wheat Storage ... in Pakistan. in* Stored Product Protection *ed. Ed Highley, CAB. International. Pp 906-10*

*As a result of the project activities the trends of adoption of improved storage techniques (metal bin) in rain fed areas have increased as compared to irrigated area during 1985-86.

In India the Pansay Committee estimated post harvest loss at 9.3 percentage, of which an estimated 6.6 percentage was attributed to storage loss The breakdown of storage loss for food grains was 2.55 percentage for insects, 2.50 percentages for rodents, 0.85 percentage for birds and 0.68 percentage for moisture. The Administrative Staff College of India (ASCI) Hyderabad in August 1976 calculated the following storage loss estimates (Table 8).

Table: 8 Estimated Storage Loss (%) of Food-grains

Cause	Farm level	Trade	Public Agencies	
			Sheds	Silos
Insects	3.4	3.4	0.5-1.0	0.5
Rodents	0.5-1.0	0.3-1.0	Neg.	Nil
Birds	Neg.	0.2	0.2	Nil
Moisture	Neg.	0.2	0.2	0.2
Others	-	0.3	0.3	Neg.
Total	**5**	**6**	**1.3-1.7**	**0.7**

Source:Sawhney, K. L. 1988. Post Harvest Handling and Storage of Food Grain in India. Workshop on Bulk Storage of Food Grains. FAO. Hanzhu, China.

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CHAPTER VI WHEAT: Post-harvest Operations

4.1 Pest species

4.2 Pest Control

4. Pest Control

Similar insects infest wheat during storage in the public sector sheds and the farm level. However, the population dynamics of different insect species varies with the factors affecting storage.

4.1 Pest species

Rice weevil (*Sitophilus orzae L.*) is the dominant pest of stored wheat causing grain damage from 2-5 percentage. Most damage is caused during Monsoon season plus the couple of months following monsoon. It feeds internally, reducing the weight and degrading the quality of the grain. For instance the grain may become humid, hot, and unfit for human consumption.

Lesser grain borer (*Rhyzopertha dominica*) is also a destructive pest causing damage throughout the country. Adults and larvae feed inside the grain. This reduces the weight and degrades the quality. The lesser grain borer is most abundant in humid climates and whenever the moisture content of wheat is high.

Khapra beetle (*Trogoderma granarium*) is a widespread but sporadic pest. It causes extensive damage in conditions of high humidity and high moisture content. Red flour beetle (*Tribolium castaneum*) and Rice moth (*Sitotroga cerealella*) also cause significant damage to wheat.

4.2 Pest Control

Pakistani farmers attempt to control insects using sun drying, applications of available insecticide, phosphine producing compounds (e.g., Phostoxin), elemental mercury and *neem*, a natural material of plant origin The use of pesticides is more common in the irrigated areas where 13 percentage of farmers use insecticides and fumigants and 41 percentage treat the grain with mercury. Although some degree of control seems to have been achieved, most chemical treatments are unsatisfactory and can be dangerous to health. Moreover, the widespread and uncontrolled use of pesticides waste scarce resources when treatments are ineffective. The exposure of insect pests to sub-lethal doses may promote resistant strains of pest species.

The amount of grain lost to rodents provides further evidence of the need to control field infestations of rodents. The rat damage to wheat in upland valleys of both wet and dry mountains, where *Bandicota bengalensis* is a serious pest, has been estimated at 6.0 percentage in post harvest system. Some reports indicate that loss due to rats have been projected as high as 4-6 percentage and as low as one percentage. The private MICAS Associates in 1976 estimated 2.3 percentage wheat loss from rats at the farm level. Studies conducted by the FSM Project of USAID indicated that the rodent infestations at the village level and in the town market measure less than five percentage.

The use of tracking dusts of zinc phosphide (5 and 10 percentage), racumin (0.75 percentage) and liquid warfarin (0.025 percentage) was highly effective in reducing the populations by 80-90 percentage. With the use of these compounds 10-20 percentage greater yields can be achieved with a 50-fold return on the cost of investment.

4.2.1 Traditional Pest Control Methods

In south Asia the following are the most important methods practised at farm level during wheat storage:

Sun drying: The sun drying is the single most popular method of moisture reduction and pest control. Luckily the temperature during and after harvest of wheat provide for the initial kill of insects and reduce moisture in the grain. This helps to delay infestation of insects and formation of mould. The effectiveness of this method for small and large farmers alike is equally good. Small farmers are more efficient in drying their grain in small-scale storage. After 2 or 3 months of storage, they kill insects which might have developed during this period and eliminate any insect problem once they have carried out sun drying in August/September.

Use of Mercury: The use of mercury is a local tradition in South Asia for insect prevention in storage particularly in the Punjab provinces of Pakistan and India and nearby districts. Despite its potential hazards farmers have adopted the practise. No studies have been conducted to demonstrate the toxic effects of mercury on human and animal health.

Use of Neem: The neem tree (Azardirachta indica) is native to the Indo-

Pakistan sub-continent and grows abundantly in this region. Neem trees are plentiful in South Asia and certain other developing countries where farmers are aware of its properties. In a diagnostic survey, it is reported that food grain is mostly stored in gunny bags in which farmers sometimes mix dried *neem* leaves. Those who store wheat in mud bins, rub fresh *neem* leaves on the inside walls of the bins. In the districts of Nawabshah and Khairpur, in Pakistan Palli is commonly used for storage. Some farmers plaster its walls and top with mud having crushed *neem* leaves. In Rahim Yar Khan District, *neem* extract is sprinkled on the wheat straw packed at the bottom of Palli before placing the grain. In other areas, farmers treat storage bags with *neem* extracts before putting in the grain. Farmers presently utilise *neem*, mixing whole *neem* leaves with grain in gunny bags or in earthen containers. They also use ground *neem* leaf paste mixed with mud used for making mud bins. Empty gunny bags are soaked overnight in water containing 2-10 percentage *neem* leaves on a weight/volume basis, and the grain is stored in these bags after drying them. Most farmers rate the first method to be superior.

Considerable research has been undertaken on the properties of *neem* as grain protectant. However, most of this research has not been adopted for practical application on larger scale. The water extract of *neem* leaves was highly repellant to major stored grain insect pests. The *neem* seeds compared with the leaves, flowers, and fruits exhibited the maximum potency. Tests show that flour beetle, fed on *neem* seed extract treated at the rate of 800 ppm, failed to produce viable progeny; and their feeding was greatly reduced. Based on experiments, it is reported that 20 percentage of water extract of *neem* leaves can block the penetration of insects into treated bags (paper or cloth) for at least 6 months during storage.

4.2.2 Chemical Pest Control

The majority of farmers in developing countries belong to the subsistence group and often cannot afford the costly modern grain protectants. Fumigation with toxic gases is most effective in airtight structures and is only economical if carried out on a commercial scale. Even if properly applied, the fumigated grains are still liable to frequent re-infestation by insect pests. This technology is not yet applicable to the farm level in Pakistan because storage structures are not airtight and located inside or near residential areas where fumigation may be dangerous.

The admixture of insecticide dusts with grain can provide protection against insects, but pose a danger from their persistent harmful residues. Breeding of resistant strains of insects cannot be explicitly prevented nor can the high cost of environmental pollution be ignored. Moreover, application of insecticides requires sophisticated techniques and complicated calculations, which farmers cannot easily comprehend.

However, there are no traditional methods adopted for pest management, in the public sheds. Local market dealers or agents procure wheat directly or from the government. Wheat is transported using private trucks to the food department sheds, which can be privately hired storage facilities.

The storage loss studies and the socio-economic surveys provided the justification for a pilot-scale program of loss reduction. Since insects were the major cause of storage loss, the loss reduction activities focused on finding ways of successfully fumigating farm grain stores. Alternative methods of insect control, such as the admixture of insecticides with grain could not be considered since appropriate formulas are not available in Pakistan. The design of the local metal bin was modified in consultation with PARC's agricultural engineers to assist the manufacturers and farmers to produce a much stronger bin, more suitable for fumigation. The fumigation of small quantities of grain in bags was also tested in villages. The bags are enclosed in a polythene envelope, which is sealed after introducing the phosphine-producing compounds. If the polythene sheet is left in place after treatment, the risk of cross-infestation is significantly reduced.

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CHAPTER VI WHEAT: Post-harvest Operations

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CHAPTER VI WHEAT: Post-harvest Operations

7.1 Acronyms

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7. Annex

7.1 Acronyms

ACIAR	Australian Centre for International Research
CABI	Commonwealth Agriculture Bureau International

CIMMYT	International Maize and Wheat Improvement Centre
CIS	Commonwealth of Independent States
FAO	Food and Agriculture Organization of the United Nations
FSM	Food Security Management
ha.	Hectares
HYV	High Yielding Varieties
IRRI	International Rice Research Institute
Kg.	Kilograms
mmt.	Million metric ton
mt.	Metric ton
NC America	North and Central America
NWFP	North West Frontier Province

PARC	Pakistan Agricultural Research Council
ppm.	Parts per million
USA	United States of America
USAID	United States Agency for International Development
USSR	United Soviet Socialist Republic (now CIS)

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CHAPTER VII SORGHUM: Post-harvest Operations

1.2 World Trade

1.3 Primary product

1.4 Secondary and derived product

1.5. Requirements for export and quality assurance

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1. Introduction

Sorghum, *Sorghum bicolor*(L) Moench, is the fifth most important cereal after rice, wheat, maize, and barley. It constitutes the main food grain for over 750 million people who live in the semi-arid tropics of Africa, Asia, and Latin America. The largest group of producers are small-scale subsistence farmers with minimal access to production inputs such as fertiliser(s), pesticides, improved seeds (hybrids or varieties), good soil and water and improved credit facilities for their purchase.

Sorghums have a structure which is broadly similar to that of other cereals (Figure 1). The major components of the grain are the pericarp (outer covering), the testa between pericarp and endosperm (which may or may not be present), the endosperm, and the embryo.

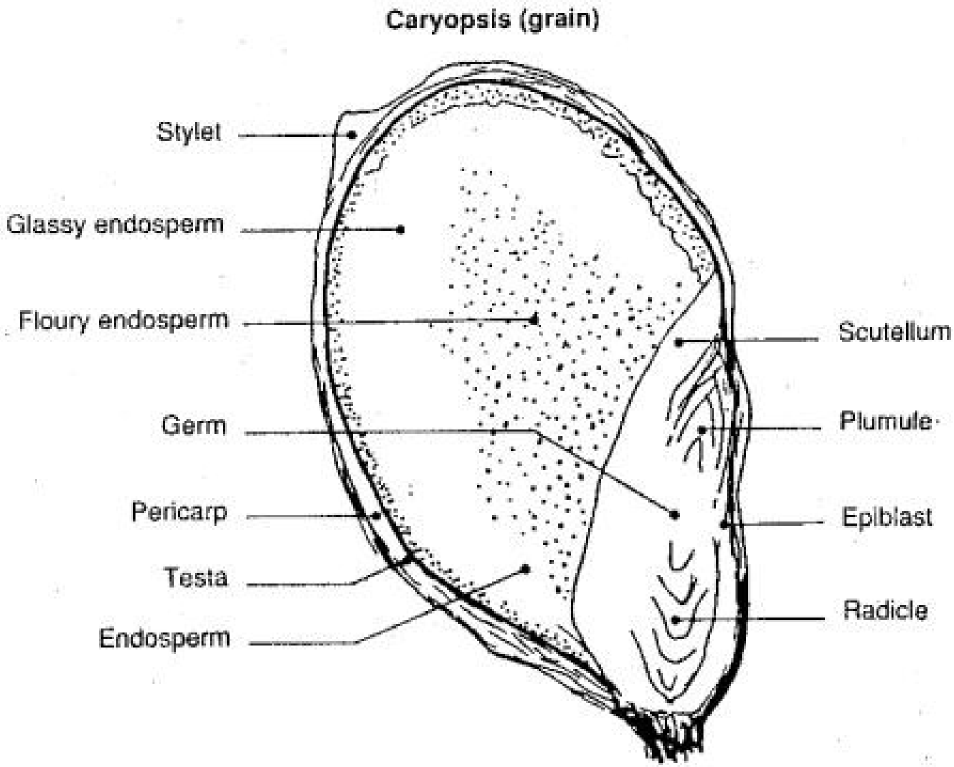


Figure 1: Structure of sorghum grain (after Sautier and O'Deye, 1989)

The endosperm may be corneous (vitreous) or floury, and the testa may contain tannins which affect the nutritional quality of the grain. Tannins are high molecular weight polyphenols (phenolics) which are found in grains with a brown pericarp and pigmented testa. Certain tannins known as condensed tannins, form complexes with proteins and reduce their digestibility. They can also form complexes with the alimentary tract proteases, reducing the digestibility of the proteins in the grain. Despite this negative nutritional effect, high tannin varieties continue to be grown due to their bird and insect resistance, and higher malting potential than white grain varieties. In some traditional foods and beverages, the phenolics of red sorghum give a desired flavour and colour. The negative effects of tannins on nutritional value can partially be overcome by removal of the testa by mechanical dehulling, or by alkaline treatment at the village level (traditionally by using wood ash) (Chantereau and Nicou 1994).

There are many varieties of sorghum ranging in colour from white through red to brown. Traditional varieties are open pollinated from which rural farmers retain seed for planting in the next season. Yields tend to be lower than the modern hybrids which are slowly being introduced. However hybrids are only cost effective when grown with supporting inputs of fertiliser, weed and pest control, and good water management. Commercial production of hybrid seed is a problem in many developing countries, and some rural farmers do not appreciate that harvested hybrid grain cannot be retained for planting the next season. Therefore they find sorghum production from hybrid seed expensive, even though the yields are higher than the land races.

Yields from open-pollinated varieties under rain-fed conditions range from 0.3-1.0 tons / ha. In contrast, hybrids can yield up to 12 t / ha under ideal inputs, soil and water conditions and higher densities of planting. Resource-poor farmers prefer varieties incorporating the characteristics of resistance to insects, disease, drought, birds, and with acceptable yields of both grain for human consumption and fodder for livestock feed. Although yields of traditional varieties are low, they are sustainable under conditions which would make maize production unfeasible or unprofitable. Commercial producers prefer dwarf varieties suitable for harvest by combine.

Grain sorghums are generally grown in regions which are too dry or too hot for successful maize production. They are adapted to the drier climates due to several factors (Bennett et al. 1990):-

The ability to remain dormant during drought and then resume growth;

Leaves roll up as they wilt reducing the area of leaf exposed for transpiration;

Leaves and stalks contain an abundance of waxy coating which protects them from drying;

Sorghum exhibits a low transpiration ratio (kg water required to produce a kg of plant material) e.g. 141 kg for sorghum, 170 kg for maize and 241 kg for wheat;

Sorghums have a large number of fibrous roots that efficiently extract moisture from the soil (the absorption area is about twice that of maize); roots may be up to 2.5m in length;

A large root absorption area and relatively large leaf area;

Sorghums can withstand temperatures above 38 _C, but dry winds coupled with hot weather during pollination reduce yields. Best yields are realised when temperatures during the season are 24-27 _C;

The water requirements for sorghum vary within the range 350-700 mm depending on the length of the growing cycle; short growing cycle is 90 days; long growing cycle, more than 130 days.

Within many semi-arid areas of developing countries, typical temperatures range from 20-38_C with annual rainfall ranging from 300-750 mm. In the USA, hybrid grain sorghums are grown where annual rainfall ranges from 380-640 mm. The growing season is longer than 130 days.

To obtain optimum yields in conditions of good soil fertility, a short growth cycle variety needs between 500 to 600 mm of well distributed rainfall; 650 to 800 mm for an average growth cycle variety; and 950-1100 mm for a long growth cycle variety. Since sorghum is predominantly a rain-fed crop grown by subsistence farmers, yields largely depend on the capacity for drought resistance of the variety used.

Sorghums can tolerate a wide range of soil pH and textures.

1.2 World Trade

Sorghum, apart from being a subsistence crop, is an important commercial and export crop for the United States of America, Australia, and Argentina. In these countries dwarf hybrid varieties are grown and harvested mechanically, predominantly for livestock feed. The major areas of sorghum production are listed in Table 1 (FAO, 1995).

Table 1. World sorghum production by area, yield per hectare and tonnage per region.

Sorghum Production Area (million ha)				
	1989-91	1993	1994	1995
World	43.4	43.2	44.8	43.8
Africa	18.5	20.6	23.3	22.0
N C America	6.1	5.2	5.2	5.2

South America	1.4	1.3	1.3	1.0
Asia	16.6	15.4	14.2	14.8
Europe	0.2	0.2	0.1	0.1
Oceania inc. Australia	0.5	0.4	0.5	0.5

Sorghum Production Yield (MT / ha)				
	1989-91	1993	1994	1995
World	1.31	1.37	1.36	1.24
Africa	0.76	0.81	0.78	0.79
N C America	3.38	3.50	3.91	3.18
South America	3.71	3.76	4.53	3.51
Asia	1.02	1.19	1.19	1.06
Europe	4.07	4.86	4.34	4.32

Oceania inc. Australia	2.15	1.28	1.90	2.02

Sorghum Production (million MT per region)				
	1989-91	1993	1994	1995
World	57.1	59.1	60.7	54.1
Africa	14.0	16.8	18.3	17.4
N C America	20.6	18.2	20.2	16.5
South America	3.6	4.4	3.7	3.0
Asia	17.1	18.2	16.9	15.7
Europe	0.6	0.8	0.6	0.6
Oceania	1.0	0.5	0.9	1.0

inc. Australia				

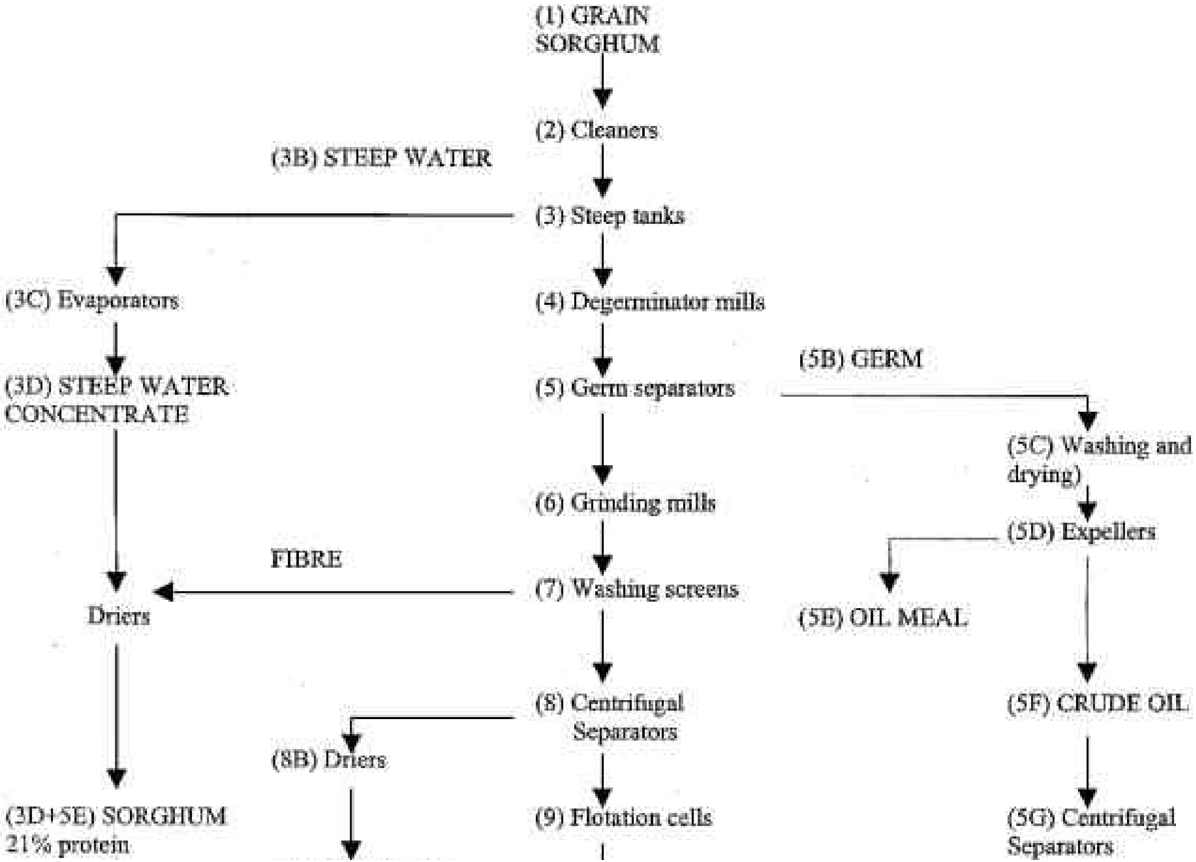
The trade in sorghum is small compared with the major grains such as wheat, maize, barley and rice. The main importers of sorghum are Japan, Mexico, the former USSR (CIS) and Venezuela. Within most developing countries, the sorghum crop rarely reaches the market. It is grown for home consumption unless there is a bumper crop, or if cash is needed. The major producers of sorghum for domestic or foreign trade are the USA, Argentina and Australia. Most is used in livestock feed.

The market price for sorghum is a function of its value in terms of its demand, its purpose, and nutritional quality. Livestock feed manufacturers procure feed materials according to a price per nutrient basis. Since the nutritional value of sorghum is broadly 85 percentage - 90 percentage of that of maize (due to the lower digestibility of the nutrients it contains), assuming that both were equally available, sorghum would have lower relative value. In reality, the price of grains has been influenced by political, social and agronomic factors, not always in support of sorghum, and often in support of maize, usually involving a subsidy.

1.3 Primary product

In communities where sorghum is grown as a subsistence crop the main food products prepared include thin and thick porridges, fermented and unfermented breads, lactic and alcoholic beers and beverages, malted flours for brewing, malted porridge mixes and weaning foods. In Kenya and South Africa, there is a small but growing market for pearled sorghum as an alternative to rice. In India, proposals have been made for use of dehulled sorghum within feeding regimes for infants and children (Pushpama, 1987)

Many countries have investigated the options for a composite wheat-sorghum flour but few have found commercial adoption. Sorghum does not contain the elastic protein, gluten, and thus the functional properties of sorghum for wheat-based bread and biscuit type products limits its inclusion level to a practical maximum of 10-15 percentage before changes in the structure of the product can be positively identified. Inclusion is also dependent upon availability of sorghum, appropriate varieties and the relative price of wheat and sorghum at the mill gate.



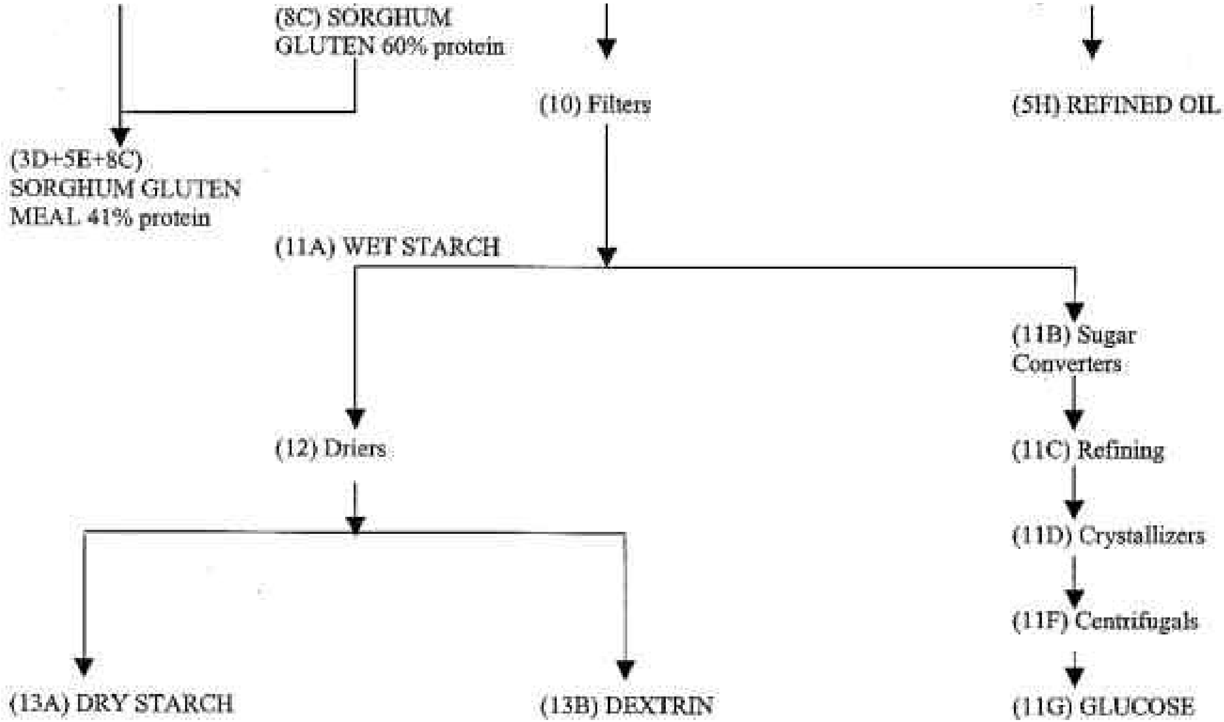


Figure 3: Flow sheet of grain sorghum wet milling (after Watson 1970)

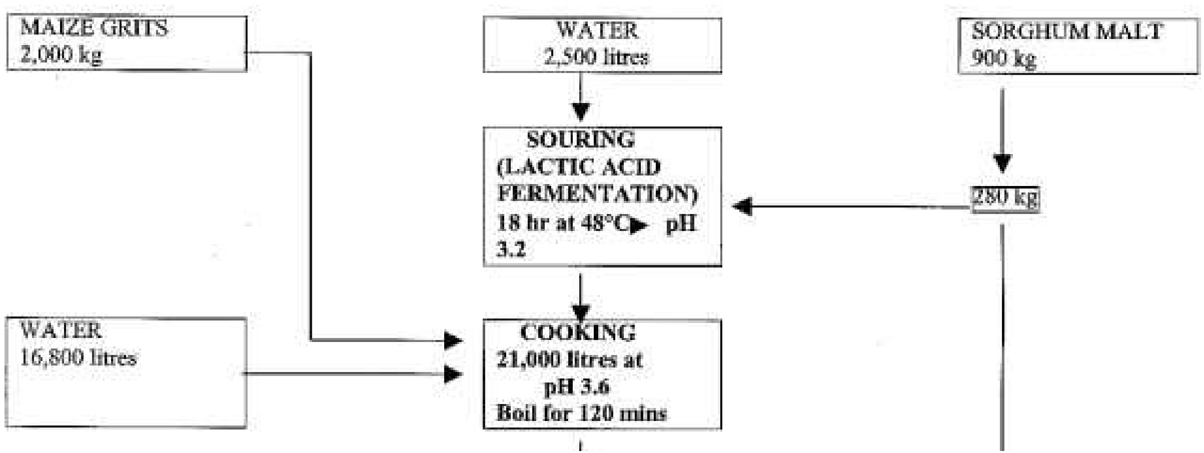
Many urban consumers consider sorghum to be a subsistence crop of low quality. This low social status for the grain constrains its desirability for inclusion in commercial products designed for urban consumers. In regions where the crop is not a staple, it may have low acceptability relative to maize due to its different organoleptic properties - unpleasant colour, aroma, mouthfeel, aftertaste and stomach-feel.

1.4 Secondary and derived product

Brewing

Lager beers: Certain varieties of red sorghums contain active amylases at concentrations suitable for certain brewing applications. For the preparation of commercial lager beers, sorghum malt is not a direct replacement for barley malt since the diastatic power of the sorghum malt is very low and variable compared to that for barley malt. Sorghum is milled for its endosperm grits as a starch source (adjunct) for hydrolysis by malt enzymes to fermentable sugars. Supplementary amylolytic and proteolytic enzymes are necessary to complete the fermentations. (Hallgren, 1995)

Opaque beers: Africa has a tradition of making opaque beers by the use of sorghum as the source of malt and the adjunct, though for commercial brewing maize may often be the source of the adjunct. Opaque beer is a product of a lactic and alcoholic fermentation which is sold in a microbially active state, with a shelf life of only 5-7 days. The principles of the process whether by traditional or commercial methods are illustrated in Figure 4 (Daiber and Taylor, 1995).



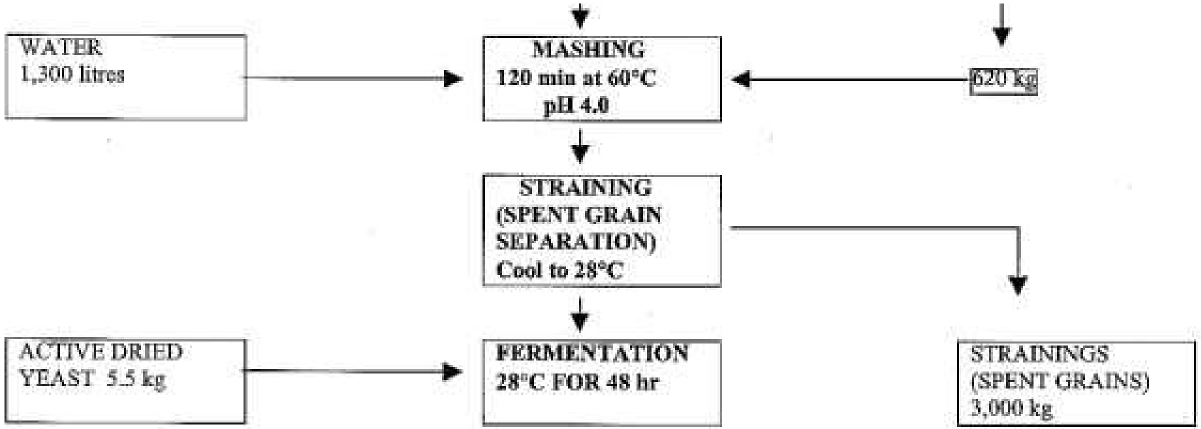


Figure 4: Principles of the production of opaque beer by the Reef-type brewing process.

Sweet sorghum

Certain varieties of sorghum are characterised by the production of high levels of sugar in the stalk. These are known as sweet sorghums and attempts have been made to commercialise their production in the USA, Argentina and

Brazil for the extraction of juice for the preparation of sugar syrup for alcohol production by fermentation.

Sorghum in animal feeds:

Livestock feed manufacturers prefer to use grains from white sorghums or low tannin pigmented sorghums due to the effect of tannins on protein digestibility. Sorghum is therefore not a direct replacement for maize in a livestock ration. Sorghum has a lower energy density and protein digestibility compared to maize (Table 6) which is reflected in the price offered for sorghum (NRI, 1988).

Table 6. Comparative data on energy and protein levels for sorghum and maize (as feed)

	Metabolisable energy for ruminants (MJ / kg)	Metabolisable energy for poultry (MJ / kg)	Protein content (%)	Lysine content (%)	Available lysine content (%)

Sorghum	12.4	13.7	11.0	0.27	0.19
Maize	12.1	14.2	9.0	0.27	0.22

Typical upper inclusion limits for sorghum and maize in feeds are;

	Sorghum	Maize
Poultry feeds	30 percentage	70 percentage
Pig feeds	30 percentage	30 percentage
Dairy feeds	50 percentage	70 percentage
Beef feeds	70 percentage	70 percentage

The above are guideline figures since the inclusion levels will be dependent upon the price and availability of other raw materials providing the desired protein and energy for a balanced diet in relation to expected levels of animal performance.

However, a major reason for low inclusion of sorghum in livestock feeds in developing countries is lack or inconsistency of supply in the market.

1.5. Requirements for export and quality assurance

The Codex Alimentarius Commission has established global standards for sorghum grains under Codex Standard 172-1989. However, individual producing countries have their own standards for internal procurement from farmers or by import. In commercial trading the quality standard for sorghum is agreed between buyer and seller and is usually associated with the intended use of the crop. Nevertheless, the principles of the Codex standard may be included within the specifications.

Summary of Codex Standard 172-1989

The standard applies to sorghum for direct human consumption.

Grains shall not have abnormal odour or taste.

Grains may be white, pink, red, brown orange or yellow or may be a mixture of grains.

Grains must be sound, clean and free from living insects.

Moisture content will not exceed 14.5 percentage; ash not more than 1.5 percentage on dry matter; protein (N x 6.25) not less than 7 percentage on dry matter basis.

Tannins: For whole grains - not to exceed 0.5 percentage on dry matter. For decorticated grains - not to exceed 0.3 percentage on dry matter basis.

Hygiene

Grain should be prepared in accordance with the Recommended International Code of Practice, General Principles of Food Hygiene (CAP / RCP 1-1969, Rev. 2, 1985).

Free from micro-organisms, substances originating from micro-organisms, or other poisonous substances in amounts which may represent a hazard to health.

Packaging

Packed in containers (including sacks) which will safeguard the hygienic, nutritional and technological qualities of the grain.

A summary of general tolerances for grain defects is given in Table 2.

Table 2. Tolerances for defects in sorghum

Defect	Limit	Definition
Blemished grains including diseased grains	3.0% 0.5%	Insect or vermin damaged. Sprouted, diseased, frost damaged or other. Evidence of decay, mould or bacterial decomposition.
Broken kernels	5.0%	Pieces which pass through a

		screen with round holes 1.8 mm in diameter
Other grains	1.0%	Non-sorghum - legumes, pulses, other edible cereals.
Foreign matter including inorganic matter	2.0% 0.55% (inorganic matter)	All organic and inorganic material which is not sorghum, broken kernels, other grains and filth. Includes loose sorghum seedcoats.
Filth	0.1%	Impurities of animal origin.
Toxic or noxious seeds	Free from amounts which may be a hazard to health.	
Contaminants	Free from heavy metals in amounts hazardous to health.	

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CHAPTER VII SORGHUM: Post-harvest Operations

2.2 Harvesting

2.3 Transport

2.4 Threshing

2.5 Drying

2.6 Cleaning

2.7 Packaging

2.8 Storage

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2. Post-Production Operations

Dehulling (removal of the pericarp)

Traditional methods

Traditional methods are time-consuming and arduous. In most traditional processes, the grain is dampened and dehulled by hand pounding in a mortar and pestle. There are local variations in this process, though common steps are:

Moisten a quantity of grain in an excess of water for about 10 minutes;

Drain off water, add grain to mortar and pound to abrade grains against each other;

Winnow off separated pericarp;

Moisten grain again with a few handfuls of water;

Repeat pounding;

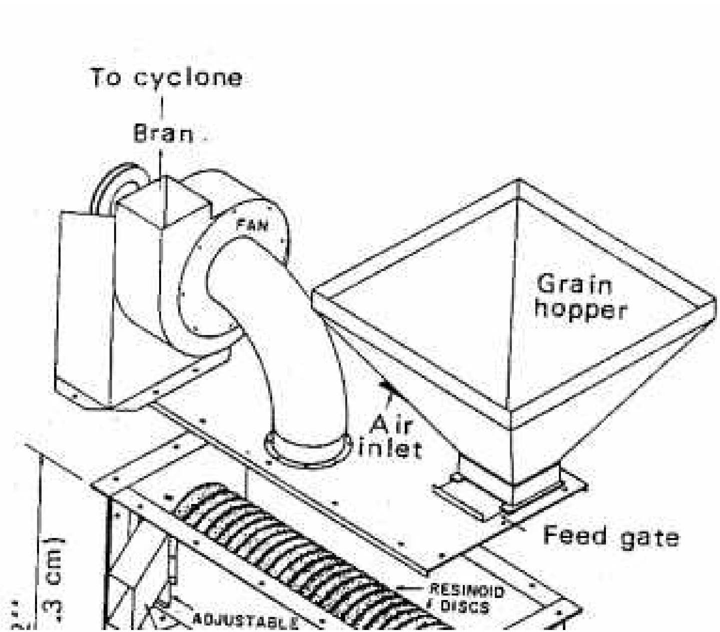
Winnow off separated pericarp;

Sun dry the grain.

The time required for dehulling depends on the skill of the operator and the variety. Typical times for dehulling would be 15 kg in 1 hour.

Machine dehulling

In recent years, the dehulling of sorghum has been successfully mechanised through the adaptation of carborundum disc barley pearling machines (Reichert, 1982). These machines dehull and debran with a single pass through the machine. The design is illustrated below in Figure 2.



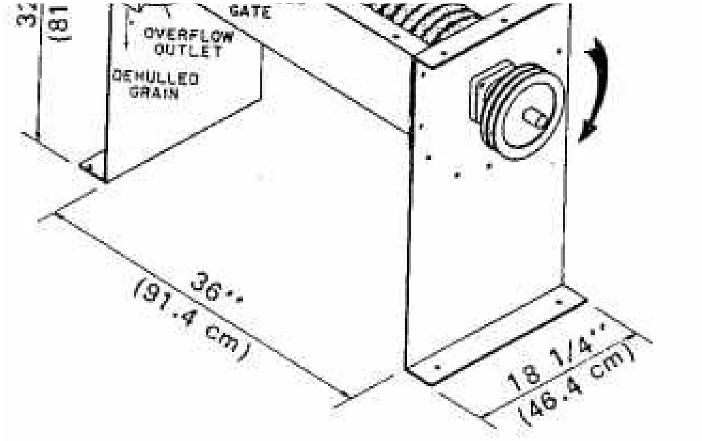


Figure 2: Typical carborundum stone type sorghum dehuller (after Reichert 1982)

Bran is separated by fan aspiration as the grain revolves between the abrasive disks. The extent of dehulling depends on the size, moisture content and hardness of the grain, the dwell time in the machine and the speed and surface characteristics of the carborundum disk. Hard varieties can yield a pearled sorghum product similar to rice, whereas soft floury endosperm varieties can shatter in the machine producing a coarse flour. Bran removed from the dehulling can be used as an animal feed.

However, abrasive disc dehulling has not found universal acceptance in developing countries. Problems have occurred due to limited technical and entrepreneurial skills of the operators, limited support from the manufacturers and difficulties in obtaining foreign exchange for the purchase of spare parts. Nevertheless in Botswana, where sorghum is the national grain, dehulling has been readily accepted by the small-scale private miller.

Traditional milling is by pounding sorghum grain in a mortar and pestle or stone grinding. The whole grain is thus converted to a wholemeal flour. This is the most arduous task of milling grains. To pound 15 kg of sorghum grain to a flour may take 3-5 hours. At rural level the sieving of flours to produce flour grains of specific particle size for specific culinary uses has yet to be introduced. In some parts of the world e.g. the Sudan, sorghum may be wet-ground by rubbing soaked grain between two stones until a fine paste is produced. This paste is used directly or left to ferment.

Machine grinding

Hammer mills

Power driven hammer mills are becoming increasingly available and offer options for reducing grain to a flour. These are:

take the cleaned grain directly to a hammer mill;

dehull at home and then hammer mill;

dehull and debran the grain in a mechanical abrasive disc dehuller and grind the grain to a flour by hammer mill, plate mill, stone mill or roller mill.

In rural Zimbabwe the relative charges for dehulling and milling are approximately equal. The charge for dehulling 12 kg sorghum was Z$ 4. Charge for milling dehulled grain to flour was Z$ 4 . In this case the miller kept the bran for sale as animal feed. Alternatively the charge for milling whole grain was Z$ 6 per 12 kg (Wood and Thomson, 1997)

Roller milling

Sorghum can be roller-milled if the variety has the desirable qualities for pericarp / bran removal, though the efficiency of bran separation from the grain is lower than that for wheat due to its different physiological structure. It is difficult to obtain a clean separation of white endosperm from the bran fraction and the final flour has a speckled appearance. Soft endosperm varieties can easily shatter in a roller mill producing a wholemeal flour with fine bran which may be difficult to remove by sieving (Hulse et al 1980). A milling process involving the friction decortication of sorghum followed by roller milling has been developed in Denmark. If the raw material is properly conditioned, the process produces more or less intact sorghum endosperm (grits) and embryo removal.

In another research development of the roller milling process, grains are soaked to a moisture content of 20-27 percentage before roller milling. This semi-wet process appears to have considerable advantage especially in milling high tannin sorghums, but extraction rates of flours are lower than commercially acceptable in milling low-tannin varieties (Munck, 1995).

Wet milling for starch extraction

Starch can be extracted from sorghum by wet milling. The process is similar to that for starch extraction from maize and is illustrated in Fig 3 (Watson, 1970). The pigments of sorghum may discolour the final starch, and to prevent this low-tannin sorghums without testa are preferred.

2.2 Harvesting

In developing countries, almost all sorghum is harvested by hand. The panicle is cut from the standing stalk at about 16-20 percentage moisture content, and the stalks left for animals to graze the best of the residual leaf material. In other communities, the stalks are cut and stored for use as dry season animal fodder, or for house thatching and fencing. Late harvesting can lead to spontaneous shedding of the grain from the panicles resulting in significant losses and grain deterioration due to rapid changes in temperature and humidity.

In the USA, Australia and Argentina where dwarf hybrids are popular, the sorghum grain is threshed from the standing stalks by combine harvester. Grain with up to 25 percentage moisture content can be harvested, but requires careful drying before storage.

2.3 Transport

The bulk density of sorghum grain at 520-720 kg/cu.m. is similar to that of maize and hence transport costs will be comparable for any particular type of consignment - bag or bulk.

2.4 Threshing

In rural Africa, threshing involves beating the dried sorghum panicles with sticks on the ground or in sacks, or using a mortar and pestle. Grain is separated from dirt and chaff by winnowing. The time required for threshing depends on variety, the degree of dryness of the grain, and the method of threshing. In some places in India, a common practice for threshing the grain is to place it on the road for vehicles to run over. It has been recorded that 2-4 ha of grain (approx. 1-2 tons) can be threshed on the road in one day by a few people. Normally about 35 labourers are required to thresh about one half hectare (300-400 kg).

General guidelines for improved threshing efficiency and yield at rural level:

To reduce the amount of winnowing, thresh the panicles on mats, adobe or cement blocks, not on sand, gravel or stones;

Thresh early to reduce field exposure to birds, rats, etc. (ensure that the moisture content is low enough);

Maximum moisture content of the grain before storage should be 10-12 percentage;

Vitreous, flinty-starch type sorghums should be threshed early to reduce the number of broken grains.

The grain may be stored as unthreshed panicles or threshed before storage. Both storage methods are practised, but small-scale producers tend to store the grains unthreshed.

In many developing countries, motorised threshers have found mixed acceptability due to breakage of softer varieties of grain, problems of machine maintenance, and availability of spare parts. They operate by passing the grain-bearing panicles between a moving rotor and a fixed metal plate. The loosened grains and panicle fibres are separated in a forced air current.

Where farms are sufficiently large, threshing can be achieved using mechanical combines at the time of harvest (Vogell and Graham, 1979).

2.5 Drying

The moisture level of sorghum must be reduced to a safe level (10-12 percentage) before storage.

The reasons are:

To prevent mould growth (and thus the possibility of mycotoxin development by a range of storage fungi - especially *Aspergillus flavus* - which can, under appropriate storage and field conditions, produce carcinogenic aflatoxins);

To reduce the likelihood of insect attack;

To prevent grain germination.

For all stored products, the maximum "safe" moisture content for storage is that which is in equilibrium with 70 percentage RH, but lower levels (in equilibrium with 65 percentage RH) are advisable if quality loss is to be minimised (Mc Farlane et al., 1995).

During storage the moisture content of the grain will equilibrate to a level which equates with the vapour pressure deficit (which is a function of relative humidity and temperature). Moulds develop if the moisture content is above 15 percentage and the temperature above 24_C.

Field drying: In many semi-arid areas, the traditional varieties tend to ripen after the rainy season and dry satisfactorily on the panicle. The most common method is to stack bundles of panicles in the field and allow them to dry in the sun. Grain on the panicles or as threshed grain should be kept off the ground on raised platforms, mats, or trays whilst it is being dried. Many insects will walk away from grain spread in the sun or aree killed if the temperature of the grain is high.

The time taken for sun drying of threshed grains depends on the ambient temperature, relative humidity, depth of grain, bulk density and the frequency of turnover. In India, on a mud floor, sorghum grain in a layer of 20-mm depth can be dried from 16 percentage to 9 percentage moisture in one day. Drying requires 12 man-hours of labour for spreading and turning the grain (Giresh et al 1990). In a study on the drying of sorghum in the shade, the moisture content of the grain was reduced from 32 percentage to 13 percentage in 24 hours at a daytime temperature of 29_C.

In developing countries, the sorghum grain is sun dried on the panicle, and/or after threshing. When the economies of scale permit, sorghum grain may be dried by warm forced air. Drying temperatures and flow rates will depend upon the design of the drier and the relative humidity of the incoming air (Table 3)(McFarlane et al., 1995).

Table 3. Three principal systems for mechanical drying of sorghum grain

Drying with unheated air forced through a drying bin	Air drying with supplementary heat when the ambient RH is greater than 75%	Heated air drying
Lowest investment Simple to operate. Relatively ineffective in wet weather or if RH is >75%. Recommended airflow rates: 0.02 cu.m/sec per cu.m sorghum at 14% moisture content (wet basis) up to 0.04 cu.m/sec per cu.m. sorghum at 20% moisture content to provide the most	Heat generated from oil, gas or electric heaters during prolonged cold and wet weather. Drying temperatures should not exceed 40_C. Drying times shorter than unheated air reducing risk of mould growth.	Batch or continuous systems using constantly heated air. Relatively sophisticated high investment costs. Typical airflows in the range 0.5-1.5 cu.m/sec per cu.m. of sorghum for batch drying and 1.5-2.5 cu.m/sec per cu.m sorghum for continuous dryers. Short drying times.

economic drying.		

2.6 Cleaning

In traditional systems, grain cleaning is achieved by winnowing (to remove the low density material such as leaf and stalk), while washing in water will remove most dust and stones. In mechanised systems, forced air (aspiration) is used to remove low density material, while most stones, dust and other material is removed as the grain passes over a series of screens. Ferrous metal should be removed by a permanent magnet placed in the flow path of the grain.

2.7 Packaging

Bags used for sorghum can be made of jute, cotton, woven polypropylene or multi-layer paper. Woven polypropylene bags are light in weight, low cost and permit aeration. Their disadvantage is that hooks can irreparably damage the bags, they have a slippery surface and can be difficult to stack.

Sacks are often re-used and care should be taken to prevent reinfestation of clean grain by boiling sacks in water and thorough drying.

2.8 Storage

The goal of good storage is to be able to deliver grain from store in good quality and with no loss in quantity. This is achieved by preventing the deterioration caused by:

Adverse climatic conditions;

Contamination by extraneous material;

Grain germination; and

Pest infestation.

Ensuring that the storage environment is clean and tidy and in a good state of repair, makes a major contribution to the quality control during storage, but it is insufficient to prevent losses by pests.

Since the introduction of high-yielding varieties, there has been a noticeable shift in the requirements to upgrade storage practices at both the rural and the commercial level. Traditional varieties tend to be resistant to insect damage whereas the hybrids are considerably more vulnerable. This difference in storage stability has raised the profile for appropriate methods for insect control in stored sorghum.

Sorghum can be stored on the panicle or as a threshed grain. At the household level, sorghum grains are kept in a variety of stores for day to day food needs, seed, sale and as insurance against the risk of periodic grain shortages. Where containers are open to air movement, such as open-walled wooded cribs, the panicles may be put in store at 15-16 percentage moisture content. Low relative humidity after harvest ensures that the grain continues to dry while in store. This figure is well above the 12 percentage moisture threshold for safe storage of threshed grain.

Storing grain on the panicle reduces the vulnerability of traditional varieties to pest and mould damage, but takes up a larger space in storage, and unthreshed grain is difficult to protect with insecticides.

Locally available materials used for storage structures include soil from termite mounds, wood, plant stalks, straw, bricks and cement. Forest products for store construction and insect control are becoming increasingly scarce as the demand for wood for fuel and construction timber increases. At the same time skills to build granaries from local materials are disappearing as young men leave villages for work in urban areas.

Common forms of storage include jute bags, metal drums and bins, baskets, underground pits, clay pots and bins of stone or mud plaster. If grain is required for seed it is often dried on the panicle. The advantages and disadvantages of different methods of storage are summarised in Table 4.

Table 4. The advantages and disadvantages of different methods of storage

Method of storage	Advantages and disadvantages
Jute bags	When kept on raised platforms they allow air

	movement through the grain and can be repaired and re-used. *Disadvantages*: high cost, risk of loss through theft, water or pest damage.
Metal drums, bins and clay pots	Can be hermetically sealed, long life if shaded from direct sunlight. Good protection from external pest attack. *Disadvantages*: minimal air exchange for moisture control. Grain must be dry before storage.
Baskets woven from stalks and plastered with mud / cow dung.	Large quantities stored at low cost - this is the most common storage method used by small-scale producers *Disadvantages:* vulnerable to pest damage
Underground pits. Walls usually heated with fire and lined with straw, brick or cement. Sealed with a straw/mud plug.	Large quantities stored at low cost; relatively secure from theft. *Disadvantages:* grain can be seriously affected by mould growth and mycotoxin development

Bulk silos or granaries	Steel, aluminium or concrete structure built to heights of 30-50m. Heat transfer from corrugated sheets is less than from plain sheets. Plain sheets are preferred for areas with wide diurnal variations in temperature. Effective for centralised storage and distribution. *Disadvantages*: High operational and social costs.

Traditional storage systems are well suited to their environments and the varieties of grain being stored. Losses are generally low, below 5 percentage of grain weight over a season. In India, local sorghum varieties show weight losses of 1 to 2 percentage after 12 months storage, compared with up to 30 percentage for hybrid varieties. Early workers confused percentage damaged grains with weight loss and reported losses exceeding 30 percentage in some countries.

Storage treatment practices must be effective whether at the level of rural crib, underground pit or concrete silo. For effective sorghum storage, the following items should be assessed:

Type / variety of grain;

Post-harvest handling methods (threshing, drying, transport) and constraints;

Advantages and disadvantages of traditional storage methods;

causes, extent and value of storage losses;

What the farmer is doing to minimise the loss;

Why the farmer is storing, and future expectations;

available, appropriate methods of storage loss reduction;

The cost and benefits of existing, and alternative methods of loss reduction, taking account of cash, material, labour inputs and anticipated market prices.

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CHAPTER VII SORGHUM: Post-harvest Operations

4.1 Pest species

4.2 Pest control

4. Pest control

4.1 Pest species

A wide range of insect pests attacks all stored sorghum grains and grain products in the arid and semi arid tropics. Typical conditions for infestation and damage for stored sorghum grains are summarised in Table 5.

Table 5. Conditions for infestation and damage for stored sorghum grains

Insect	Optimum conditions for infestation	Damage symptoms and losses
Rhizopertha dominica	Heating follows infestation	Adults and grubs make ragged holes in grain; losses in improved cultivars range from 17-66% (Gupta *et al.*, 1977).

Sitophilus oryzae	Preferred moisture content 10-16%. Red varieties with soft endosperm are more susceptible.	Adults and larvae feed on grain; losses 2-21% for improved cultivars in India (Gupta *et al* 1977).
Tribolium castaneum	Does not attack whole grain; feeds on damaged grains; fairly resistant to high temperatures.	Tunnelling damage; when attack is severe, grains turn greyish yellow and mouldy with pungent smell.
Sitotroga cerealella	Infestation starts in the field; develops rapidly on low moisture content sorghum stored on the panicle.	Field infestation on the upper layer of the grain; larvae bore and consume grain contents adding excreta and webbing.
Ephestia cautella, Plodia interpunctella, Corcyra cephalonica	Adult moths are active at dawn and dusk, particularly during periods of high humidity; inactive	Attack the embryo of whole grains; thick web left on grain surface; can cause losses in excess of

	in complete darkness	10%

4.2 Pest control

Sorghum is a vital subsistence crop for rural populations in semi-arid regions and most farmers are aware that newer high yielding varieties are more susceptible to storage insects. Good management practices, including: examining stores regularly for signs of insects, moulds and rodents; cleanliness in and around the grain store; and cleaning, and keeping grain dry, all contribute to quality and reduce the extent of losses. Varietal resistance to insect attack, physical, mechanical and botanical pest control measures integrated with minimum use of insecticides reduce considerably the damage done by pests.

Fumigation of grain is a widely used method of controlling storage insects. The practice is usually restricted to commercial stores where adequate safety precautions can be maintained. The two most commonly used fumigants are methyl bromide and phosphine. Methyl bromide is in the process of being withdrawn from use because of its ozone depleting properties, and is no longer recommended.

It may well not be cost-effective to treat all grain immediately after harvest but rather only the proportion of the produce which is to be stored for three months or more. Such advice helps the farmers to decide on actions to be taken, encouraging assessment of the need to store or sell, given market prices, the quantity harvested and so on.

For the last 20 to 30 years, it has been a standard recommendation that farmers should treat the crop to be stored with an organophosphate (OP) dust. Several OPs, including malathion, fenitrothion, iodophenphos and pirimiphos-methyl have been approved by the UN Codex Alimentarius Commission for application to raw cereal grains, flour, pulses and some oilseeds; acceptable daily intakes and maximum residue limits have been prescribed.

Many of these compounds are commonly applied as sprays for other agricultural purposes. However, it requires the use of a sprayer which most farmers do not possess or cannot afford. Furthermore, spraying requires dilution of an insecticide concentrate, a hazardous process especially for untrained small-holder farmers. Dilute dusts are composed of at least 95 percentage inert material. They are therefore very bulky, difficult to package in quantities suitable for an individual producer's needs, and difficult to distribute to rural communities at a time when they are most needed and to where they can be conveniently obtained. Families frequently complain they have no access to insecticides when they want to apply them, and whatever little is available is expensive. Farmers who cultivate cash crops or have other sources of income may be able to afford these high prices, but most farmers in the semi-arid tropics are poor and do not have cash or credit to be able purchase insecticides. During the last decade, efforts have been made to identify alternative methods of protecting grain against insect damage which are of low or no cost to the farmer and are therefore likely to be acceptable and utilised. Furthermore, these methods are more environmentally sustainable and less of a health risk than the synthetic insecticides.

Botanical pesticides:

Throughout the developing world, farmers have traditionally used the plants and trees around them as sources of insecticides. The number and type of species used for this purpose is considerable. The literature contains many references to the effect of plants on storage insects (Dales, 1996), but this work is mostly confined to laboratory investigations. There is very little direct evidence which demonstrates that plants used by farmers are effective grain protectants. Few studies have been conducted to replicate farm methodologies, one reason being that farmers themselves are uncertain of the details of the methods and can only provide subjective assessments of effectiveness.

Plants with known insecticidal or repellent properties include: *Securidaca longipedunculata, Chrysanthemum cinnerariafolium* (pyrethrum), and *Azadirachta indica* (*neem*). Both pyrethrum and neem are relatively unstable and may not be suitable for long term grain storage. Although more than 130 plants have been reported as being used as storage protectants, only pyrethrum and *neem* have been used commercially.

In some countries, palm and coconut oils are used to protect grain, particularly those for seed. However, they are usually considered too costly for storage insect control.

Mechanical control:

Sieving, winnowing combined with sun drying, sticky bands, water traps and baits can be used for insect control in storage. Turning grain to interrupt population development is quite feasible for bulk grain in silos.

Physical control:

Low and high temperatures (> 60_C) inhibit development, and may kill several insects. Dusts such as ash, sand and other mineral powders can be used to fill the interstitial spaces in grain bulk. These provide a barrier to insect movement and damage the insect cuticle causing death by dehydration. Diatomaceous earths (naturally occurring aluminium silicates) absorb waxes from the insect cuticle and cause death by dehydration. These are `Generally Regarded As Safe' (GRAS) by the US Environmental Protection Agency for use with grain.

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CHAPTER VIII: Industrial use of sorghum

1.3 Primary product

1.4 Secondary and derived product

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1. Introduction

Sorghum (Sorghum bicolor (L) Moench) is a globally cultivated cereal that is called a `Life Saver' in some areas. It is a major crop grown in the semi-arid and arid regions of Africa and Asia where it is used as a staple food. In China, sorghum or *kaoliang*, is one of the earliest cultivated crops growing mainly in Northeast, Northwest and North China temperate zones.

Chinese sorghum production is based on grain sorghum, to sugar-refining sorghum, forage sorghum and craft sorghum. It is a unique due to its tolerance to drought, waterlodging, saline-alkali, infertile soil and high temperatures. Sorghum can obtain a consistent high yield even in certain semi-arid and arid areas where rice, wheat and corn are not well adapted. Sorghum plays an important role in crop rotation systems. Sorghum is a C4 species with high photosynthesis efficiency. It can achieve higher yields with a lower input of resources in compared to other crops.

Most grain sorghum in China is used as food to make various breads, cakes, dumplings and noodles. But sorghum is commonly called "coarse food "because of its amino acids imbalance and high tannin content (Table 1).

Table 1. The Composition of Chinese Sorghum Resources and Hybrids

		Starch %	Protein %	Lysine %	Tannin %
Chinese	the highest	16.30	0.43	1.29	

sorghum
resources

	the lowest	6.62	0.10	0.04
mean	11.46			
Hybrids	the highest			
	15.20			
	0.41			
	2.64			
	the lowest			
	6.50			
	0.07			
	0.03			

In recent years, Chinese sorghum researchers have directed their attention to improving sorghum quality by breeding and processing. Obvious improvements have been gained (14). Sorghum kernels provide good concentrated feed similar to corn in nutritional value. Sorghum stalks and leaves can be used as green fodder, ensilage or hay.

In China, making strong liquors from sorghum kernels represents a long history and high technological level. The world famous *Maotai* and *Fen* liquors are made from sorghum. Its by-product of distillers' grain can be used as high quality feed. Sorghum grains produce starch, starch noodles and vinegar.

Chinese Kaoliang is a special sorghum group in the world. There are about 17 thousand sorghums cultivars in China, the representatives of them are: *Guandong Qing, Luyi Waitou, Shanchishan, Wawa kaoliang, Bakecha, Xiaongyue 253, Fenzhi Dahongsui, Xiang Kaoliang, Zhuyeqing, Hongke Nian, Waibo Zhang* and etc. (7, 11).

Chinese sorghums have great variety of panicles (Fig. 1) (4), growing periods, plant heights, head lengths, and 1,000-kernel weights (Table 2) (2). Typically they are high dark red soft glum, white vein and dry pith.

Figure 1: The Sketch Map of Chinese Kaoliang Spike 

Table 2. Structural Features of Chinese Sorghum

	Growing period day	Plant height cm	head length cm	length 1,000 kernel weight g
Max.	166	435	50	39
Min.	88	92	11	12
Mean	115-125	250-300	22-33	21-26

1.3 Primary product

Milling is very important in China, because many sorghum foods are made of decorticated sorghum and sorghum flour. Milled sorghum is usually decorticated to remove the pericarp, followed by crushing of the decorticated grains into flour.

Milling machines can be divided into three types: friction milling (pressure system), grinding milling (speed system) and mixed milling.

Friction milling decorticates grains depending on the friction between components and grains or between grains. The method suits the corneous endosperm variety. Peeled grains from this method are smooth, even, with less breakage and higher milling yields.

Relying on its hard, concentrated and sharp edges, the emery roller in grinding milling cuts pericarps repeatedly by relative motion at a set speed, so the pericarps are removed. The method is suited to floury endosperm varieties. The decorticated grains derived from this method are rough and uneven with poor colour.

Mixed milling was invented by China combining the advantages of grinding milling with friction milling, with stress on the former. It is a good milling method with a great future.

There are two kinds of dry flour milling methods: whole grain flour milling and decorticated grains flour milling. Making flour from whole grains can yield 90 percentage, but digestibility is low at 18.55 percentage with poor flavour. Making flour from peeled sorghum grain can produce high quality flour with good digestibility, but yields 8.5 percentage.

The wet flour milling method is better than dry milling. Flour produced by this method is good quality with white, fine grains and 5 percentage higher digestibility than dry milling. The flour is easy to store. The procedure of wet flour milling is described in Figure 2. (4).

Unprocessed grains ->	**Cleaning ->**	**Washing ->**	**Heating ->**	**Making flour ->**	**Drying ->**	**Packaging**

Figure 2: Processing Method of Wet Flour Milling

Traditional sorghum foods

Sorghum is a staple food crop in China, especially in North China. People there can make many kinds of rich and colourful sorghum foods which have

different flavours. According to Shukun Zhao (12,13), there are about 40 kinds of sorghum foods. Table 8 summarises some different sorghum foods.

Table 8 Classification of Sorghum Foods

Type		Name of representative
decorticated grain foods	cooked produces	gan mifan, lao mifan, shui mifan, er mifan dou mifan
	porridge	chazi zhou, doumi zhou, ermi zhou, Jianmi zhou, naibuzi.
flour foods	steamed products	YuYu, baocha, wowo, tiaotiao, jiaozi, dundun, boboye, fagao
	boiled products	hele, miantiao, mianpian, gangsimian, miangedatang, daoxuemian, suantangzi
	baked products	jianbing, famianbing, dabingzi
	parched products	chao mian, youchamian
	glutinous products	niangao, niandoubao, nianhuoshao, nianbing, suhaozi
Popping foods		penghuasu, baomihua, chaomihua

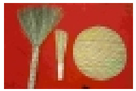
Popping foods penghuasu, baomihua, chaomihua

1.4 Secondary and derived product

In China, almost every part of sorghum can be used (Table 9 and Figure 3).

Table 9 Utilisation of Sorghum By-Product

Sorghum component	Utilisation
root	fuel
stalk	fuel, mat, hat, building materials, frame materials, barrier
peduncle	cover
threshed spike	broom, potscouring brush

Figure 3: Articles Made of Sorghum By-products 

Making sorghum liquor using sorghum grains

Sorghum liquor is a unique Chinese alcoholic drink with a history of about 1500 years. It is one of six kinds of world famous distillation liquor. There are many kinds of sorghum liquor in China. The characteristics of Chinese sorghum liquor are:

a. Strictly selected materials;

b. Meticulous processing;

c. Excellent quality;

d. Special flavour;

e. Very strong.

The traditional ingredient of alcoholic drinks in China is sorghum. "Good liquor is always connected with sorghum" is a well-known adage. China is the first country to make distillation liquor with sorghum. Famous and precious sorghum liquors of China include (4,9,15):

***Maotai*: It was produced in Guizhou province, in 1704. In the International Fair of Panama between 1915 and 1916, *Maotai* gained the second prize in the competition and was elected *World Famous Liquor*. It is the most famous liquor in China served at state banquets. The key ingredient of *Maotai* is local high quality sorghum.**

***Fen Liquor*: It is manufactured in Shanxi province, China. It has the longest brewing history (about 1500 years). In the International Fair of Panama of 1915, it won the First Class Gold Medal.**

***Wuliangye*: It is made in Sichuan province of China. It was awarded the Gold Medal in the International Fair of Panama in 1915. It uses five kinds of crops as materials (Sorghum, glutinous rice, rice, corn and wheat). 60 percentage of *Wuliangye* is sorghum.**

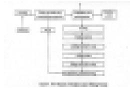
***Jiannanchun*: It is also made in Sichuan province of China. It begun to be produced 300 years ago in Qing dynasty. Its materials are five crops: Sorghum, rice, corn, wheat and glutinous rice, Sorghum accounts for 40 percentage of the recipe.**

***Xi Feng*: It is produced in Shanxi province. It won second prize in Southeast Asia Competition of 1909. It is made exclusively from sorghum.**

***Luzhoutequ*: It is produced in Sichuan province of China. It has about a 300-year history. It won the Gold Medal and Certificate of Merit in the International Fair of Panama in 1919.**

Sorghum and corn have very similar composition, but for making liquor, sorghum is better than corn. First, sorghum has a lower protein and lipids content than corn. During the fermentation, protein is hydrolysed for amino acids, and then the amino acids are changed into senior alcohol. These senior alcohols are the main source of the liquor flavour. If the protein content is too high, too much mixed alcohol will be produced, and the high mixed alcohol content in the liquor will produce white sediment in lower temperatures. Similarly, if the lipid is too high, a lot of fatty acid is produced causing a bad smell and white precipitate. So, suitable protein content will benefit distillation. Second, and most important, sorghum has a small tannin content (about 0.5~2.0 percentage). Tannin inhibits harmful micro-organisms and increases liquor-making productivity. Tannins also produce some

aromatics which give sorghum liquors their special flavour. The general method of making sorghum liquor is described in Figure 4.

Figure 4: Flow Diagram of Sorghum Liquor Making Process 

Making liquor using sweet sorghum stalk and waste residue from sugar refining

Sweet sorghum stalks have a high sugar content good for making liquor. Usually, 4.5-5.0 kg 62 percentage liquor can be distilled using 50-kg sweet sorghum stalks. The method is similar to using sorghum grain (Figure 5). The advantages of processing sweet sorghum stalks on the spot are that the residue can be used to produce methane, feed or manure. Moreover, the waste residue of refining sugar also contains some sugar, which can be fermented for sorghum liquor. About 1.5-2.5 kg 50 percentage sorghum liquor will be produced from 50-kg waste residue (4).

Figure 5: Processing Method of Liquor Using Sweet Sorghum Stalk 

Making liquor using sweet sorghum stalk

Here the juice of stalks is directly fermented and then filtered (Figure 6).

Figure 6: The Processing Method of Making Keller Liquor

Making Liquor By Sorghum Bran

Sorghum bran is a by-product of milling sorghum where generally, more than 20 percentage sorghum bran will be derived. The composition of sorghum bran is 40~ 60 percentage starch, 11~ 15 percentage raw protein, 4~ 10 percentage raw lipids and higher tannin content. Because the high content of lipids in sorghum bran cause too much acid, the temperature of cellar should be lower to guarantee the quality of the liquor (4).

Brewing beer

Traditional brewing ingredients of beer are barley and rice. Along with the development of the beer industry, there were insufficient resources. Sorghum

is a new potential substitute for barley or rice, which can not only resolve the ingredient problem, but also raise economic benefits (10).

Although there is a traditional sorghum beer in Africa, it is an acid type of beer quite different from traditional beer in Europe. Chinese sorghum beer is similar to European beer. Its colour, flavour and quality are similar to barley beer. The brewing method is as follows (Figure 7).

Figure 7: Brewing Method of Sorghum Beer 

Refining sugar

Making syrup from sweet sorghum stalks has a long history in China, but the production of crystalline sugar is only several decades old. There are three end products in sugar refining--yellow granulated sugar, brown granulated sugar and syrup. Their quality was up to standard. The total sugar in crystalline sugar can generally reach about 92 percentage (82.09 percentage sucrose+10.5 percentage reducing sugar), and water content is about 7 percentage (4).

The sugar extracting productivity with sweet sorghum stalks is about 4 percentage (1). Figure 8 gives the details of sugar refining.

Making vinegar

Vinegar with its acid flavour can whet the appetite, help digestion, or assist medicine. A large amount of high-quality vinegars in North China are made from sorghum grains.

Sorghum vinegars are thick quality, mellow flavour and full of delicate fragrance. *Shanxi Old Mature Vinegar* is one of the most famous Chinese sorghum vinegars.

To make vinegar get ethanol from the starch by fermenting. Ethanol becomes vinegar by oxidisation. So, its processing method is similar to making sorghum liquor. Besides sorghum grains, many kinds of residues from sugar extraction, such as sediment foam, also can be used to manufacture vinegar. About 1.3-1.5 kg vinegar can be distilled from 1-kg sediment. Its quality is the same as vinegar made from grain.

Figure 8: The Processing Method of Sugar 

Making monosodium glutamate

Monosodium glutamate (MSG, $C_5H_8O_4NNa.H_2O$) is the reactant of glutamic acid and sodium carbonate, and glutamic acid is fermenting product of glucose ($C_6H_{12}O_6$).

$$2C_6H_{12}O_6+2NH_3^{+} +3O_2 \; 2C_5H_9O_4N +2CO_2+6H_2O$$

In China, the raw component to make monosodium glutamate is starch, such as rice, corn and sorghum. If we use sweet sorghum stalks to make MSG, it should be very convenient, because the process from starch to sugar can be omitted. What we need to do is transform sucrose to glucose. If the yield of sweet sorghum stalk is 75,000 kg/ha, grain yield is 4,500 kg/ha, the output of MSG will be 243.8+80.4=324 kg. It is 2.5 times more than rice which is a considerable economic benefit.

Making Sorghum Sweetmeat

In ancient China, people made malt sugar as a food; its other name is water malt sugar. Any kind of starch can be used make maltose. Because maltose has very strong hygroscopicity and gentle sweet taste, it is one of the necessary constituents in candy, cake and jam. Sorghum sweetmeat, a kind of maltose made of sorghum starch, is a famous special local product from the Shandong province. The main composition of sorghum sweetmeat is maltose (about 50~65 percentage) and dextrin (about 20~25 percentage). It also contains some moisture and a small amount of protein, starch, and ash (4).

Making paper

The leaves and stalks are the materials of the grass family paper making, which can be used to make writing paper (rough straw paper), wrapping paper, and other products. In addition, the residue which from sugar refining of sweet sorghum stalks is also used for papermaking. Comparing other papermaking materials, sorghum leaves and stalks are easy to convert into pulp Size chemical pulp use only a small amount of chemicals to fabricate

paper products that are homogeneous and smooth. However, the paper made from sorghum stalks and leaves show strong transparency and brittleness plus poor folding and bursting. The process of making paper is described as Figure 9 (4).

Figure 9: The Method of Making Paper Using Sorghum Leaves and Stalks

Making plywood using sorghum stalks

The cellulose content in sorghum stalk is very high, at about 48 percentage of dry weight (4). Sorghum stalks are not only light, but also pliable and hard. Sorghum stalks can be used to produce sorghum plywood. Comparing shaving board and fibreboard, sorghum plywood has many advantages.

A. Light with high strength;

B. Better insulation capability;

C. Highly durable;

D. The size, thickness and specific gravity of board are suitable for multi-function applications;

E. The holding power of nails and screws is generally lower than that of wood board;

F. Tropical rainforests for wood making materials are conserved.

The material used for sorghum plywood is from sorghum stalks. Sorghum is an annual plant with great deal planted all over the world making it simple to get raw materials for plywood. On the other hand, sorghum stalks are by-products of sorghum. By using sorghum stalks to make plywood, farmers can earn 3000 yuan/ha more than before. Because sorghum plywood is a substitute for woodboard, it can reduce the use of wood materials to conserve acres of forests.

Shenyang Xinyang Sorghum Plywood Company Ltd., which is a joint venture of China and Japan, can produce about 60,000-m3 plywood each year. Their processing method is described in Figure 10. The sorghum plywood can be

used to construct tables, doors, furniture and decorative materials (Figure 11).

Figure 10: The processing method of sorghum plywood 

Figure 11: The Furniture and Ornament Made of Sorghum Plywood (the picture is kindly provided by Shenyang Xinyang Sorghum Plywood Company Ltd.) 

Making alcohol

The oil crisis is a world-wide problem, creating urgency to seek new replaceable energy source with no delay. Alcohol can partly replace oil. So the challenge is how to get enormous volumes of alcohol? Sorghum is an efficient material in making alcohol.

Making alcohol using sorghum grains

In China, the main method to make alcohol is fermenting starchy materials. (Figure. 12). Because of its high starch content, sorghum grains are an

important material of making alcohol. Normally, 1,000-kg sorghum grains can produce 390-L alcohol (9).

Figure 12: Flow Figure of Making Alcohol 

Making alcohol using sweet sorghum stalks

Sweet sorghum is similar to sugarcane as its sugar storage organ is stalk. Sweet sorghum stalk contains considerable sugar and rich fibre. Compared to sugarcane, the advantages of sweet sorghum are:

A: it reproduces with seeds, do not use stalk as seedling;

B: growth period is only half of sugar cane.

Figure 13 is flowing diagram of using sweet sorghum stalks to make alcohol (4)

Figure 13: Flowing Diagram of Making Alcohol by Using Sweet Sorghum Stalks

In this procedure, the process of converting starch into sugar is eliminated shortening the producing time. The stalks can be utilised comprehensively. For example, the juice of the stalks cane used to produce alcohol and nitrogenous fertiliser which can satisfy the need of crops or herbage, leaves and residue may be used as feed, waste is used to produce methane used to generate electricity. So, the main products of pastureland are not only livestock products, but also liquid fuel. It takes about 18.2 tons sorghum stalks to produce one ton alcohol, the net income is 300-yuan (1).

Extracting pigments from sorghum glume

Most of sorghum pericarps and glumes are coloured, According to variety, their colour can be dark to light, such as brown, red, yellow, and white. Sorghum pigments belong to isoxanthoketone galactoside which has many kinds of components. In ancient China, people found glume pigment sorghum to be very stable useful to dye woollens, cotton, linen, and other textiles. However, most of sorghum glumes are either discarded or used as fertiliser,

because no suitable pigment extracting method. In recent years, researchers in Sorghum Institute of Liaoning Academy of Agricultural Science have done a great deal of research work about pigments on its physiochemical properties, extracting methods and applications. They successfully extracted pigments from sorghum glumes, named Sorghum Red Pigment (Figure 14) (3). After the pigments extracted, sorghum glumes can be reused. For example, if one can use sorghum glumes as material for making vinegar and extracting glue, or as fillings to produce mushrooms. When it encounters light and heat, the pigments keep stable colouring and excellent function. Along with improvement of people's living standards, edible pigments are evolving from synthetic pigments to natural pigment. It is because synthetic pigments are harmful to human's health. People are more and more interested in natural pigments. Based on Chinese Law, synthetic pigments are not permitted to be used in food and cosmetics. Extracting pigments from sorghum glumes provides a good way for people to get treasures from waste.

Sorghum Red Pigment is dark red powder with natural soft colour, containing no poison or no special odour, which is able to be used in foods, meat products, beverage, cosmetics, medicine and textiles.

The main components of sorghum red pigment are 5,4'-dihydroxy-7-0-isoxanthoketone galactoside (molecular formula: $C_{21}H_{20}O_{10}$, molecular weight: 432.37) and 5,4'-dihydroxy-6, 8-dimethoxy-7-0-isoxanthoketone galactoside (molecular formula, $C_{23}H_{24}O_{12}$, molecular weight, 492.42), Their structural formulae are described as Figure15 (2).

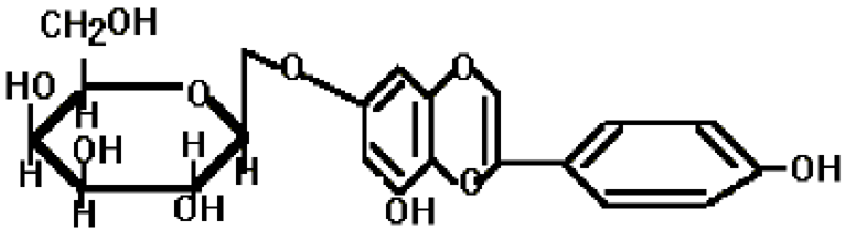
Material (sorghum glumes) Cleaning Washing Extracting Filtering

Concentrating Centrifuging Drying Sterilising Inspecting Packing

Products

Figure 14: The General Extracting Method of Sorghum Red Pigment 

(1) 5,4'-dihydroxy-7-O-isoxanthoketone galactoside



(2) 5,4'-dihydroxy-6, 8-dimethoxy-7-O-isoxanthoketone galactoside

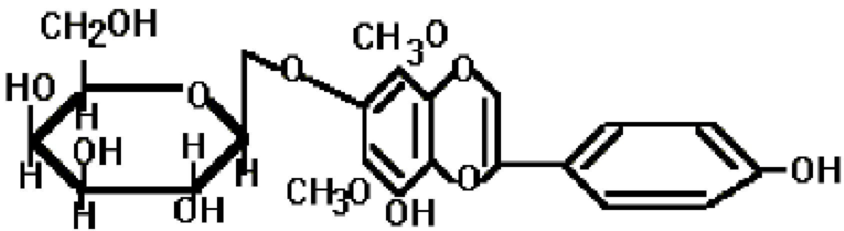


Figure 15: The Structural Formulae of Sorghum Red Pigments

In 1992, The Extracting Technology of Sorghum Red Pigment declared their

invention patent. In 1995, Liaoning Keguang Natural Pigment Company Ltd. was established, which is a joint venture of Liaoning Academy of Agricultural Sciences, China and Koyo Shangyo Company Ltd., Japan. Their products fall into two series: alcohol soluble (A) and water soluble (W), produced through 6 technological processes. A-100, A-200,W-300,W-400, W-500, etc. are the main varieties sold at home and abroad. Annual output of natural Sorghum Red Pigment is more than 20 tons. Both economic performance and social effects are good. Following is some applications of Sorghum Red Pigment (6).

Meat products

Between August and November 1992, Shenjin Meat products Factory of Shenyang used Sorghum Red Pigment researched by Sorghum Institute, Liaoning Academy of Agricultural. Science as an additive for ham, (The dosage was 0.34 g Sorghum Red Pigment in one kilogram ham.) roasted 400 kg ham at 300^{0}C, which expresses soft nature tone and reality.

Cosmetics

Baita Daily Chemical Product Factory successfully used Sorghum Red Pigment on lipstick and shampoo. The Products has soft and bright colour, therefore natural Sorghum Red Pigment is thought to be a substitute of synthetic pigment in cosmetics.

Medicine: Using as colouring agent of sugar-coated tablets and capsules

In November 1992, Shenyang Pharmaceutical College successfully used Sorghum Red Pigment as colouring agent of sugar-coated pills. In March 1994, Tiexi Capsule Plant of Shenyang, added 4.6 g Sorghum Red Pigment per kilogram Capsule, got ideal results. The product is dark red, smooth, with no unpleasant door, no gaps or shapelessness. When inspected, every target adheres to national standards.

Using as Colouring Agent of Traditional Chinese Patent Medicine

Xinmin Hongqi Pharmaceutical Factory used Sorghum Red Pigment as colouring agent of traditional Chinese patent medicine. The problem has been resolved for the colour tone match of traditional Chinese patent

medicine to pharmaceutical requirements.

Candy

In April 1993, Shenyang Bakery successfully made 10 kg fruit candy using Sorghum Red Pigment with the dosage of 0.025 g. The candy had stable colour with no unpleasant odor. The results were satisfactory.

Another confectionery manufacturer, Shenyang Dayi Manufactory, used Sorghum Red Pigment as a colouring agent of health-care candy, and got positive results. Moreover, Sorghum Red Pigment also can be used in colouring of beverage, jellies, cakes, and textiles.

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CHAPTER VIII: Industrial use of sorghum

2.1 Pre-harvest operations

2.2 Harvesting

2.3 Threshing

2.4 Drying

2.6 Cleaning

2.8 Storage

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2. Post-Production Operations

When sorghum grains are ripe, it is time to harvest. Using appropriate methods to harvest, thresh, dry and store at right moment, are the best guarantee of getting a high yield and good quality.

2.1 Pre-harvest operations

If the sorghum pollinates and fertilises normally, grains will form rapidly. Usually, it takes about 30-50 days from fertilising to ripening. The period includes three stages--milk stage, dough stage and ripening stage. During milk stage, sorghum grain is green or light green in colour, filled with milky liquid. At this the moment, embryo has the ability to germinate. In the dough stage

the grain is slightly yellow with (almost solid and waxy) fillings. If you press the grain, it is not easy to crush which signals its ripening stage. During this stage, the head and grain appear in its original shape and colour with moisture content of 15-20 percentage. The highest accumulation of dry substance is in the dough stage, which contains about 20 percentage moisture. It is the optimum harvest time (5,8). If harvest takes place too early, the filling stage will be interrupted causing low 1,000-kernel weight, which corresponds to lower grain yield. If harvesting is too late, there will be moisture loss, natural grain falling, sprouting on the head, drought or respiration. The 1,000-kernel weight will drop, thus causing a decrease of grain yield. (Table 3) (5). Sweet sorghum, forage sorghum or ensilage sorghum, can be harvested at any time from heading stage to milk stage. The optimum time to harvest ensilage sorghum is at the end of the milk stage to obtain the highest biomass and nutrition. If grains are intended to be used as food and the stalks and leaves as ensilage, then the optimum harvest is at the end of the dough stage (4).

In addition, different harvest time will affect grain quality and viability. Premature harvesting will result in protein content that is a little higher while

starch content and unit weight is lower. By slightly delaying harvesting time, starch content and unit weight are almost same, but protein and soluble sugar content drop. Late harvested sorghum measures lower for all indices (Table 3). In addition low temperatures decrease germination rate. Grains for seed must be harvested at the right time.

Table 3. The Influence of Harvest Time to Sorghum Grain Quality of Xiongyue 253

Harvesting time
Grain yield
(%)
Unit weight
(g/L)
Moisture
(%)
Starch
(%)
Soluble sugar

(%)
Protein (%)
1,000 Kernel weight (g)

Early milk stage	100.0	700	66.6	66.6	1.41	8.63	7.5
Late milk stage	123.9	727	37.5	70.2	1.50	7.79	26.0
Middle dough stage	144.6	744	33.3	72.0	1.62	7.86	29.0
End of dough stage	162.1	741	20.0	72.9	1.50	7.74	29.0
Ripening stage	160.9	739	13.0	68.4	1.41	7.76	29.5

2.2 Harvesting

In China, there exist two harvest methods--traditional hand cut and

mechanical harvest. At present, the dominant way is manual harvest:

a. The harvest tradition of the Chinese;

b. Reflects the economic situation, as many Chinese farmers are still poor;

c. Most of planting fields for sorghum are on hillsides and fields are too small to harvest with machines;

d. Too many sorghum cultivars are planted, and sometimes plants are not in good condition;

e. There are not enough satisfied harvesters.

Manual harvesting cuts sorghum with a sickle. The first method is harvesting the plants with their heads on. The method is to cut plants first, then bind 20-30 plants together. After binding all the plants, a vertical rafter is made using 25 bundles for drying the sorghum in the field. If rainfall is not too great, the farmers put sorghum bundles on the ridge of the field for drying.

The height of stubble is diverse. If the stubble is used as fuel, the stubble height will be 30 cm, otherwise, it will be 10 cm. After drying about 10 days, the heads are cut (about 50 cm long) and bound. Then the heads are sent to threshing site. This method can clear the fields allowing farmers to prepare fields for the next season. It is the most popular production method.

In the second method the sorghum heads are cut first tied up and dried. The straws are cut last. The method is primarily used in the coastland, low-lying land and southern China. Sometimes, the method is also used to harvest the short-stalked variety.

In some areas of Henan, Shanxi and Shandong province, the farmers dig the whole sorghum plants with roots, and then cut the heads in order to get more fuel,

Two kinds of mechanical harvesters are used in China. One is designed for short-stalked sorghum, the other for long-stalked sorghum. The advantages of mechanical harvest are efficiency and fewer losses.

The Dongfeng combine harvester is for short-stalked sorghum demanding sorghum less than 100 cm. However most Chinese sorghum cultivars have medium-long-stalks of 180-250 cm high. This machine is seldom used.

The Liaoning 4G-4 sorghum harvester is used for long-stalked sorghum varieties. Its efficiency is not as high as the combine, but it has only 15 kg grain loss per hectare. Today, the small holders and subsistence farmers use the traditional hand cut method. Harvesters are used on large farms.

2.3 Threshing

After being fully dried in the sun, sorghum needs to be threshed. The threshing methods can be divided into artificial threshing, animal threshing and mechanical threshing. Along with the rise of mechanisation, more and more farmers use mechanical threshing machines. Table 4 details different threshing methods (4).

2.4 Drying

Grain drying is the key to ensure good storage quality. Without drying, the moisture content of sorghum grains remains too high. The grains generate heat because of its respiration and a great amount of nutrition is wasted, so the edible and seed grain qualities decrease.

Natural drying is usually used for sorghum production, in the case of small holders and subsistence farmers. They spread sorghum grains out about 10 cm thick. To increase the irradiated area of grains, some small ridges can be made from south to north. Then they turn the grain over again and again to decrease moisture more rapidly. After 3~4 days when the moisture content is about 13 percentage, the grain is ready to store.

More and more grain depots and seed companies use mechanical drying. There are 8 kinds of dryers shown in Table 5.

Different sorghum cultivars should be dried separately. Also to speed up the drying process, the grains with different moisture content should be treated separately.

Table 4. Difference of Three Sorghum Threshing Methods

Threshing method
Threshing tools

Procedure
Threshing output (kg/person)

Artificial threshing
flail
wooden fork
Spread sorghum heads in the threshing field, dry in the sun for half a day, then

beat sorghum heads with flail. After most of grains have been threshed, turn over sorghum heads, beat sorghum heads again. Repeat these steps until all the grains are threshed. The method is inefficient and labour intensive, so it is seldom used now.

250

Animal threshing

livestock
stone roller
wooden fork

Spread sorghum heads on threshing field (about 25-35 cm thick). Then let livestock pull the stone roller (rolling and pressing). When most of grains are threshed, turn over sorghum heads. Roll stone roller again, until all of grains are shelled. This is the most popular method in China.

1000

Mechanical threshing

drum thresher

**large cereal-
thresher**

Place sorghum heads into thresher. Inspect the heads frequently to see if all the grains have been threshed. Monitor if there are crushed grains. The advantages of the method are high efficiency, clean threshing and low glumaceous rate.

4000

2.6 Cleaning

In the course of harvest, storage, and transportation, many kinds of impurities can easily enter the crop. Cleaning becomes a necessary step to ensure grain quality and machine safety.

In sieve cleaning separating grains from impurities by size is the principle of the method. The most popular equipment types are the vibrating screen and holding sieve (4).

The vibrating screen is composed of a deed hopper, sieves, dust remover, cleaner and drive equipment. The sieves lie on three layers with different slopes. The slope of the first layer is 3-5 degrees for removing large foreign matter. The slope of the second layer is 4-6 degrees for screening medium-sized impurities. The slope of the third layer is 6-9 degrees for cleaning impurities smaller than the grains.

The holding sieve is suitable to unprocessed grains with more glumaceous and obstinate grains. The components are the holding sieve, rubber mill and

specific gravity separator. The use of the holding sieve is to separate good grains from glumaceous or obstinate grains. The rubber mill is for dehusking. The specific gravity separator can separate glumaceous grains from obstinate grains.

The principle of pneumatic cleaning is to separate impurities using the various specific gravity values of grains and impurities. The common equipment of pneumatic cleaning is the wooden windmill, aspirating separator and model 600 double board aspirating bellows.

2.8 Storage

Sorghum grains are not only an important food crop, but also provides animal feed and major industrial material. Maintaining good sorghum grain quality for food, industry, feed and seed are the significant objectives of storage. Over the period of storage, the grains' physical and chemical changes will have major impact.

During sorghum storage, air temperature, humidity, storage microbes, storage

pest and moisture content of grains are key factors which affect storage quality. Among these factors, temperature and moisture content are the most important ones. Lower temperature and moisture content are the most efficient to restrain mould growth. The lower the moisture content, the longer keeping the grains from mildewing at high temperature. For example, if grain moisture content is 13 percentage, the grain temperature should be lower than 30 ^{0}C, but when grain moisture content is 14 percentage, the highest temperature should be 25 ^{0}C.

In order to safely store sorghum, according to grain quality, utilisation, moisture content, climate, and storage equipment, different storage methods can be used. The common storage methods in China are: drying storage, low-temperature storage, sealing storage, lack oxygen-free storage, ventilating storage and chemical storage. Table 6 details these methods. (4)

Generally, small holders and subsistence farmers use natural storage methods, while large producers and grain depots use natural and mechanical storage methods.

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CHAPTER VIII: Industrial use of sorghum

4. Pest control

While sorghum is stored, keeping pests away is a very critical task because insects, moulds, mice and birds can cause tremendous loss and pollution of grains. Table 7 presents major pest species (4).

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CHAPTER IX SORGHUM AND MILLET: Post-harvest Operations

Preface

IDRC describes its mission to be[1]: "The cornerstone of the Centre's foundation is a commitment to improve people's lives through the generation and use of knowledge. The sustainable and equitable use of global and indigenous resources depends on equitable access to knowledge and research capability, and on men and women's direct involvement in their own social and economic progress.

"To improve lives through research and the application of knowledge, the Parliament of Canada created and empowered IDRC with a far-sighted legal mandate (IDRC Act, 1970) "to initiate, encourage, support and conduct research into the problems of the developing regions of the world. In fulfilling this mandate, the Centre has concentrated on encouraging and supporting Third World scientists to conduct research in their own institutions and, in so doing, has assisted the developing regions to build up the research capabilities, the innovative skills and the institutions required to solve their problems."

The thrust of this document will be to identify the issues researched, the institutions, which performed the research, and where detailed results can be found.

The applied research supported by IDRC was directed to three geographic areas: Eastern and Southern Africa, West Africa, and India.

1 Taken from IDRC publicity materials.

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CHAPTER IX SORGHUM AND MILLET: Post-harvest Operations

1.3 Primary product

1.4 Secondary and derived products

1.5 Requirements for export and quality assurance

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1. Introduction

1.3 Primary product

Table 3 in the book *Abrasive-disk dehullers in Africa* (Bassey, Michael W., and O.G. Schmidt. 1989.) provides a listing of products in Africa. IDRC could furnish the FAO with an electronic copy in a desktop publishing language. The other author, Dr. Michael Bassey, is currently with IITA, and would likely agree to the re-use of the table, as does O. Schmidt, who is the consultant preparing the present IDRC document.

1.4 Secondary and derived products

Table 3 in the book *Abrasive-disk dehullers in Africa* (Bassey, Michael W., and O.G. Schmidt. 1989.) provides a listing of products in Africa. IDRC could furnish the FAO with an electronic copy in a desktop publishing language. The other author, Dr. Michael Bassey, is currently with IITA, and would likely agree to the re-use of the table, as does O. Schmidt, who is the consultant preparing the present IDRC document.

1.5 Requirements for export and quality assurance

ICRISAT for its grain and cereal quality research group in Hyderabad, plus the work by Manel Gomez while at the SMIP in Bulawyo, Zimbabwe, are the best resources for this section. Mrs. Gomez was in contact with the Carlsberg Laboratories in Denmark, where some very insightful and useful work was done by Hallgren (Hallgren, L. 1985.)

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CHAPTER IX SORGHUM AND MILLET: Post-harvest Operations

2.6 Cleaning

[2.8 Storage]

2. Post-Production Operations

The applied research supported by IDRC emphasised small scale processing of sorghum and pearl millet near the farm in West Africa, Eastern and Southern Africa, and India. The key hardware technology was the dry abrasive disc dehuller, which was able to remove the seedcoat. Women have traditionally decorticated sorghum and pearl millet to improve the taste and eating quality of the grains. Decorticated grains also benefit the flavour of the flour produced from milling. Manual decorticating was time and labour consuming; the dehuller technology was intended to free women from this drudgery.

The experiences with research on processing of sorghum and millet in the semi-arid areas of Africa between 1970 and 1987 were reviewed in the monograph *Abrasive-disk Dehullers in Africa: from research to dissemination* (Bassey and Schmidt, 1989). This paper was widely distributed to institutions

and libraries in the Third World. The abstract maintained:

"Recent droughts in the Sale and eastern and southern Africa have increased the urgency with which national policymakers are considering drought-resistant crops. National systems for agricultural research in many African countries have strengthened their programs to improve sorghum and pearl millets. A food crop, however, only becomes food when it is actually consumed. Efforts to increase food production must, therefore, be matched by corresponding research on food after harvest. The absence of appropriate dehulling equipment, especially for small grains, has often been cited as a reason for past national neglect of these cereals.

"This publication reviews the development of small-scale, inexpensive, versatile abrasive-disk dehullers in Africa. The rural deployment of mechanical dehullers offers an opportunity to enhance national cereal self-sufficiency and to increase use of the productive capacity of the low-rainfall areas of Africa.

"The topics discussed in detail include the need to understand traditional food habits and preferences; the scope for applying small dehullers in Africa;

detailed technical descriptions of various dehuller designs and criteria to be considered in a design process; important grain characteristics as they relate to dehulling and the effect of the dehuller's abrasive agent on the grain; installation and operation of some typical, rural, small-scale milling systems; and the process of introducing technology as one moves from applied research to applying the results."

The scope of the work done in Africa since the mid-80s and in India since 1975 is summarised in the following paragraphs:

West Africa

In Senegal, close collaboration between the National Agricultural Research Institute and a machinery manufacturer led to the latter's marketing of a small-scale dehuller (Mbengue, H.M. 1990, Seck, I. 1990). By now, total volume of sales is in the scores, if not in the hundreds. The agricultural research institute tested village based application of the dehuller technology as small enterprises to the sorghum and the pearl millet subsistence food systems. SISMAR accordingly made the prototype design more rugged, easier

and cheaper to build. Technical reports can be obtained from Centre National de Recherches Agronomiques (CNRA), B.P. 53, Bambey, Senegal, and equipment for dehulling and for wet milling can be obtained from Societe Industrielle Sahelienne de Mecaniques de materiels Agricoles (SISMAR), BP3214, Dakar, Senegal.

In Gambia, the Catholic Relief Services modified the original Canadian design of the mini-dehuller, contracted the manufacture of the dehuller to local metalworking workshops, and installed approximately 20 small self-sustaining enterprises serving their own neighbourhoods where pearl millet was the main cereal staple. (For research reports and equipment suppliers contact the Catholic Relief Services, P.O. Box 568, Banjul, The Gambia.)

In Niger, a Canadian-based non-governmental agency, in association with the Ministry of Agriculture and Adult Education Services, tested the rural appropriateness of two dehuller and milling installations as co-operatively owned enterprises in the semi-arid areas which depended on pearl millet as the main cereal staple (Mahamadou, et al. July 1990.). Reports can be obtained from Institut pour L'Etude et L'Application du Developpement

Integre. Institute for the Study and Application of Integrated Development (ISAID), B.P 2821, Niamey, Republiqe du Niger.

In Mali, the Compagnie Malienne de Developpement des Textiles (CMDT) (BP 487, Bamako, Mali), sought to improve cotton productivity by introducing dehullers to the participating farmers to alleviate food preparation problems with the sorghum subsistence crop part of each smallholder's lands.

Some early work was also done in Maiduguri, Nigeria in 1972-74, and at the Food Research Institute in Accra, Ghana.

These projects all had an initial introduction of hardware. Closer identification of the household level food problem and testing of the hypothesis that a hardware intervention was the most appropriate kind of applied research, prompted the advent of techniques called Rapid Rural Appraisal to the researchers (Gueye, B. and K. Schoonmaker Freudenberger, 1990; Schoonmaker Freudenberger, K. 1990)

The projects working on dehullers in West, Eastern and Southern Africa

participated in a number of workshops aimed towards networking among countries. The purpose was to link the post-harvest research closer to national policy and to biological production-oriented research. Another objective was to document a series of comprehensive national case studies (Bassey, and Schmidt. 1989). Another important issue was to understand the food/feed system from production to consumption in each national or sub-national context. Efforts were focussed certain that applying hardware technology at the rural level was indeed the most cost-effective intervention.

Eastern and Southern Africa

Work in Botswana, proceeded in two stages. Stage 1 between 1976 and 1978, established a small sorghum dehulling and grinding factory with the Botswana Agricultural Marketing Board. In the second stage, between 1978 and 1981, a medium size dehuller was adapted for use by rural milling enterprises, at the Rural Industries Innovation Centre (contact the RIIC, Private Bag 11, Kanye, Botswana for purchasing small milling systems and engineering drawings, as well as for copies of research reports). A minimum of 25 rural enterprises flourished by the early eighties, leading to the formation

of the Botswana Mill Owners Association (PO Box 483, Gaborone, Botswana).

It must be emphasised that in the mid-70s sorghum was still the preferred staple grain in the country, partly responsible for the rapid adoption of suitable technology to replace women's manual decortication labour. As one example, within two years of establishing the small dehulling and milling enterprise at the RIIC, it was processing up to 14 tons of sorghum daily in two 8-hour shifts, especially in the first three months post harvest. The majority of the processing was for traders and grocery stores who packaged the flour in 1kg, or 2 kg paper bags, and in 2.5 kg and 5 kg plastic bags with their own brand names. An important part of the mill's activity was to also process the small amounts (5 kg-90 kg) brought by individual families living within walking or donkey cart distance of the mill.

During the 80s, the RIIC manufactured and sold no less than of 70 additional systems for the semi-arid areas of South Africa, formerly known as Bantustans. The manufacture of the dehullers is now being done by two different companies in Botswana, with the RIIC continuing to do the marketing, installation of the machinery and the training of the operators and

owners of the enterprises.

In Zimbabwe, the Environment Development Activities-Zimbabwe (ENDA-Zimbabwe, Box 3492, Harare, Zimbabwe) conducted initial rural trials of small-scale dehuller/milling enterprises between 1987 and 1989. Next ENDA became the implementing agency, on the behalf of the Ministry of Agriculture of a CIDA-(Canadian International Development Agency) supported technology-dissemination project (1989-93) resolved to establish up to 60 self-sustaining enterprises. The selected crops were sorghum and pearl millet.

ENDA-Zimbabwe directed an extremely active project on traditional grains. In the project traditional cultivars were exchanged among farmers' groups throughout the semi-arid areas of Zimbabwe, and yield and eating qualities (measures of household acceptance) were being tracked by ENDA. This was done with active collaboration with the National Agricultural Research and Extension systems, and with the SMIP (Regional Sorghum and Millet Improvement Program , PO Box 776, Bulawayo, Zimbabwe) program in Bulawayo. (Note: This project was not funded by IDRC) As the policy criteria began to change, a useful assessment was written in late 1993 by and for

ENDA-Zimbabwe on sorghum and millets, also known as the small grains (Rukovo, A. and J. Gwitira. January 1994). In 1992, the University of Zimbabwe's Development Technology Centre (DTC, PO Box MP 167, Mount Pleasant, Harare, Zimbabwe) began a three year project to follow up on enhanced community participation in problem identification and intervention testing to solve problems in the sorghum food systems in the semi-arid areas, particularly in the South of the country. ENDA can supply technical reports, and contact with local equipment manufacturers.

In the early nineties, a regional ENDA was established for southern Africa, and it expanded its program to include dehulling of pearl millet in Namibia. (See also the UK NRI efforts: Hay et al. 1991; Dendy, D.A.V. 1995)

The Ethiopian Nutrition Institute (ENI, PO Box 5654, Addis Ababa, Ethiopia) in the early 80s worked on several threads: measuring the nutritive absorption of sorghum-based gruels in small children, the feasibility of using sorghum flour for the production in volume of injera (unleavened fermented pizza-sized flat "breads") by a state food supplier, and the incorporation of sorghum flour in weaning foods manufactured and marketed by a state

corporation. Prevailing policy inhibited the impact of the work.

Parallel to this attempt the Institute of Development Research (IDR, Addis Ababa University, PO Box 1176, Addis Ababa, Ethiopia), placed one dehulling-milling system with a rural agricultural co-operative, in conjunction with the Alemaya University in the province of Hararghe. State policies, still in effect, sought to replace all individual enterprise ownership with co-operatives (with little entrepreneurial skill), The experiment was affected first by Ethiopia's severest drought in the mid eighties, and, later, by a change in government which established a new policy framework.

The Kenya Industrial Research and Development Organisation (KIRDI, PO Box 30650, Nairobi, Kenya) in the mid-80's accrued useful knowledge about the technical and economic feasibility of processing sorghum and pearl millet by mechanical means. However, the involvement of small-scale entrepreneurs, and the accrual of knowledge about enterprise development did elude that IDRC-supported project. KIRDI did achieve a useful survey on the acceptability of dehulled (pearled) whole sorghum grain by the general population and institutions such as schools (Anonymous. 1990). KIRDI can supply research

reports, as well as contacts with local equipment suppliers.

The University of Nairobi's College of Agricultural and Veterinary Science, (c/o Dean of Agriculture, P.O. Box 29053, Kabete, Kenya) also conducted a related project, Sorghum and Millet Food/Feed System, which sought to encourage increased networking among all national researchers who were active on aspects of the crops from production to consumption. They convened several national workshops, did some field-work and maintained a modest, specialised library collection on the topic. (See also Singh et al., 1992)

In Tanzania, the Small Industries Development Organisation (SIDO, PO Box 2476, Dar es Salaam, Tanzania) starting from 1979 conducted two phases of IDRC-supported efforts to determine where and how small enterprises dehulling and milling of sorghum would fit into the rural situation. Prevailing agricultural policy, weak rural infrastructure, long distances from Dar es Salaam to the experimental sites in the drier west, and punishing road conditions militated against useful results. Research reports and contact with local manufacturers can be obtained by contacting SIDO.

A companion project on sorghum utilisation at the Sokoine University Department of Food Science in Morogoro (PO Box 3006, Morogoro, Tanzania) provided some useful technical insights, but had little impact on utilisation of sorghum by the populace.

The Sokoine University's Department of Agricultural Economics, in collaboration with the Regional Sorghum and Millet Improvement Program (SMIP) in the early 90s studied the trading and pricing system of sorghum and millet in the post-liberalisation economy providing important knowledge for policy formulation. A national workshop was held in May 1993 in Arusha and workshop proceedings can be obtained from the sponsors.

The Zambian Small Industries Development Organisation (SIDO, PO Box 35373, Lusaka, Zambia) began in 1986 to experiment with dehullers in rural settings. Weak infrastructure and foreign exchange limitations, as well as staff limitations resulted in indifferent findings. Similarly, few useful results seem to have been achieved by the work done by the Uganda National Council for Scientific and Industrial Research, at a time when that country was under extreme military and economic stresses.

In 1987 the Sorghum and Millet Improvement Project (SMIP) of the Southern Africa Development Cupertino Conference (SADCC), implemented by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), held a conference to review the utilisation of sorghum and millets, and IDRC presented its experiences there (Schmidt, O.G. 1992). There has been a continuing interaction between these two institutions on the subject of the semi-arid food grains.

The Post Production Systems Group of IDRC paid increasing attention to two issues, which related to the foregoing group of projects, which had a technology-led theme. The two issues were to improve national knowledge of the total food system of sorghum and pearl millet, and to link this understanding more directly to national grains marketing policy issues. As well, IDRC sought to bring about a closer dialogue among the national food systems researchers and international donors in the post harvest area (Anonymous. 1987, Anonymous. 1991; see also Rohrbach, 1990).

Sorghum and pearl millets have significant impact on the nutrition of the human body, especially for young children, in areas where they are the main

staple cereals. A workshop in 1987 examined current knowledge about household level food preparation techniques, including those for sorghums and pearl millets (Alnwick, D., S. Moses, and O.G. Schmidt, eds. 1987). These proceedings of the workshop can be worthwhile to the village level nutrition worker and to the food scientist.

India

Between 1975 and 1990, researchers at the College of Home Science of the Andhra Pradesh Agricultural University (APAU) in Hyderabad were involved in a systematic process of promoting the utilisation of sorghum (Pushpamma, P. 1993). The abstract of the book will gives a good description of the topics addressed:

"The need to increase the use of sorghum is explained and the current food system using sorghum is described, looking at improved varieties, marketing, storage, current processing and utilisation methods, and the nutritional status of sorghum foods. The effects of dehulling on product quality and nutrient status are considered, emphasising that flour from sorghum milled in

the right way can compete with wheat and rice flours, at much lower cost, in areas where sorghum is extensively grown. Finally, the problems of using sorghum as a substitute in popular and traditional cereal foods are considered and the details of successful food enterprises based on sorghum, with active support from Andhra Pradesh Agricultural University, are described. Various countries have attempted to get this kind of work done: nowhere else has the whole chain of research been so logically and successfully designed and carried through right to the point of successfully promoting small-scale, sorghum-based, food enterprises."

Here is a brief description of the applied research process:

"During the first phase of the project, market surveys were carried out in three agroclimatically different regions of the state-Coastal, Rayalaseema, and Telangana-to assess production, storage, processing, and consumption practices for sorghum and their effects on nutritive availability."

"The second project phase was to elaborate feasible ways of upgrading these operations using a small mechanical dehuller to remove the drudgery of

traditional processing methods and obtain sorghum products that could be used in a wide range of popular foods, including weaning and supplementary foods for infants and mothers. Extensive field testing was conducted to establish the levels of demand for mechanical dehulling systems in rural Andhra Pradesh and the acceptability of products based on dehulled sorghum."

"The last project phase concerns attempts to develop feasible systems for establishing small enterprises based on sorghum processing to produce nutritive foods for rural-household, semiurban, and urban markets in Andhra Pradesh. Also, the feasibility of developing small enterprises operated by women was considered as a means of directing additional income specifically to vulnerable socio-economic groups-women, children, and infants-and have a positive impact on improving nutrition in the poorer sectors. (Two extensive existing government programs-Integrated Child Development Services (ICDS) and Development of Women and Children in Rural Areas (DWCRA)-were identified to serve as channels for implementing such activities regionally)."

The previous document was written for scientists. Dr. Pushpamma had the

opportunity to present the experiences summarized above in the form of a manual, as a case study of Development Market Research and Social Marketing (Pushpamma, P. 1994). This version is written for the lay practitioner who is involved in social development activities.

A related study, centred on the western dryland region of India, highlights the utility of rapid rural appraisal (RRA) in assessing community nutrition problems and formulating recommendations for nutritional improvement (Kashyap, P. and R.H. Young. 1989). The village of Parbhani is located in Maharashtra State, India.

Special mention should be made of John Cecil's work on industrial milling of sorghum, work which anticipated questions about the technical and economic feasibility (Cecil, J.E., 1986). The work will probably be highlighted by the submission from the UK Natural Resources Institute (NRI).

2.6 Cleaning

The main distinction is between industrially processed bulk grain and small

lots (5-90 kg) brought to a small-scale dehulling/milling enterprise by individuals. In the former case, stone removal and soil sifting equipment are required. In the latter, the household has already cleaned the crop with great care since the grain is to be used for the family's food eliminating the need for additional cleaning.

2.8 Storage

In the African context, it is important to distinguish between a subsistence crop which provides food for the household, and a cash crop sold to industrial processors. The smallholder subsistence farmer, from Ethiopia to Southern Africa uses "traditional" seeds. These are non-hybrid low yielding species with the preferred food and taste qualities. Often a mix of cultivars are planted to spread the risks against drought and pests while in the field. The cortex is extremely hard and insect resistant. Storage of traditional varieties does not present a major problem. For example, there are traditional hard varieties in Zimbabwe, which store well for years, maintaining good seed viability. Problems of storage have emerged as farmers adopt higher yielding varieties, with softer cortexes or other propensities to

insect and mould infestation.

The industrial processing of sorghum for food was systematically inhibited by state policies in Africa until the mid to late 80s. It is advised that readers refer to ICRISAT contribution for relevant technical information on storage for industrial processing, or contact commercial manufacturers of processing machinery.

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CHAPTER IX SORGHUM AND MILLET: Post-harvest Operations

5.2 Major problems

5.3 Proposed improvements

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5. Economic and Social Considerations

5.2 Major problems

The most problematical issues for smallholders are those presented by

national agricultural and marketing policies, which had a systematic, depressing effect on the economy of the rural household. (Also see Mwangi et al, 1993)

West Africa

A major policy package was defined by the joint fiscal policies of the overvalued CFA, the common currency among the French-speaking countries, underwritten by France until the end of the eighties.

One result was that relatively inexpensive imported wheat displaced other products for urban populations induced to switch to bread and other wheat products. This left the rural population to fend for itself. There was no urban demand for the locally grown semi-arid cereal grains. Several countries attempted to ensure urban markets for rural surpluses of sorghum and pearl millet by unsuccessfully seeking legislation to force local bakers to use a composite wheat and pearl millet or wheat and sorghum flour.

After the French withdrew and the CFA was floated, the cost of imported

wheat more than doubled. National economies are still adjusting to this change. It is anticipated that urban food industries will look carefully at the lower cost of indigenous cereals, and that urban families will increasingly buy indigenous grains in ready-to-cook forms in the local open-air markets.

Nigeria has its own interesting story to tell with regard to sorghum. When the petroleum revenues dried up, a ban was placed on the imports of all non-indigenous cereals. One major beneficiary of that policy was the soft-drinks industry, which made non-alcoholic drinks from malted sorghum. Dr. Tunde Obilana of the SMIP in Bulawayo was preparing a review of the monumental changes which took place in Nigeria for use of sorghum (SADC/SMIP, P.O Box 776, Bulawayo, Zimbabwe).

Eastern and Southern Africa

Two sets of policies constrained the smallholder farmers of sorghums and pearl millets before the spate of structural adjustment and market liberalisation programs which began in the mid eighties. These policies were initiated shortly after independence, steadfastly maintained for 20 to 25 years

in spite of the socialist or capitalist political leadership.

The first policy affected to industrial organisation and trans-border trade. The state assumed that it was best qualified to regulate and manage food processing immediately after harvest until it reached the consumer. There was a tendency to favour the needs of the urban consumer, and to assume that the rural consumer was not a relevant participant in the "modern" post-harvest food chain. The second policy was to establish maize as the sole staple cereal by setting pan-territorial producer prices, fixing consumer prices, and subsidising farm inputs such as fertiliser and maize seed for planting.

The post-independence planning viewed the country as an integral unit, isolated from its neighbours. Under this scenario rural areas were suppliers of raw materials for the cities, usually the capital alone. Grain processing was therefore visualised as one single plant in the capital, with the capacity to mill the country's total needs. Intermediate size plants at, say, the provincial headquarters were, on the whole, not part of the plan. Even if the country's "grain basket" was a thousand km from the capital, the harvest was transported to the capital, and the resultant products were shipped back to

the urban and rural areas. Transport costs became a substantial portion of the price consumers paid for the ready-to-cook product. While small-scale, rurally located milling systems or hammermills for maize were encouraged, such policies were not necessarily aligned with agricultural and marketing policies because small scale enterprise was the responsibility of a separate Ministry.

The effect of pan-territorial prices was that each farmer, regardless of the distance from industrial processors, was paid the same price for the grain harvest. The state absorbed or equalised the costs for transport, collection of the grain and distribution of the milled product. Equally, the cost of inputs was the same throughout the country.

The policy favouring maize, coupled with the pan-territorial producer price, meant that a farmer in distant semi-arid areas was in effect being urged to plant maize. Surplus quantities only of maize were saleable, and could bring in cash to the household, regardless of the agro-climatic zone in which the farmer lived and tilled. Further, the national cereals marketing agency, a monopoly also announced annual producer and consumer prices for the

cereals and other key food crops. These policies had the effect of changing the food preferences of consumers in the semi-arid areas away from the semi-arid food grains to maize, and of altering farming skills. Whenever drought occurred, food relief to the semi-arid areas was often in the form of maize, not sorghum or millets. Subsidised fertiliser further induced the farmers in the semi-arid areas to plant maize, especially with subsidised hybrid seeds. To offer one example, Zimbabwe for many years had regulations which prohibited the movement of whole grains from grain surplus to grain deficit areas. All surpluses had to be sent to the capital city, and deficit areas were supplied with milled maize flour only, not with whole grains.

Smallholders, in the era following the structural adjustment programs and market liberalisation now face a totally new set of constraints and opportunities. They receive less money for their maize surplus than they did before while the cost of hybrid seed and of fertiliser has increased dramatically. The newly permitted intermediate free-enterprise marketing companies charge the real transport costs. These new marketing companies have to learn techniques of storage of intermediate-sized quantities of harvests, at the district and small-town level. Initially, one can predict

increased post-harvest losses, until those skills and techniques are learned and applied. Farmers, in the meantime, now possess reduced levels of knowledge of farming the drought-resistant cereals, after a generation or two of being wooed towards maize.

A number of countries have permitted or even encouraged the creation of Commodity Exchanges offering new opportunities for export of surplus crops in larger quantities. As well, the converging tariff structure among all the countries in the Common Market for Eastern and Southern Africa (COMESA) will enable cross border trade in grains, especially where distances to the national capital city are substantially greater than to district markets in neighbouring countries.

The opportunities for re-acquainting semi-arid area dwellers with their traditional cereals, food preparation and eating patterns are apparent, as is the introduction of value-adding technologies near the farm gate. A substantial, though minority, part of the population, the semi-arid area farmers also have the potential of demanding agricultural research services aimed at their agro-climatic niche.

India

India has not engaged in the price control approaches described above for Africa. As a result, there are existing market prices for sorghums and millets of different grain characteristics. The work of the APAU group was situated in a market environment which was much less distorted by state agricultural policies, and this undoubtedly contributing to their success.

5.3 Proposed improvements

The first step is the introduction of the small-scale machinery as sustainable enterprises in the rural areas. This step will put sorghum and pearl millet ready-to-cook products, on a par with maize meal. Further, much work has been done on new-product development in national cereal processing laboratories in both West Africa and in Eastern and Southern Africa (e.g., Luhila et al, 1989), at the SMIP in Bulawayo, at ICRISAT Centre, at CIRAD in Montpelier, and at the NRI in the UK.

Over the last few years, several medium-sized processors in Kenya have

begun to supply grocery stores with single cereal "flours" or composite flours (mixtures of pearl millet, finger millet and sorghum) for the making of ugali (the stiff porridge), and of uji (the thin gruel, whether the household fermented eats it in the "sweet" form or the sour, fermented form). In South Africa, and several Southern African countries similar products have been available in urban open-air markets and grocery stores for years.

Sudan has long marketed pearled sorghum as a product which consumers boil, in the way that rice is prepared, with its own distinct taste and mouthfeel.

Each country and sub-region within will have unique factors which will determine the scope of what to introduce and where in the post-harvest chain (Forrest et al, 1979). A starting point is a multidisciplinary examination of the particular cereal, from on-farm production to its consumption by the end user, both urban and rural (Navarro et al, 1992, Navarro and Schmidt, 1993). An initial listing of all the stakeholders and key players in that Production to Consumption System will provide valuable insights. Figure 1 gives an example of such a stakeholder/key player diagram.

The policy climate had, before the mid-eighties been relatively less than supportive of the semi-arid food grains. Changes in agricultural and price policies have occurred since then, prompted by the Structural Adjustment Programs, and offer new opportunities for sorghum and millet. The new opportunities will be realised if a number of conditions can be fulfilled:

An enabling policy envelope is required, aimed specifically at the smallholder rural economy in the semi-arid areas; as household incomes rise, the households will be able to afford the cost of labour-saving services such as dehulling and milling of grains;

New targets have to be determined for agricultural research, and farmer-usable (and affordable) outputs from research must be achieved and delivered to those dry areas (Navarro and Schmidt, 1993; Navarro, L, et al. 1992.).

As the commercial banks increasingly assume the role of provider of agricultural credit, they will have to be acquainted with the economics of small-scale rural value-adding enterprises such as dehulling and milling of the

semi-arid food grains. Case studies exist. Showing the profitability of such enterprises, but the banks had shown little interest prior to liberalization of the economies. Banks are known to be conservative, but they will need to develop new strategies for lending for the creation of off-farm agricultural processing enterprises.

With the changes in policies, new opportunities also exist for the lesser or minor millets (Riley et al., 1993).

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CHAPTER IX SORGHUM AND MILLET: Post-harvest Operations

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CHAPTER X RICE: Post-harvest Operations

1.2 World Trade

1.3 Primary product

1.4 Secondary and derived product

1.5 Requirements for export and quality assurance

1.6 Consumer preference

1. Introduction

Rice (*Oryza sativa* L.) is a staple food of over half the world's people and is grown on approximately 146 million hectares, more than 10 percent of total available land. Total world production is about 535 million tons of unmilled or rough rice (paddy). Ninety seven percent (97 percent) of the world's rice is grown by less developed countries, mostly in Asia. China and India produce about 55 percent of the total crop (IRRI, 1997).

Asian farmers plant 89 percent of the world's harvested rice accounting for 91 percent of global rice production. In Bangladesh, Cambodia, Indonesia, Lao PDR, Myanmar, Thailand and Vietnam, rice provides 56 to 80 percent of the total calories consumed. In the tropics, rice is the primary source of human nutrition (See Table 1.0.1, Annex 1.0). With the exception of the highest income countries, per capita rice consumption has remained stable in Asia over the past 30 years. In most African and Latin American countries, rice is less important than other crops (Henry and Kettlewell, 1996). On average, rice

contributes 10 percent or less of the total calorie intake, although in Guinea, Guyana, Surinam, Liberia, Madagascar, and Sierra Leone, 31 to 45 percent of the calories eaten come from rice.

Rice production and consumption are often associated with low incomes and poverty. Most of the major rice-producing countries are developing countries categorised by the World Bank as "low income economies". For these countries, rice is not only their staple food, but also a major economic activity and source of employment and income for the rural population.

By 2025, more than 5 billion of the world's anticipated 10 billion people will depend on rice as their principal food. Recent projections indicate that the world will need about 880 million tons of rice in 2025 - 92 percent more rice than was consumed in 1992. In South Asia where poverty is extensive, the need for rice is expected to double over the next 40 years. Production requirements will be even higher, to provide stocks, seed and for non-food uses.

Rice is one of the cheapest sources of food energy and protein. Most rice is

consumed as white polished grain, despite the valuable food content of brown rice. These nutrients are lost when bran is removed in milling. Brown rice, once the form of rice eaten before the advent modern rice mills, has lost its appeal due to consumer preference changes for colour, nutty taste and other traits. Health-conscious people in European countries where rice is not a staple prefer brown rice. Drawbacks of brown rice are it requires more fuel for cooking than white rice, it may cause digestive disturbances and the oil in the bran tends to turn rancid and reduce storage life (Henry and Kettlewell, 1996).

Annex 1.0 includes tables on population demographics and agricultural production in 41 important rice-producing countries plus the current, forecast and historical production and consumption of rice.

1.2 World Trade

In most of Asia, rice is grown on small, one to three-hectare farms. Farms can be less than one hectare in more densely populated countries. A typical Asian farmer plants rice primarily to meet the family's basic needs. In Brazil, 70

percent of the rice cultivated is on commercial farms of more than 50 hectares (IRRI, 1997).

Less than 5 percent of the worlds rice production is traded internationally. For example, *Basmati*, the high-quality rice produced in Pakistan and Northwest India, commands an international market price four times higher than the domestic price of the coarse, local rice which the low-income people eat. In 1993, the major rice exporters were Thailand, (31 percent of the world market), the United States (16 percent), Vietnam (11 percent), China (9 percent), Pakistan (6 percent), and India (5 percent). Myanmar is an emerging exporter of rice.

With this narrow and volatile global market for rice, most countries cannot depend on imports to meet the food needs of their people. Self-sufficiency in rice production in order to maintain price levels, is an important political objective in most rice-dependent countries. For example, if China wanted to buy 10 percent of its domestic consumption, the demand for rice in the world market would increase by more than 88 percent and that would dramatically affect international prices. (Henry and Kettlewell, 1996). Few developing

countries have adequate foreign exchange for major international purchases.

There is variation in the price of rice brought by farmers to market effected by annual climate changes. This situation makes domestic prices highly unstable. Price controls through maintenance of large stocks can benefit urban consumers, but often keep farm prices below a profitable level. The world market is small and few reserves are held.

World trade is projected to increase at around 2.5 percent per annum to admit 17 million tons by the year 2000. This exceeds the 2 percent annual growth during 1978-1988. Some countries in the Far East, particularly those that have recently achieved self-sufficiency, are expected to emerge as exporters in the next decade. In most other regions, demand for rice would generally continue to exceed domestic production, stimulating a global rice import demand.

Imports in Africa are forecast to rise by a slightly faster rate than the previous decade to 4 million tons more than the present. Although output of paddy is projected to increase at 4 percent per annum, demand for rice would be

marginally larger. As a result, Africa is likely to continue to rely on imports to fulfil over 80 percent of its total demand.

Latin America will most likely remain a large net importer of rice, and many countries in North America and Europe will also show significant increase in imports (ASEAN, 1992).

Annex 2.0 shows tables regarding the world trade in rice.

1.3 Primary product

Parboiling is the hydrothermal treatment of paddy before milling. The three important steps are:

(a) Soaking (sometimes called steeping) paddy in water to increase its moisture content to about 30 percent.

(b) Heat treating wet paddy, usually by steam to complete the physical-chemical change;

(c) Drying paddy to a safe moisture level for milling.

Parboiling of paddy is an age-old process in parts of Asia. Africa, and to a limited extent today, in some European countries and America. The advantages of parboiling are improved recovery percentage, salvaged poor quality or spoiled paddy, and met demand or preferences by certain consumers. The process causes certain changes in the milled rice; physical-chemical and aesthetic. The changes include the following:

(a) Change in taste and texture of the rice, preferred by some consumers and disliked by others;

(b) Gelatinization of starch, making the grain translucent, hard and resistant to breakage during milling. Thus, milling recovery rates for head rice and total rice yields are improved;

(c) Inactivating of all enzymes; all biological process and fungus growth

are stopped;

(d) Easier removal of the hull during milling but more difficult bran removal;

(e) More rice swelling during cooking and less starch in the cooking water.

All the above changes affect the results obtained during milling, storage and cooking and ultimately affect consumer preferences. (Wimberly, 1983).

Parboiling paddy has advantages over ordinary drying without parboiling and also some disadvantages as follows:

Advantages of parboiling	Disadvantages
1. Milling or dehusking is easier; costs less.	Bran removal is more difficult and costs more.
2. Milled rice has fewer brokens; is nutritious.	Cannot be used in starch making or brewing.
3. Increased head and total rice out-turn.	Doubles the total processing cost.
4. Rice more resistant to storage insect pests.	Rice easily becomes rancid.

5. Bran contains more oil.	Requires large capital investment.
6. Cooking losses less starch and keeps longer.	Takes longer to cook and uses more fuel.

Some research studies report that parboiled rice retains more protein, vitamins and minerals and thus is more nutritious than a raw milled rice. (Wimberly, 1983). However, other studies show no significant nutritional differences between the two.

The process involved in soaking, steaming, and re-drying is expensive. In many cases, however, poor quality paddy (improperly cleaned, dried, handled, and stored) can be improved by parboiling. Properly parboiled rice receives a premium price, again offsetting the added cost of parboiling.

Milling

Paddy or the rice grain consists basically of the hull or husk (l8 - 28 percent) and the caryopsis or the brown rice (72 - 83 percent). The brown rice consists of a brownish outer layer (pericarp, tegmen and aleurone layers) called the

bran (5 - 8 percent), the germ or embryo (2 - 3 percent) connected on the ventral side of the grain, and the edible portion (endosperm, 89 - 94 percent).

Rice milling is the removal or separation of the husk (dehusking) and the bran (polishing) to produce the edible portion (endosperm) for consumption. This process has to be accomplished with care to prevent excessive breakage of the kernel and improve the recovery of the paddy. Actual milling process, however, removes also the germ and a portion of the endosperm as broken or powdery materials reducing the quantity of grains recovered in the process. The extent of losses on the edible portion of the grain during milling depends on so many factors as variety of paddy, condition of paddy during milling, degree of milling required, the kind of rice mill used, the operators, insect infestation and others. What comes out during the milling operation are the husk or hull, milled rice or the edible portion, germ, bran and the brokens. Depending on the rice mill used, the by-products come out from the mill as mixed or separated. Milling is usually done when paddy is dry (about l4 percent moisture content). Wet soft grain will be powdered. Very dry brittle grain will break and produce brokens and powdery materials during the milling operations.

Losses in milling could be qualitative and quantitative in nature. Quantitative or physical losses are manifested by low milling recovery while quality losses are manifested by low head rice recovery or high percentage of broken grains in the milled product.

Rice mills

Rice mills being used in rice-producing countries vary from the manually operated hammer beam pounder or mortar and pestle to the very sophisticated rice mill used in big commercial or government installations. In remote areas where power is not available the beam hammer pounder or the mortar and pestle are used by farmers usually operated by the female members of the family. When an engine powered single -pass rice mill is brought to the community by enterprising individuals, the manually operated mills disappear. Women bring their paddy for milling to reduce their workload and have time to socialise with their neighbours in the rice mills.

As the volume of grain being milled increase and people become knowledgeable and concerned with the milled rice recovered from paddy, rice

millers upgrade their machines and prospective entrepreneurs acquire a bigger and efficient machine to satisfy the demand of the customers.

Table 3.8.1, Annex 3.8 includes the machines that are involved in the actual removal or separation of the husk and bran during the milling process. The extent of rice mill sophistication to improve quantity and quality of grain processed depends on the number of these motorised equipment included in the table used in series and parallel installations together with ancillary components. The ancillary equipment not included in the table are paddy cleaner, husk and bran aspirator, destoner, paddy separator, automatic weighing device, brown rice thickness grader, automatic weighing and bagging, grain elevators and conveyors.

The milling of rice involves at least two basic operations. i.e., removing the outer covering called the husk, or hull and removing the seed coat called the bran. The former called dehusking or dehulling while the latter, is polishing or whitening process. Different methods of accomplishing these two operations range from the traditional hand pounding using pestle and mortar to high capacity sophisticated milling systems.

Pestle and mortar. This process is a manual form of milling, which is found in isolated and remote areas in most of the Third World countries. In this process, milling is accomplished by the impact and friction acting between the paddy kernels. The grain is dehulled and whitened every time it is pounded in the mortar. However, excessive impact and pressure result in high breakage of the milled rice. This method has been losing popularity since a wide range of size of milling systems had been introduced at the grass-roots level. small and large capacity processing systems. Small- and large- capacity processing systems such as steel hullers, rubber roll type mills and other systems consisting combinations of efficient milling equipment, have become available.

Steel huller. The steel huller, sometimes referred to as Engleberg steel huller rice mill, is more efficient than the pestle and mortar. The impact force in the steel huller is absent. A rotating steel roller inside a screen cylinder provides pressure and friction among the grains and effect simultaneous dehulling and whitening or polishing of the kernels. Tests have shown that it yields 3 - 5 percent more total rice with 15 to 25 percent fewer brokens (Wimberly, 1983). Studies in the Philippines indicated that the milling recovery of steel

hullers vary from 60 to 63 percent depending upon the variety and condition of paddy (PRRPO). Among the4 commercial rice mills surveyed steel hullers exhibited the lowest milling and head rice yield, averaging 66.23 percent and 41.70 percent, respectively.

Under-run disk shellers. The under-run disk sheller, often referred to as a disc sheller, consists of two horizontal iron discs partly coated with an abrasive layer. Paddy is fed into the centre of the machine and moves outwards by centrifugal force. It is evenly distributed over the surface of the rotating disc. Under the centrifugal pressure and friction of the disc, most of the grains are dehusked.

The main advantages of the disc sheller are its operational simplicity and its lower running cost since the abrasive coating can be remade at the site with inexpensive materials. The main disadvantages are grain breakage and the abrasions caused to the outer bran layers.

Rubber roll paddy huskers. The rubber roll paddy husker, referred to also as huller or sheller, consists of two rubber rolls rotating in opposite directions at

different speeds. One roll moves about 25 percent faster than the other. The difference in peripheral speeds subjects the paddy grains falling between the rolls to a shearing action that strips off the husk.

Compared with the disc sheller, the rubber roll husker has the advantage of reducing grain breakage, loss of small brokens, and risk of damage to the grain and machine by unskilled operators. It does not remove the germ and therefore sieving the resulting brown rice is unnecessary. Its hulling efficiency is high and it does not require a beard-cutting machine. The main disadvantage is the cost of replacing the rubber rolls as they wear. That is offset, however, by the reduction of breakage and increased total rice overturn.

Multiple machine mills. The large capacity multiple machine rice mill uses a different machine for each processing step: cleaning, dehusking, separating, bran removal and grading. These processes are integrated into one system by bucket elevators linking machine to machine to accomplish each stage of processing to the end of the output polished rice.

A number of manufacturers have introduced small capacity (500 to 1000 kg/h) rice mills. They fill the gap between the small capacity single machine and the large capacity multiple machine mills.

The modern multiple machine rice mill is more efficient than the traditional steel huller and consumes about one-half to two-thirds the power of the steel huller operating at the same capacity. The rice recovery rate is considerably higher in terms of total rice and head yields.

Recovering the maximum amount of endosperm or the edible portion of paddy grain with none or minimum brokens is the main objective of rice milling. The removal or separation of the husk and bran to get the edible portion of the grain is done in many ways. In remote areas where no power is available some farmers just remove the husk and cook while others use the mortar and pestle or the beam hammer pounder to remove the husk and bran. This process is very laborious; recovery of milled rice is low; and presence of broken grains is high. Farmers do not mind the losses probably because of low volume processed and there is no other better alternative to mill paddy in remote areas. The steel huller or the Engleberg rice mill is the

most common rice mill in the rural areas where power can be made available. The process of husk and bran removal by this machine is through intense pressure and friction in a single pass over a very short period of time. The result is milled rice with high percentage of brokens and low grain recovered.

In the combined rubber roll husker and friction polisher, husk is aspirated after the grain pass through the rubber roll husker and the brown rice-paddy mixture is fed directly to the friction polisher (one pass) to produce the milled rice. This machine performs better than the steel huller mill because of separate husking and polishing, lower quantity of abrasive husk in the polisher reducing friction and pressure in the process.

In the under-runner disc husker and the pearling cone polisher, the pearling cone can not separate husk. A paddy separator is added to separate brown rice before feeding to the pearling cone. Separated paddy is returned to the disc husker. This machine combination performs still better than the steel huller mill because of the separate husk and bran removal. To further improve the milling performance, a series of up to three pearling cones is installed to have a gradual removal of the bran layer. Although milling

efficiency is improved, the proper setting and adjustment of the disc huller and the pearling cone by the operator is the critical factor in the milling operation.

Modern commercial rice mills employ more sophisticated equipment to clean, sort, weigh, separate paddy from brown rice, separate brokens and others. Several rubber roll huskers in parallel to increase capacity, abrasive whiteners and friction polisher in series are employed to subject the grain to less pressure and friction in removing the bran. This controlled milling operation results in more grain recovered, more whole grains and less brokens. The design and operation of big commercial rice milling complexes produce quality milled rice with minimum loss. The solvent extractive rice milling developed in Houston, Texas (USA) is another step taken by the industry to improve and refine the milling operations in order to improve the process and increase further the milling efficiency and reduce losses.

A large portion of the paddy harvested in the Asian region is retained and milled in the farm. The steel huller (*kiskisan* or Engleberg) is the most common mill found in the rural areas. This mill was reported to produce

milled rice lower by 4.1 percent and 6.6 percent compared with the disc sheller-pearling cone and rubber roller-abrasive and friction whiteners, respectively. Farmers do not mind the milling loss in the steel huller milling because of small quantities milled at a time and the utilisation of the husk-bran mixture for animal feed.

Studies have been conducted in improving the design of the steel huller but results were not promising because of process limitation. That is, husk and bran are removed in a single process over a very short period. Excessive pressure, friction and rubbing of the grain results in sudden increase in grain temperature, increase brokens, powdering of the endosperm and ultimately reduce grain recovery. Attempts have been made to separate husking and whitening in regular milling using the steel huller mill. Two steel hullers in series, the first as husker and the second as polisher, rubber roller husker-steel huller, emery stone disc-steel huller, centrifugal husker-steel huller are some of the tests conducted. Other combinations of rubber roller and disc husker combined with pearling cone whitener and friction polisher.

Improvements in the milling performance were observed when husking and

whitening or bran removal was made as two separate operations. The best performance was observed when rubber roll was used as the husker. The hard and rough surface of the disc huller scratches and breaks some grain during the husking process affecting the quantity of milled rice afterwards.

It is recommended that the removal of husk and bran in a single operation as the steel huller should be avoided. The minimum milling operation should be husking and polishing or whitening as separate processes which could be assembled in a single frame. Machine with separate husking and polishing in a single frame is already commercially available. A steel huller can be used as husker and as polisher but a rubber roll husker is preferred for husking. Rubber roll is presently readily available.

1.4 Secondary and derived product

Straw, husk, bran and brokens are the by-products resulting from harvesting of paddy in the field and in its processing into milled rice the final consumable staple food, are. Rice and its by-products can either be used directly or further processed for other uses.

The whole grains can be transformed into flakes or popped rice. Brown rice has become a speciality rice, which is attractively packaged and marketed as health food in developed countries. Special upland coloured rice varieties are preferred by farmers in Lao PDR that practice slash and burn cultivation in the mountainous areas. These are fermented and made into rice toddy (*lao hai*) and liquor *(lao khao*). In Japan, rice wine or *sake* is a part of meals and social gatherings. Rice is used as an ingredient for brewing beer in some parts of the rice-producing states of USA.

Applications of rice by-products include:

Rice straw: Animal feed, sometimes treated with urea to improve its digestibility; Thatch, fuel strips with cowdung as binder (Bangladesh); mushroom bed; mulch in horticulture; processed into paper or compost.

Husk: Fuel used directly or in briquettes or cakes with dung binder in cooking stoves and furnaces for dryers, brick kilns, steam boilers, as gasified fuel for engines and burners, as insulating boards, packing material in transporting eggs and other delicate products, bedding materials in the livestock and

poultry industry, ash cement or component for making light weight cement blocks for partition walls, in tile industry, oil absorbent, washing powder, and mulch.

Bran: Commonly used as animal feed in most developing countries, either directly or mixed with other ingredients as done by commercial feed producers. Rice bran has a high percentage of oil, which can be extracted by solvents. Edible bran oil is used extensively in Japan and India. Bran is also used in food processing industry for making biscuits and speciality cookies. Spoiled bran can be used in compost and used as organic fertiliser. De-oiled bran can be safely used as animal feed. China, Indonesia, Malaysia, Sri Lanka, Thailand and Vietnam produce and export edible bran oil. India also produces edible bran oil and plans to increase output over the next few years.

Rice brokens: Used in breakfast cereals, baby foods and for making several food items with rice flour base, such as noodles, rice cakes and rice delicacies. Rice brokens are an export item from large commercial rice mills in Thailand.

Annex 2.1 gives information on the production, utilisation of by-products of rice post-harvest processing in various countries. It also gives information on the Asian trade of edible bran oil. Other internationally traded by-products are hand-made paper products using rice straw as one of the raw materials.

1.5 Requirements for export and quality assurance

Major problems in quality arise from lack of incentives to farmers. Especially noteworthy is the corresponding price for value added in drying paddy. Manifestations of poor quality are yellow rice, brokens, contaminants, ageing, storage changes, variety mixing and mislabelling, lack of screening methods to differentiate among rice with similar starch properties and among special rice for rice food products. Parboiled rice is susceptible to high aflatoxin level from fungal growth.

International standards for export of rice are particular about the permissible dirt, moisture, pesticide residue and pest situation in the traded rice. Table 2.2.1 and Table 2.2.2, Annex 2.2 give the quality standards for international trade in rice.

Some developing countries with chronic rice shortages specify lower than international standards in terms of brokens but at least at par with the national standards to obtain cheaper price than the national counterpart rice.

The importer of high quality rice may specify one variety. However, Thailand, a major exporter of rice faces the problem of mixed varieties because paddy is collected from different areas and different farmers. Thailand was faced with complaints from discriminating Japanese consumers that Thai rice exported to Japan did not meet the taste, texture and sanitation standards in Japan (The Bangkok Post, 1994). It was reported that some complaints were politically motivated because trade liberalisation would be inimical to the interests of Japanese farmers who received as much as 10 times the international market price for rice.

1.6 Consumer preference

Quality of milled rice means different things to different consumers in various Asian countries. One of the distinguishing factors influencing consumer preferences is the type of amylose content of rice. Table 2.2.3, Annex 2.2

shows the distribution of such preferences in various Asian countries.

Quality has also different meanings to different people involved in the processing and trading industry, to producers and to consumers. The following are broad meanings of quality:

(a) Producer: Quality grain is of good variety, filled, well-ripened, winnowed and cleaned, commands high farm gate price and in demand by traders, millers and consumers;

(a) Trader: Quality means dry, insect-free, undamaged grain, which will store well;

(b) Miller: Quality means grain batch is of pure or homogenous variety and yields a high percentage of finished products or has high milling recovery:

(c) Consumer: Quality of milled rice means that it has good appearance (polish or whiteness, wholeness, uniformity, purity

and attractive packaging for more sophisticated consumers) and the preferred texture (see Table 2.2.3, Annex 2.2), flavour, and cooking properties (also high nutritional value for health-conscious consumers).

Quality deterioration.

The condition of the grain at harvest which is a result of influencing factors such as climate, soil, production management, as well as harvest operations and post-harvest techniques, can only be sustained at best and may no longer be improved by processing. However, processing could increase the value of the raw product. On the contrary, improper and incomplete post-harvest operations could cause a deterioration of quality, which could have been potentially excellent.

Grain deterioration may be measured in terms of losses in quantity and quality of the final milled rice product. For example, the nutritional value of rice is reduced when it has turned yellowish caused by stackburning. Table 2.2.4, Annex 2.2 shows that protein of yellow rice has a lower lysine content

than that of sound grain. Rat experiments showed that the net protein utilisation and protein quality were also lower in yellow rice than in white rice (Eggum et al. 1984).

Table 2.2.5, Annex 2.2 shows the effects of the environment, processing, and variety on grain quality at different steps in the post-harvest system (Juliano, 1996).

Some of the factors contributing to deterioration are impurity, too high or too low moisture content, immature and unfilled grain, cracked kernel, chalky grain, and red rice and other impurities. The following describes how each major factor affects the grain quality:

(a) Moisture content of grain. Too high rather than too low (overdried) moisture content is the common problem encountered among the traded paddy because it is more expensive to overdry the paddy except when the method used is sundrying. High moisture content results in the rapid deterioration of the paddy because the grains continue to

respire and heat builds up giving favourable conditions for mould to grow, fermentation to set and micro-organisms to multiply. Insects and mites will be most active when the equilibrium relative humidity inside the grain mass gets to about 60-80 percent aggravated also by the biological activities. The result is yellowed and damaged grains.

(b) Temperature. High grain temperature has damaging effects on the grain because of the increased respiration and reproductive activities of insects. Most insects infesting paddy complete their life cycles at temperatures of 15-45oC while moulds and bacteria have a wide range of temperature (0-60oC) for their activities.

(c) Insects and micro-organisms. Insects cause damage to the paddy by eating the food matter, causing reduced weight and volume of the grain bulk, as well as indentation and deformation of the kernels, which reduce the milling recovery. They also leave black marks on the kernels and increase the

temperature in the bulk grain. They also contaminate it with their wastes and dead bodies. At high grain moisture content (25-30 percent) and high relative humidity (70-75 percent) the activity of fungi and bacteria also increase and cause further damage by discolouring of the grain, giving off or bad odour, causing off-flavour and producing mycotoxins.

(d) Impurities. Matter other than grain such as stones, dirt, sand, plastics, glass and metal bits as well as organic materials such as chaff, straw, empty grains, red kernels and seeds of weeds and other crops, animal and insect parts and even human hair constitute the common impurities in the grain bulk. The inorganic materials damage the mill and the organic ones rot rapidly, cause uneven distribution of moisture content and induce the growth of micro-organisms.

(e) Immature grains. While not exactly impurities, immature grains do lower grain quality by causing uneven distribution of moisture and themselves the favoured food of insects, hence

causing a chain of actions leading to increased infestation and quality deterioration.

(f) Thermal and mechanical stresses. The rapid rate of moisture removal induces stresses in the grain because of the differential expansion and contraction of the inner and outer layers of the grain. Fissuring occurs and eventually during milling, the grain breaks along the fissure lines. Accidental or unavoidable re-wetting by rain of dried grain as during retrieval from the sundrying floor, also cause stresses and eventually fractured kernels. A worse situation occurs when the grain is chalky or already damaged by insects and water as well as by mechanical handling and processing such as in threshing or sundrying.

(g) Mixed varieties. Harvests from different fields get mixed in the rice mill compound for various reasons. Milling of different sized grains result in poor quality rice because no one adjustment of the mill may satisfy the requirements of the non-uniform grain sizes.

Table 2.2.6, Annex 2.2 shows the different quality indicators during each post-harvest operation from harvesting to marketing.

A knowledge and understanding of the factors that induce grain deterioration is essential in achieving the quality of the processed grain at each stage of post-harvest operations. The quality of output at each grain-processing episode determines the quality of output of the next process. The chain of events starts from pre-harvest operations or production of the paddy itself. The complication is that unless a particular rice milling industry firm is integrated with farm production and processing under one management, total quality assurance of the grain is difficult to achieve. Table 2.2.7, Annex 2.2 summarises the methods of preventing grain deterioration and maintaining rice quality.

The rice milling industry has little control if any of the variety supplied by farmers and traders. Moreover, the traders obtain their paddy from different farmers who are likely unaware or could not care less of the importance of purity of the variety they are planting because they are not given incentives by traders or millers for such specification. Red rice or other admixture variety

in the field could be rouged or pulled out since the rice plants are likely different in growth characteristics than the particular variety chosen for planting. Thorough weed control is important in preventing contamination of the grain with weed seeds and plant parts.

Chalky, immature and unfilled grains could be avoided by timely harvesting which means also timely planting with respect to climatic conditions, insect infestation and synchrony with the planting by other farmers. A guide for harvesting date is the information on the maturity duration. The exact date however, could vary because of climate and soil conditions. Normally, the grain may be harvested if the hulled test grains from the upper portion of the sample panicle are clear and firm and most of the grains at the base of the panicle are in hard dough stage. The decision to harvest or postpone it is influenced by the risk involved due to weather conditions at the intended time of harvest, the availability of labour or hired threshing services and severity of rodent infestation.

Field drying of the harvested paddy, if it is not a shattering variety, should be practised moderately during the dry season only. If hand-harvested by sickle

the grip size bundles are better laid out separated rather than stacked to achieve greater aeration rather than stacked. Stacking of moist paddy will cause heating up of the paddy, increasing the activity of micro-organisms and initiate a major deterioration in quality. A safe way is to thresh the paddy immediately after harvesting.

Threshing by foot is the mildest method and will not cause any mechanical damage to the grain. The risk of grain breakage increases depending upon the method used in threshing. Beating the panicle by a stick, impacting it against a wood block or slatted platform; trampling upon it by buffaloes or cows, rubbing it against a wire-looped drum in a pedal-operated or sheared and beaten between a peg-tooth or raspbar drum and concave in a mechanical-powered thresher incur different degrees of mechanical damage to the grain. The damaged grain is the staging point of attack by insects and micro-organisms and so the better it is if mechanical damage could be minimised or avoided through improved machines and handling. The axial-flow threshing principle, in which the panicle is stripped and the grain is mildly impacted, has been used in IRRI-designed small and large rice threshers since the 1970s.

Immediate drying of the grain after harvest is imperative to avoid its deterioration. The use of mechanical dryers at the small farm level has not caught on because of its high initial cost, uneconomical operation and seasonal utilisation. Sundrying of paddy is still the most popular method even among medium-scale rice mills in developing countries because of the free heat energy although handling costs are high. However, it is unreliable and the drying rate is not as controllable as mechanical dryers.

In the absence of heated-air or mechanical dryer during cloudy or rainy weather after harvest, the paddy should at least be aerated by thinly spreading it on a floor or piling it in small heaps and frequently turning it over. The idea is to increase the surface area of the grain bulk to the air, drain any surface water and prevent the build-up of heat within the grain bulk. Farmers during such emergency situations have resorted to blowing with an electric fan over the surface of the heap or laid wet paddy. Spreading or heaping the wet paddy on a mat of fine net laid over a raised slatted platform would further increase the aeration surface and drip off any free water. This technique will save the crop until sunshine weather comes.

Two-stage drying consisting of flash or high-temperature short-exposure or fast drying to 18 percent during the first stage and low-temperature and slow drying or sundrying to 14 percent during the second stage is another technique to save a large volume of wet grain. Paddy at 18 percent moisture content can be stored for two weeks. However, re-wetting of the grain should be avoided to prevent cracking or fissuring which will have telling effects in milling.

Sanitation, prevention of entry of insect, rodent and bird pests, and prevention of contamination of the grains during storage of the grain should be practised meticulously. Storage in a dry and cool place with proper aeration to bring temperature to about 17oC effectively minimises insect infestation.

Prolonged storage under ordinary conditions even without the presence of insects and micro-organisms will cause grain deterioration in terms of colour, texture, odour, flavour, and nutritive value because of uncontrolled moisture and temperature. The re-entry of moisture in milled rice should be avoided.

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CHAPTER X RICE: Post-harvest Operations

2.1 Pre-harvest operations

2.2 Harvesting

2.3 Transport

2.5 Drying

2.6 Cleaning

2.7 Packaging

2.8. Storage

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2. Post-production operations

2.1 Pre-harvest operations

The farming management and field operations as well as the post-field operations determine the quantity and the quality of milled rice, the final

product from agricultural production. The influence on such output of the total production and processing system starts from the decision made on the agronomic parameters such as what variety of rice to plant. It goes through the series of decisions and actions made on cultural parameters such as crop establishment and care, harvesting, drying and milling.

Decisions related to production of rice are important in attaining the quality desired for the processed grain. For example, the choice of a variety to be planted determines the stand (erect or lodging), stature (tall or short), maturity (early to late), grain to straw ratio (high to low), shattering characteristics (easy to difficult), husk tightness (loose to tight), amylose content (low to high), grains size (short to long), grain length to width ratio (small to large), panicle stature at maturity (erect to drooping), and other characteristics pertinent to that variety. These characteristics in turn become factors influencing the ease, efficiency, grain loss magnitude, and choice of harvesting and threshing technology. They also affect the rate and quality of the drying process and the quality of dehusked rice (brown rice) and eventually the total recovery and quality of milled rice. The differences in varieties planted in a locality also affect the final product, milled rice, as the

high-value rice market usually prefers a pure and single variety. In terms of the desirable bio-diversity for sustainable agriculture however, planting of different varieties in a locality, not necessarily in the same field, is a food security strategy of the government. A high degree of management is required to monitor the plantings of farmers and to make sure that the varieties do not get mixed. In some practices, the high quality and medium quality varieties are deliberately mixed to produce a blend of aroma, flavour, consistency, other characteristics desired or preferred by the consumer for bulk rice but which could not be attained in a single variety.

The degree, extent and efficiency of material, technology and management inputs as well as the timeliness of activities with respect to weather, pest and disease incidence, the growth stage of the crop and all the critical stages of field production and post-harvest processing of the rice have a bearing on the yield and quality of paddy and eventually the amount, quality and cost of milled rice and the by-products. The degree of weed, pest and disease infestations, the type and management of their control, particularly the chemical aspects, the timeliness and techniques used, the harvesting and the handling of paddy even before the processing is done can have telling effects

on the consumable product and on the individuals, including women, involved in the operations.

Proper timing is important in harvesting the crop as losses could be incurred if rice is harvested too soon or too late. Immature grains due to too early harvest result in high percentage of brokens and low milling recovery. Delayed harvesting exposes the crop to insect, rodent and bird pests, in addition to increased risks of lodging and grain shattering. The ideal is to be within the window of optimum harvest period.

Table 3.1.1, Annex 3.1 shows the losses incurred when rice is harvested one week early and up to four weeks delayed based on the maturity date of the crop. On this basis, the recommended harvesting time is one week before the maturity date of the particular crop variety. Table 3.1.2, Annex 3.1 confirms the values for two varieties studied in the Philippines.

Table 3.13, Annex 3.1 shows that the least grain losses before and during reaping are incurred when harvesting is done 5 days before the maturity date for the variety. However, while there is less grain shatter, the yield is reduced

because of immature kernels. Cutting length of the straw should be as close to the ground as possible and not to be less than half the length of the stalk to reduce grain losses due to unharvested grain (Calpatura, 1978).

More information on losses incurred in harvesting and related activities as affected by the harvesting system used, timing of harvest and variety of the rice crop is given in Table 3.1.4, Table 3.1.5 and Table 3.1.6, Annex 3.1.

The indicators of optimum harvest of the grain are as follows:

> **(a) The variety has reached the particular date of maturity or number of days after heading, 28 to 34 days, as shown in Figure 3.1.1. The period of flowering and maturity dates of IRRI varieties are shown in Table 3.1.5, Annex 3.1. The field should be drained about 7 to 10 days before this maturity date;**
>
> **(b) Eighty percent (80 percent) of the grains or the upper portion of the panicle has changed from green to straw colour;**

(c) At least 20 percent of the grains at the base is already in hard dough stage;

(d) Grain moisture content ranges from 21 percent to 24 percent, as shown in Figure 3.1.2; and

(e) The hand-dehulled grain, as indicated by daily tests near the projected harvest date, is clear and hard.

Figure 3.1.1, Annex 3.1F shows the optimum time of harvesting rice in terms of grain yield and head rice, germination, moisture content of the grain, and green kernel. Figure 3.1.2, Annex 3.1F shows the optimum time of harvest in terms of moisture content.

2.2 Harvesting

Harvesting generally refers to all operations carried out in the field which include cutting the rice stalk or reaping the panicles, either laying out the paddy-on-stalk or stacking it to dry, and bundling for transport. Harvesting

and its related handling operations and processes should be understood to prevent considerable amount of post-production losses. There is a positive relationship between the method of handling and the degree of loss as shown by various studies. Too much paddy handling create problems both in quality and quantity. (NAPHIRE, 1997).

Harvesting and its related handling operations are significant points in the post production sequence because grain losses can be incurred. Each additional handling step produces a loss of 1 to 2 percent, for highly shattering varieties (Samson and Duff, 1973). The sequence of manual harvesting, field drying, bundling and stacking in traditional systems can incur losses of from 2 percent to 7 percent (Toquero and Duff, 1974). In-field transport which includes bundling of the cut stalks and done by using manually or animal-pulled sleds can incur losses ranging from 0.11 to 0.35 percent. Field stacking of the harvested stalks incur losses ranging from 0.11 to 0.76 percent. The longer the stack is left in the field, particularly where the grain moisture content is high, the greater is the degree of loss. Stackburning or heating up of the harvested crop stack causes yellowing of the milled rice due to attack of micro-organisms and fermentation. Table 3.2.1, Annex 3.2

shows the grain losses resulting from the traditional method of harvesting for IR-24 variety. Related loss values are given in Annex 4.0.

2.2.1 Harvesting methods

Several methods of harvesting have evolved during the progress of rice production. The most common among the developing countries are still the traditional manual methods.

The traditional methods of harvesting rice are the following:

> **(a) Panicle reaping. This is accomplished by using a hand-held cutting tool or knife (called *yatab* in the Philippines and *ani-ani* in Indonesia and *kae* in Thailand). The blade quarter-circle blade fixed cross-wise on a wooden, grip-sized handle is passed between the index and the middle fingers which grab the panicle stems and execute the cutting action by pressing the panicle stems against the blade. The method is still used in areas where the traditional varieties are grown which are**

resistant to shattering, an important feature when handling and transporting the bundles of panicles from the field to the house.

The labour required for panicle reaping (240 labour hours/hectare), done mostly by women and big children, is at least four times that of hand sickle harvesting. Panicle reaping has evolved as a social custom, which provides income generation for the landless rural folks. It is advantageous over the stalk cutting by sickle when fields are flooded or terraced, as in the hilly areas that are inaccessible by wheeled vehicle. The carrying capacity of transport labour is more than that when the straw is cut long by sickle.

(b) Long-stalk cutting by sickle. This is the most widely-used manual method of harvesting. There are many variations in sickle design, depending on the socio-cultural acceptance of the harvesters. It requires from 80 to 180 labour hours to harvest one hectare of rice crop. There are many variations in sickle design, depending upon the socio-cultural acceptance of the harvesters. The stalk is cut about 10-15 cm above the ground or

the stalk length is about 60-70 cm for ease of bundling and threshing. The stalks are laid in small bundles on the stubble. In some places in Thailand the bundles are sized such that each one will give about 10 kg of paddy and laid up on the field for a few days to dry up. The reaping efficiency depends upon the various cultural practices, the plant density and variety, degree of lodging, the soil condition and the skill of the harvester. Lodged paddy and saturated soils may reduce the cutting rate by 50 percent. In Bhutan, bringing home the long stalk paddy is related to socio-cultural practices.

Modern mechanical methods. Unless labour in harvesting has become scarce in a locality due to industrialisation or migration to employment-rich areas, rice harvesting will continue to be done with the sickle method in most developing countries. In the Philippines, the income or share in kind (usually 1/6 of the harvested paddy) gained by a manual harvester is high compared with other field operations. In times of calamity as in a typhoon where the rice crop is lodged and soaked, a farmer-owner is sometimes constrained to share up to 1/2 of the harvest to the harvesters rather than lose the crop

altogether.

The following mechanised harvesting methods are used in a country depending upon the custom and the suitability of the machine to the soil conditions and the crop being harvested, the local custom, affordability of the machine, and other socio-economic factors.

(b) Reaper-binder. This had once been popular in Japan but is being replaced by the combine. The machine cuts and bundles the stems together and lays them in the field in one operation. Other Asian farmers have never adopted it.

(c) Combine. The small combine has become popular in Japan since the 1960s. The Republic of Korea has also manufactured it commercially since the early 1980s. It is gradually being introduced in other Asian countries but primary resistance to adoption is the high initial cost and adaptability to local conditions. The self-propelled machines have cutting widths of 50 to 150 cm and have capacities of about O.05 hectare per

hour (NAPHIRE 1997). Thailand has local versions of large combines popular in developed countries and are being adopted because of the increased costs and scarcity of labour. As a rice-exporting country, Thailand attempts to mechanise rice production and processing operations. Vietnam that has overtaken Thailand in the rice export trade may also adopt mechanised methods because of economies of scale. Although Malaysia is a net importer of rice, it depends on modified large combines imported second-hand mainly from Europe to harvest its basic rice crop. Large combines are being used in commercial rice production in countries like Brazil and Uruguay in Latin America and in Europe and the USA. Their introduction and failed use in some African countries through aid programmes have been the subject of much criticism as to their appropriateness in situations where ready and efficient repair and maintenance facilities and services are not available.

(d) Stripper harvester. This is an innovation from the International Rice Research Institute which adapted the rotary

stripping comb principle developed by the Silsoe Research Institute in Silsoe, U. K. The rice stripper-gatherer ideally works with a variety which is non-lodging, of medium stature with erect panicles, and low to medium shattering. A high grain:straw ratio is advantageous in achieving high harvesting productivity.

The IRRI-designed pedestrian stripper-gatherer has undergone several field trials in more than 20 rice-producing countries since 1994 and the reactions to the machines were mostly favourable, except when the machine has to be used in wet or soft fields where traction is a problem. Efforts however, are needed from the national institutions in the various countries to extend the machine to farmers or to harvesting custom operators and to modify the machines to suit local soil and crop conditions. The local manufacturers must first be trained in its fabrication and in the provision of efficient and reliable after-sales services. The attempt to make a small and ride-on combine version of the machine has been beset by traction and floatation problems in wet and soft soils. The design and development activities on it have been discontinued or suspended indefinitely by IRRI.

The following situations hinder the adoption of mechanised harvesting methods:

(a) Low income, inability to raise capital, reluctance to change traditional methods, poor mechanical aptitude, and the desire to save straw for off-farm uses.

(b) Small land holding, very small plot size with high bunds, poor water control, inadequate ground support and poor trafficability for powered harvesting equipment, and lack of access roads to the fields.

(c) Excessive moisture content at harvest time, uneven ripening, severe lodging and entangling of paddy (specially the traditional long-stalked varieties), and high-shattering and low grain-straw ratio varieties.

There is still a lack of functionally and economically suitable equipment for tropical conditions due to inadequate research, development and thorough field testing activities in the developing countries in the area of mechanical harvesting. The high cost of imported equipment and the requirement of

good machinery management must compete with relatively low-cost labour.

2.3 Transport

In most developing and least developed countries that produce rice, transport methods of paddy from the field to processing areas are mainly by means of human and animal power and sometimes mechanical power with the corresponding devices, tools and equipment. In hilly and mountainous areas where paddy fields are terraced, like in Bhutan and Nepal and in some parts of the Philippines and Indonesia, paddy in panicles or in long stalks, are bundled and transported by human or sometimes animal power. Such method of transport, which is related to the method of harvesting and field drying activities often result in high grain losses. Small- and family-sized volume of paddy is transported in bags from the house storage to the small rice mill by foot, bullock carts, bicycles, motorcycles, small-sized vehicles, or public transport vehicles whichever mode is available and affordable.

In Bhutan, the practice is to windrow the cut paddy in the field for drying from 3 to 7 days depending upon the crop and the weather conditions. For

the shattering varieties, tremendous grain losses in the field may be incurred specially if harvesting is delayed with respect to crop maturity date. Apart from harvesting losses incurred in cutting, windrowing, sundrying, collecting and bundling the cut crop, further losses are incurred in loading the bundled paddy-in-straw on a person's back for transport to the house. Along the way, grains continue to shatter because of the jarring action while the carrier (oftentimes a woman) walks, leaving a trail of fallen grains. At rest points, the jarring action is more severe than in walking because of the dropping of the bundle on a ledge, self-loading it again and adjusting it for comfort on the carrier's back with jarring action. At the house or destination where the bundle will be stored by stacking, grains will again be shattered and when threshing time comes the handling will yet cause another shattering action. This traditional method is used for cultural and practical reasons, like food security and use of the straw as thatch animal feed and mulch.

In such difficult cases, however, manual transport may be the only feasible and practical means because of the terrain, terraced fields and lack of access roads. In other developing countries in Asia, women carry bundles of harvested panicles on top of their heads. Men do it by means of a carrying

pole over their shoulders. Where paddy is field threshed, men usually carry the 40-75-kg bag of paddy on their shoulders or back from the field to the nearest road. Animals such as donkeys and water buffaloes are sometimes used for transport but resources available to the farmer limit owning them. In areas accessible by river, canal and lake, such as in Bangladesh, Vietnam, China and Thailand, paddy is usually transported by boat.

Threshing paddy in the field and transporting the grains in bags will minimise grain losses. It is therefore an improved method over transporting paddy on stalk but the straw, if needed in the house, will have to be retrieved later. Sundrying of paddy may be done in the house yard instead of drying paddy on stalk in the field. Surplus paddy is usually sold fresh to traders or directly to rice mill entrepreneurs as dried paddy commands so little added value to make drying attractive to farmers.

In Myanmar, most of the harvested paddy in straw is sundried in the field; spread on bare dry and hard earth; and then threshed by animal trampling. The threshed paddy in bags is then transported using animal-drawn cart or sled. This threshing and transport scenario is fast changing because of the

government's drive to mechanise field operations in a bid to increase its capability to export rice.

In the lowland areas, transport of paddy can be partially mechanised, that is, the bags of paddy are brought from the field to the roadside manually or by animal power. They are then transported to the drying area or rice mill from the roadside by means of motor vehicles like tricycles, power tillers with trailers, tractors with trailers, trucks and lorries. The loading and unloading of the bags or sacks of paddy incur extra labour costs which are assumed by the trader or buyer of the paddy on site.

In the developed and advanced developing countries, paddy is harvested by combines and is handled and transported in bulk. The paddy is power unloaded from the combine by means of an auger conveyor into a waiting lorry or tractor-trailer at the field road, which is part of the infrastructure established for mechanised rice production. Paddy is unloaded from the lorry or trailer onto a floor hopper at the rice mill area for conveyance by either auger or belt conveyor to a mechanical dryer. In Malaysia, each lorry or truckload of bulk paddy is weighed at the unloading site for claiming subsidy

from the government.

Commercial or traded rice is bagged at the rice mill and is normally transported to the wholesale and retail markets by means of vehicles of the kind and size depending upon the volume of the rice.

The largest disadvantage of manual transport is the large amount of losses incurred. Field threshing and bagging of the threshed paddy may improve the harvest and transport system but this greatly depends on favourable weather conditions and is adversely affected when harvesting coincides with the monsoon season. Threshing should be done as soon as possible after harvest. Quick threshing can be done only with powered threshers. Even then, timing with good weather is essential as the thresher may clog up or huge losses may be incurred when wet grain and straw are put through the machine.

2.4 Threshing

This operation involves the detachment of paddy kernels or grain from the panicle and can be achieved by rubbing action, impact; and stripping. The

rubbing action occurs when paddy is threshed by trampling by humans, animals or tractors. The impact method is the most popular method of threshing paddy. Most mechanical threshers primarily utilise the impact principle for threshing, although some stripping action is also involved.

Paddy threshers may either be hold-on or throw-in type of feeding the unthreshed paddy. In the hold-on type, paddy straws are held stationary while threshing is done by the impact on the particle from cylinder bars spikes or wire loops. In the throw-in type of machines, whole paddy stalks are fed into the machine and a major portion of the grain is threshed by the initial impact of the bars or spikes on the cylinder. The initial impact also accelerates the straw and further threshing is accomplished as the moving particles hit the bar and the concave.

The third type, stripping has also been used in paddy threshing. Some impulsive stripping occurs ordinarily with impact threshing in conventional threshing cylinders.

In the throw-in type of thresher, large amounts of straw pass through the

machine. Some designs utilise straw walkers to initially separate the loose grain from the bulk of straw and chaff.

Manual threshing. In this method, threshing is accomplished by either treading, beating the panicles on tub, threshing board or rack, or beating the panicles with stick or flail device. The pedal-operated thresher consists of a rotating drum with wire loops which strip the grains from the panicles when fed by hand. It can be operated by women and can be used in hilly or terraced areas because of its portability.

Power threshing. Treading of the harvested crop under tractor tires is a method used in some Asian countries. The popularity of this method can be attributed to its convenience and the lack of suitable tractor PTO-driven threshers. The grain is separated from the straw by hand and then cleaned by winnowing.

Most, if not all powered paddy threshers are equipped with one of the following types of cylinder and concave arrangement: (a) rasp bar with concave (b) spike tooth and concave (c) wire loop with concave (d) wire loop

without concave. Tests by IRRI indicated that the spike-tooth cylinders performed well both with the hold-on and the throw-in methods of feeding and its threshing quality is less affected by changes in cylinder speed.

In the axial-flow thresher, the harvested crop is fed at one end of the cylinder/concave and conveyed by rotary action on the spiral ribs to the other end while being threshed and separated at the concave. Paddles at the exit end throw out the straw and the grain is collected at the bottom of the concave after passing through a screen cleaner. Several versions of the original IRRI design of the axial-flow thresher have been developed in most countries to suit the local requirements of capacity and crop conditions. Thus, there are small-sized portable ones and tractor PTO-powered and engine-powered ones. Many custom operators in Asia use the axial flow threshers to satisfy the threshing and grain cleaning requirements of rice farmers.

2.5 Drying

Paddy is a hygroscopic, living and respiring biological material. It absorbs and gives off moisture depending upon the grain or paddy moisture content

(m.c.), air relative humidity (RH) and temperature of the surrounding atmosphere. As a living biological material paddy respires at an increasing rate with m.c. Paddy respiration is manifested by decrease in dry matter weight, utilisation of oxygen, evolution of carbon dioxide and the release of energy in the form of heat. Respiration is negligible at moisture content of about l2-l4 percent.

Paddy is usually harvested at moisture content of about 24-26 percent (wet basis), higher during the rainy season and lower during the dry season. At this moisture content at harvest, paddy has a high respiration rate and is very susceptible to attack by micro-organisms, insects and pests. The heat evolved during the respiration process is retained in the grain and in the bulk because of the insulating effect of the rice husk. This heat increases the temperature of the grain resulting in increased mould growth, fungi, insects and pests infection, which increases the quantitative loss and qualitative deterioration. Grains become rancid, mouldy, yellowish, insect and pest infested. Newly harvested grain with high moisture content must therefore be dried within 24 hours to about l4 percent for safe storage and milling or to at most 18 percent for temporary storage of up to two weeks in case the drying capacity

will jeopardise the drying of the rest of the wet paddy and thus get them spoiled. At moisture content of 14 percent or less, wet basis, paddy will be less susceptible to fungal infestations and likely retain its germination potential. Its shelf life will likely be prolonged and its quality preserved.

In wet grain, vapour pressure is high because of the high moisture content. When this grain is subjected to an atmosphere where vapour pressure is low, vapour transfer or movement will occur from high to low until such time that the vapour pressure is the same or the grain is in equilibrium with the atmosphere. Drying therefore is subjecting the grain to an atmosphere of low vapour pressure and providing the necessary heat to vaporise and means to remove the evaporated moisture from the grain. The same is true to moisture movement within the grain. Moisture from the outer surface of the grain is evaporated during drying. Moisture transfer from the core to the grain surface occur during and after drying until such time that moisture is evenly distributed within the grain. Thus, in sun or solar drying, energy from the sun heat the grain evaporating the moisture and the natural air movement on top of the grain removes the evaporated moisture. Also, in heated air drying, the heat from the drying air vaporise the moisture from the grain and the same

drying air removes the evaporated moisture away from the grain. The higher the temperature of the drying air the faster is the drying rate.

Delayed drying may result in stackburning of wet grain due to non-enzymatic browning and microbial growth and mycotoxin production in parboiled rice. Yellow or discoloured grains result from a non-enzymatic browning type reaction (NRI 1991) and all varieties are affected.

Caution however, should be made in paddy drying. Slow drying is recommended to preserve the viability and wholeness of the grain. A heated air temperature of 43^{o}C is recommended in drying paddy for seeds or for food grain milling. High drying air temperature will affect grain viability and the quantity and quality of milled rice during milling. High drying air temperature will not only expose the germ to high temperature but also dry the outer surface of the grain faster than the moisture can move from the core to the grain surface. This uneven dryness of the grain results in internal stresses that cause the grain to crack. The same is true when water is poured on a dry grain as rain on g rain during sundrying. These cracks on the grain are

not externally visible but manifest during milling as low grain recovery and high percentage of brokens. The table below shows the different methods and equipment usually used in drying paddy.

The magnitude of losses attributed to drying ranges from 1 to 5 percent. Considering the volume of production in a country, losses due to improper drying and inadequate drying facilities alone would be tremendous considering the equivalent monetary value.

Drying is the most important method in minimising post-harvest losses, since it directly affects safe storage, transportation, distribution and processing quality. Currently, considerable losses are incurred annually during storage and transportation of grain, as a result of inadequate drying.

Specific properties relevant in drying are moisture content (water activity) and both critical and equilibrium moisture contents, and hull of husk tightness. Drying should consider the varietal differences in critical moisture content (11-16 percent), below which the grain fissures upon moisture adsorption (Juliano et al., 1993).

Improper and over-drying as it normally happens in sundrying, which is difficult to control, may reduce head rice yield and aroma. Low temperature drying preserves the rice aroma principle, 2-acetyl-1-pyrroline (Itani and Fushimi 1996).

Hot sand flash drying results in parboiling when done in the wet season because of the high moisture content at harvest. However, when it is done in the dry season and under control, it results in the improvement in grain translucency and milling quality (Arboleda, 1983).

Table 3.5.1 and Table 3.5.2, Annex 3.5 T describes the features of different methods of drying paddy. The dryers listed in Table 3.5.1, Annex 3.5 T are used by farmers, co-operatives, and the private and public sectors involved in post-harvest handling and processing of paddy. The kind of machine and process used depends upon the season, quantity and moisture contents of paddy handled.

Field drying is practised solely by the farmers. This method is resorted to during rainy season or harvesting immediately after the rain to remove

surface moisture on the cut panicles, grains, reduce heating when harvested stalks are piled for threshing and to reduce the weight for easier handling in the field.

Shade drying is also practised by farmers particularly for grains intended for seeds. This method of drying is also used in cooling grains, which heat up in storage.

Sun or solar drying of threshed grain, being the cheapest method, is practised by all sectors (farmers, co-operatives, commercial millers, and the government grain agency) in most developing countries. Almost all the 70-90 percent of field harvest retained in the farm is sundried. Women and children in the family usually do sundrying. Co-operatives, private and public sectors handling and processing paddy use this method extensively as shown by the big drying pavements adjacent to the warehouses and rice mills. These pavements are usually undulating and slightly sloping. The surface profile provides for water drainage to the furrow portion and for piling and covering of the grain on the crested portion during drying in the rainy season. Sundrying labour is usually contracted to a crew on per bag or quantity basis.

To augment their drying capacities, rice processing co-operatives, private and public sectors have heated air dryers of suitable size, process and system and according to their available resources and other factors.

Shallow bed batch dryers are sometimes used to supplement the sun drying method when processing requirements are comparatively small. The University of the Philippines, Los Baños (UPLB) designed and developed during the late 1950s the one ton capacity shallow bed batch dryer primarily for use by farmers with about 2 to l0 hectares of rice fields. IRRI and other national agricultural engineering research and educational institutions in developing countries modified the dryer as to construction, fuel used and other technological improvements and tried to promote the dryer among farmers and farmer groups. While the design was technically sound in that drying was accomplished to the desired degree and quality, the dryer has not been adopted by small rice farmers because of certain industry constraints, notably the unsound economics involved. There was not enough incentive for farmers to dry their paddy intended for sale. Small volume of rice production by individual farmers, high cost of dryer and drying, new dryer technology requirements, and lack of industrial promotion and after sales services to end

users are some of the other constraints enumerated by Andales (l996) in drying paddy. The size of the dryer was not suitable for co-operatives and private sector millers because they require larger capacity units.

Studies have been conducted that high moisture newly harvested paddy could be dried faster without any detrimental effects on the quality and quantity of the milled rice if subjected to a very high temperature for a very short time before final solar or heated air or shade drying is done. Khan et al. (1973) subjected very wet paddy to sand heated to 150 - l80^{o}C and another to direct flame for less than one minute before final drying was done. Results showed that total drying time was reduced by about 50 percent and the quality and quantity of milled rice was improved because of the gelatinization of the grain in the process. Bulaong et al. (1996) reported that subjecting the wet harvested paddy to drying air temperature of 80-90^{o}C for 15-20 minutes reduced the moisture content to about l8 percent which could be further dried in storage or other methods. This same principle is being utilised by the big recirculating mixing or non-mixing dryer where wet grain is subjected to heated air temperature of about 70-90^{o}C for about l0-l5 minutes and placed

in an aerated tempering bin before it is recycled to the dryer until the grain is dried. In this method, total drying time is drastically reduced.

Field drying is commonly done by farmers world-wide, particularly in the least developed countries. By definition, natural or field drying involves the reduction of paddy moisture while the grain is still attached to the panicle. This is achieved by letting the moisture of the field crop to decrease or by cutting the stalk and leaving it in the field to dry.

Farmers resort to field drying out of tradition and necessity because threshing equipment or labour is not always available on time. The introduction of mechanical thresher has reduced the time interval between harvesting and threshing. Farmers field dry their crops by laying the cut stalks in bundles on the stubbles, either horizontally or upright with panicles on top. The latter is a better method because of better aeration and exposure to the sun and avoidance of soaking in the undrained field, especially when it rains. However, it is laborious. Stacking the stalks in rectangular or conical piles for about a week until a mechanical thresher becomes available often results in stackburning, especially when the paddy is wet or has very high moisture

content. Loss in quality due to yellowing of the grain is attributed to inappropriate field drying particularly, stacking when paddy is wet. Field stacks are however, subjected to re-wetting when it rains and should therefore be amply protected during rainy season harvest.

Majority of farmers rely on sundrying of threshed paddy. The process is normally cheaper than artificial drying and requires no special skills. Essentially, it is a natural method of drying since it relies mainly on solar energy and natural air movement. It is different from natural field drying since conventional sundrying involves drying of threshed grains and requires a drying floor and occasional mixing or turning of the grain to avoid uneven drying or subjecting the grain to excessive temperatures which induce cracking or fissuring.

For small-scale drying operations, concrete pavements such as sports game and open-air courts as well as roads are popularly used when available and tolerated as in some places. Some well-to-do farmers construct their own paved surfaces for drying while smallholders use drying sheets such as nylon nets, gunny sacks, canvass, plastic films, bamboo mats and tarpaulins in lieu

of paved floors. Depending on the volume of paddy to be dried at one time, the stirring or turning devices consists of hands or feet, hand rakes and motorised rakes. Most small farmers occasionally sell their marketable surplus paddy either wet as harvested or partially dried.

Sundrying is a labour-intensive operation. Rice mill owners hire labour groups to perform drying operations in the rice mill yard. A commercial large-scale rice mill owner in Thailand innovated a partially mechanised sundrying system on about 2000 square meters of concrete pavement. The equipment consisted of a payloader, a dump truck and a vehicle-drawn rake/spreader. It has mechanical dryers heated by rice hull furnace as back-up.

Harvesting early when paddy is still at high moisture content will minimise shattering losses in the field. The increased volume of paddy production of high yielding rice varieties and the adoption of advanced production technology, have created a problem of drying large quantities of wet grain at the shortest possible time to minimise the risk of spoilage. Fast drying can only be achieved by means of artificial or mechanical dryers. Sundrying is no longer adequate to meet the drying needs especially during the peak harvest

of the wet season crop.

The use of mechanical dryers eliminates the problems associated to sundrying. Mechanical drying offers the advantage of timeliness in drying, reducing handling losses, maintaining grain quality, and better control over the drying process.

Mechanical drying of paddy basically involves the heating of ambient air to increase its water holding capacity and then forcing the heated air through the wet grain mass. The basic components of a mechanical dryers consist of a drying bin to hold the grain, a power driven fan or blower to force the air through the grain mass, and an air heating system to raise the temperature of the drying air and increase its moisture absorbing capacity. The forced heated air drying system accelerates the drying process, thus, reducing the drying time.

The choice of the dryer for a particular drying operation depends on several factors such as the drying capacity needed, ease in installation and operation, portability, fuel heat source and the initial cost of acquisition. The most

common type of dryers are batch-in-bin, recirculating batch, and continuous-flow.

Batch dryers. In this type, paddy is placed in a drying bin and hot air is forced through the stationary grain mass until the desired moisture level is reached. This can be flat-bed or circular bin type. Specifications of the dryer include an axial-flow fan, internal combustion engine or its equivalent electric motor to drive the fan. Temperature for drying paddy should not exceed 43.3 ^{o}C for seed and 54.4^{o}C for food grain.

Flat-bed dryers are classified as shallow bed drying system. Deep-bed batch dryers have grain layer thickness of 2.5-3.0 meters. The recommended airflow rates for this type of dryers range from 3 to 4 m^3/min per ton of paddy. The grain is cooled in the same unit for 2 to 4 hours using ambient air.

Continuous flow dryers. Mostly used for large-scale commercial rice mills, the continuous flow drying process has large capacity requirement. The system has advantages of shorter drying time, larger volume of paddy handled, and

more uniform drying of the grains over the batch-type drying system.

This system involves the movement of both the drying air and the grains in either cross-flow in counter-flow manner. The LSU and the columnar dryers which may be of the mixing and non-mixing are the most common types used.

Columnar dryers use large airflow rates/ton of paddy. It is a recirculation batch dryer with high capacity and drying air temperature of 60-88^{o}C. The column has perforated metal sheets on both sides allowing a grain layer thickness of 50 cm across through which air flows. The other features are the presence of a holding bin, an elevating device at the discharge side, and a return conveying system.

The LSU dryer offers the largest drying capacity of 1-10 tons per hour. Drying of large volumes of wet paddy is accomplished by exposing the paddy to a high temperature of about 66^{o}c. Several passes of 15-30 minute-exposure per pass are required for complete drying. After each pass, paddy is transferred to

tempering bins to allowed cooling and migration of moisture to the grain surface before the next pass. Tempering period ranges from 4-8 hours. Depending on the initial moisture content, drying may be completed in 2-5 passes. Tempering bins and conveyors are integral parts of the system.

The following are some of the constraints to adoption of artificial drying technologies for rice:

(a) Mechanical drying suffers from high fuel cost;

(b) There are farmers with small land-holdings and the volume of paddy produced is small and can easily be sundried;

(c) Some believe that because of the bleaching effect from the sun sundried paddy results in whiter grains than artificially dried paddy;

(d) There is lack of capital to invest in mechanical dryers;

(e) There is lack of knowledge about the technology.

Some of the farmers' perceptions about mechanical drying are as follows:

(a) Mechanical drying entails high fuel costs;

(b) Mechanical dryers are only used when sundrying is not possible due to bad weather;

(c) Utilisation period of the equipment is short;

(d) There is limited volume of production to justify dryers;

(e) Poor quality is produced from mechanical dryers;

(f) There is lack of training on the part of the mechanical dryer operator.

Rice millers have the following perceptions about mechanical dryers:

(a) Mechanical drying entails high fuel costs;

(b) Mechanically dried paddy is of poor quality;

(c) Mechanical drying operation requires more attention;

(d) Flat-bed dryers have limited capacity especially during peak wet harvest season.

The traditional sundrying of rice is carried out on any of the following surfaces by small landholders and landless workers who are paid in kind for their harvest labour: concrete pavements, earthen yards surfaced with cattle dung and clay mortar, plastic sheets, woven bamboo or palm leaf mats and fine mesh net overlays on hardened earth or grass area. Sundrying is low cost, utilises free heat energy and does not need any machine except for simple and home-made stirring devices and scoops. However, this method is adapted for small quantities of paddy at a time and even then, often brings problems of spoilage during the monsoon season harvest due to inadequate sunshine hours and rain interruptions.

Women usually do the stirring and tending of the paddy being sundried to shoo away birds, chickens and sometimes livestock. Men assist them in carrying the bagged paddy to and from the drying area. Commercial rice mills generally have large-area concrete pavements and a core or contracted drying crew for the purpose. In one large-scale rice mill in Thailand, sundrying is partially mechanised with a tractor-drawn rake for spreading and stirring, a dump truck for unloading the paddy on the pavement and a payloader for loading the paddy onto the dump truck.

Artificial or mechanical dryers are generally expensive to establish even the small one-ton capacity due to the structure, equipment, storage space and labour required. Attempts to popularise these small-scale dryers among farmers or groups of farmers have met only partial success and then only in exceptional cases such as viable co-operatives. There is very little, if any incentive for the farmer to dry paddy and sell it as such.

Commercial-scale dryers normally operate in conjunction with rice mill operation or enterprise because of the low appraisal for value added in drying in spite of the necessity for proper drying. The drying operation is

usually not a stand-alone enterprise as it may not be economical to do so especially on a small scale. The heating of air and forcing it through the grain mass as well as the moving of the grain mass as in the circulating types entail large amounts of heat and mechanical energy which may only be feasible in commercial scale drying and milling operations. The labour usually used in such mills are males as manual lifting and moving are required in short-run moving, loading and unloading of the grains within the premises of the rice mill. Table 3.5.2, Annex 3.5 T gives information on types, capacities, source of supply and prices of grain dryers in the Philippines as of October 1995.

The University of Agriculture and Forestry (UAF) in Vietnam has developed a so-called very low cost dryer (SRR) claimed to be suitable for small holders who may want to store only about one ton of paddy for own family consumption. It is made of bamboo mat cylindrical container and an electric powered heater and blower for slow and low temperature in-store drying. The technology is attaining wider acceptability among farmers in Vietnam through the extension efforts primarily by UAF. Figure 3.5.1, Annex 3.5 F shows the design of the SRR.

Sundrying, the method commonly practised for rural family-consumption paddy in developing countries, is mostly done by women. Since the drying space available is usually limited, the drying batch is limited. When the paddy is harvested very wet as in the case of rainy weather, the paddy is aerated at the same time to prevent spoilage. Sundrying has become to some extent, a family activity during the harvest season with the smaller children assigned as watchers to shoo away birds and domestic fowls from the drying area.

In introducing new drying technologies either to the farmers or to commercial rice mill operators, the aspect of economics of operation is a major factor in decision-making. If the eventual rice product is for the high-end market, that is, for high quality and high price, investments in more sophisticated mills may come as an easier decision. However, since rice is often a political commodity, the government may have a direct or indirect control on pricing of rice. Usually, the high-grade rice is exempted from such regulations but the quantity may be restricted to avoid politically damaging shortages of the staple for the masses that cannot afford the high quality rice.

A new technology replacing sundrying of household-scale paddy for own

consumption with artificial drying may meet resistance unless the economic advantages of the new technology are obvious. The Vietnam SRR dryer mentioned above may show some promise but the additional investments, even if small, may hinder the adoption of the technology under most circumstances. The effect on the traditional role of women in the drying operation may change as the technology changes. In the conservative society of the rural area, the change in gender roles demanded by the new technology may also hinder the adoption of the technology even if it is recognised as superior over the traditional one.

Drying of paddy is done on the farm as well as off the farm. Drying could be accomplished by field drying, conventional sundrying or by artificial drying. Drying methods or techniques vary from place to place and are dictated by the farmers' socio-economic condition or the degree of awareness of post-harvest technology.

The dryers listed in Table 3.5.1, Annex 3.5 T are used by farmers, co-operatives, and the private and public sector users involved in post-harvest handling and processing of paddy. The kind of machine and process used

depends upon the season, quantity and moisture contents of paddy handled.

Field drying is practised solely by the farmers. This method is resorted to during rainy season or harvesting immediately after the rain to remove surface moisture on the cut panicles, grains, reduce heating when harvested stalks are piled for threshing and to reduce the weight for easier handling in the field.

Shade drying is also practised by farmers particularly for grains intended for seeds. This method of drying is also used in cooling grains, which heat up in storage.

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pavements are usually undulating and slightly sloping. The surface profile provides for water drainage to the furrow portion and for piling and covering of the grain on the crested portion during drying in the rainy season. Sundrying labour is usually contracted to a crew on per bag or quantity basis. To augment their drying capacities, rice processing co-operatives, private and public sectors have heated air dryers of suitable size, process and system and according to their available resources and other factors.

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reduced the moisture content to about l8 percent which could be further dried in storage or other methods. This same principle is being utilised by the big recirculating mixing or non-mixing dryer where wet grain is subjected to heated air temperature of about 70-90°C for about l0-l5 minutes and placed in an aerated tempering bin before it is recycled to the dryer until the grain is dried. In this method, total drying time is drastically reduced.

2.6 Cleaning

Cleaning of paddy involves the separation of undesirable foreign matter or materials other than grain and leaving a cleaned paddy for storage and processing. Depending on the production management, harvesting, threshing and handling methods used, the field-processed paddy may contain various other crop and weed seeds, straw, chaff, panicle stems, as well as empty, immature and damaged grains. Sand, rocks, stones, dust, plastic bits and even metal and glass particles can contaminate the grain bulk due to careless handling after threshing of the paddy. The cleaning or separation process utilises the differences in aerodynamic and other physical properties of the

paddy grain from the other materials.

In most developing countries where threshing is done manually, paddy is usually contaminated by a large percentage of foreign matter. Rough paddy cleaning is accomplished in the field right after the threshing operation. It consists of hand raking and sifting the bits of straw, chaff and other large and dense materials from small piles of paddy followed by hand winnowing against the breeze. In some places, a hand/pedal-operated blower or an engine-powered fan is used to remove the chaff, dust, weed seeds and other light materials from the paddy. Cleaned paddy commands higher price than the non-cleaned paddy and therefore there is incentive in cleaning it. If the harvesting and threshing labour is paid for in kind, the farmer will demand that the paddy be cleaned. Rice for home consumption is desired to be clean. Women normally do the cleaning process of the paddy in the field and finally, of milled rice in the kitchen prior to cooking.

Cleaning of grain involves the separation of bulk straw, chaff, empty kernels, and very light and fine impurities from the grain. In the simplest form, and chaff is manually separated and the grain is dropped through a crosswind to

remove the light impurities. Air can only remove impurities that have different aerodynamic properties from the grain. In the hold-on type of thresher, a major portion of the straw does not pass through the machine, and only the removal of chaff and light impurities from the grain is necessary. This requires pneumatic means and in some cases the combination of screen and air is required.

During sundrying, paddy may be further contaminated with sand, soil, stones, animal excreta, fowl droppings and bits of other biological materials depending upon the place, the activities involved, and the techniques used.

In small-scale and village rice mills, no prior cleaning is usually done on the paddy except perhaps using a screen or sieve on top of the hopper of the paddy husker. The absence of effective cleaning devices often result in poor quality milled rice in terms of contaminants. Stones and other hard object admixtures in the paddy also shorten the life of the milling machinery. The milling recovery is usually low.

In commercial large- and medium-scale rice mills, scalping is the first stage in

the industrial process where most foreign matter is removed to reduce drying cost, eliminate clogging or damage to conveying equipment and prevent paddy deterioration during storage due to high-moisture spots of non-grain organic matter. The second cleaning stage occurs after storage prior to milling process to remove the remaining foreign matter that could damage the milling machinery and affect the grain quality or grade of milled rice and therefore, its market value. Cleaning devices may include vibrating or rotating sieves, aspirators, destoners and magnetic separators.

2.7 Packaging

In small-scale production and processing, field-threshed and partially cleaned paddy is bagged in jute or propylene sacks for handling purposes in transporting paddy from the field to the roadside or to the house. The weight of each bag ranges from 30 to 100 kg depending upon the trading practice in the locality or country.

In large-scale and mechanised rice production operations where the combine is used, the paddy is not packaged but instead delivered in bulk to the rice

mill or drying compound. From the combine hopper, paddy is transferred by means of an auger conveyor to a waiting lorry or wagon at the roadside or alongside the combine depending upon the trafficability of the field.

Milled rice, the final product for marketing, is packaged in polyethylene, propylene or jute sacks in weights ranging from 1 kg to 1000 kg depending upon whether the market is for retail or wholesale or for export. Higher quality rice normally retailed in speciality groceries and in supermarkets is packed in attractively labelled packages made of polyethylene, propylene, jute and paper bags or cardboard boxes. Brown rice, which has a special market, is packed in sealed polyethylene bag inside the cardboard box or the outer bag. This is to increase the shelf life of the grain, which is prone to rapid rancidity due to the free fatty acid in the bran.

Rice is retailed in small village stores and displayed in their original large sized sacks or in wooden bins and labelled as to variety and price per unit weight or volume as may be required by law in some developing countries. In this case, purchased rice is weighed or measured and packed in plastic bags or other container brought in by the customer.

2.8. Storage

Paddy is a seasonal crop generally harvested once a year. In fully irrigated, well-developed farming systems in the tropics, paddy can be planted and harvested throughout the year. As a staple food in most of the rice producing countries, harvested paddy must be dried, cleaned and stored as a source of food supply until the next harvest. Not all of the paddy produced are retained by the farmers. Decisions on how much to retain is influenced by previous cash commitments, labour scarcity at harvest, transport difficulty, weather conditions, and lack of handling and storage facilities, current prices and immediate source of cash during emergencies. Up to about 70-90 percent of farm produced in the Asian region is retained in the farms. The rest is deposited/sold to agricultural co-operatives and/or sold to the private and public sectors.

Rice in either milled or paddy form, is stored to provide a buffer stock of the staple, the amount, form, and sophistication of which depend upon whether the level of storage is household or own consumption, rice mill, wholesaler, retailer or distributor and government logistics. At any level and scale of

storage, drying of paddy to the moisture content level of about 14 percent is a basic requirement to prevent spoilage. Uniform drying and prevention of moisture spots and moisture migration inside the grain mass by means of aeration is essential especially in large-scale storage where metal or concrete silos are used. Proper storage for seed purposes is necessary to maintain its viability. Hence, the storage structure must protect the paddy from extreme heat or cold, moisture levels at which the seed will spoil and be subjected to microbial or fungal attacks, insect pests and rodent consumption or damage. The place of storage is as important as the storage structure itself as the storage container should be protected from the weather elements and other stresses such as heat from fire and possible damage or structural failure due heavy loads.

At the farm household level, storage is usually equated to food security or as commodity bank for conversion to cash when the need for it arises. As the small-scale or marginal farmers do not have the resources to store large amounts of grain or to have large storage facilities, they usually sell out their paddy to traders or buyers immediately after harvest. No further processing such as drying, cleaning, and grading is done because of the immediate need

for cash and the lack of incentive to dry the paddy as the price differential between wet and dried paddy is usually marginal. Therefore, they only dry for safe storage, the amount of paddy for their own consumption until the next harvest or a little more for cash conversion in time of need for cash or for a better price. Otherwise they sell the surplus paddy. These small farmers as well as the landless rural workers who earn their harvesting labour in kind store their paddy in bamboo, wooden or metal bins of about one ton capacity. In some countries the common storage method is by using jute or propylene sacks. These storage sacks or bins are secured against theft and are protected from rain or moisture, insect pests, and rodents.

Commercial-scale rice mills have drying and storage facilities for paddy and for milled rice. Paddy needs to be dried to about 14 percent moisture content for safe storage. As the mill has to procure large stocks of paddy for year-round milling, the drying and storage capacities of the facilities are balanced with the milling and the distribution capacities or outputs. Paddy is sometimes stored in bulk on floor or platform with built-in ducts for heated air drying and subsequent aeration. The warehouse is within the rice mill compound which invariably has a sundrying pavement also even if mechanical

drying is the main drying system.

Milled rice wholesalers usually store their product in sacks which are stacked in secured warehouses using one or a combination of sandwich, window or block stacking technique to permit maximum air flow through the spaces and maintain aeration. Where space permit and there is need for longer storage period either by design to wait for better prices or there is an overstocking, retailers also stack their rice bags in such a way that aeration is maintained. This is to prevent rice from deteriorating in quality due to moisture absorption. Rodent traps and other means of controlling them and insect pests are also instituted by necessity. Keeping only enough inventory is also a way of avoiding storage problems by retailers.

In the mountain areas in the Philippines, special rice varieties are for ceremonial or special purposes, such as wedding, other celebrations and rice wine making. Dried paddy in panicles, are usually stored on a platform above the kitchen to protect the grains from insects and varmints.

Government storage systems in countries where rice is a regulated

commodity usually have standards following international practice or adaptations from those of developed countries. Their establishment usually has benefited from foreign expertise assigned by international aid or financial organisations or by the suppliers of storage equipment and facilities. Nevertheless, operational problems leading to quality deterioration or spoilage losses of paddy or milled rice do occur because of lack of sustained training of personnel in technical requirements, occasional lapses in management and other causes.

In India, Nepal, and other developing countries, sheet metal storage bins were promoted among rural households by the governments in line with the "Save grain" program of FAO. One of the major purposes is to protect the rice or paddy from attacks of insects and rodents. This is aimed at improving the traditional wooden bin or jute sack storage method in terms of avoiding or minimising losses of grain while in storage.

The traditional storage structure is usually a crude container made of woven bamboo or palm leaves or wood. The design is simple but the maintenance of the storage integrity is usually not ideal as spoilage due to high grain

moisture, wetting by rain due to inadequate protection from rain, storm or flood, dirt contamination, insects, rodents and losses due to theft or pilferage and grain retrieval, collapse of the storage structure, and complete loss due to flood and fire.

The commercial grain storage silo is made of either sheet metal or concrete. In the developing countries, the metal silos are usually imports from developed countries but due to storage problems brought about by the humid conditions and also of their doubtful sustainability as shown by past experiences with them, such storage structures have never become popular in the humid tropics. However, concrete silos are common in these countries but the problem is the over capacity or inadequate rice production except in the rice-exporting countries. Such silos must have aeration and stirring systems to maintain the ideal storage moisture of the grain and to minimise moisture migration and concentration. They must also have the necessary loading and unloading equipment integrated with the grain receiving, drying and milling operations.

(a) Own consumption. Rural households set aside a portion of

the rice production or acquisition during harvest for food security. For this purpose the paddy or milled rice must sustain its integrity in terms of quality and quantity by preventing spoilage and other losses;

(b) Commodity bank or financial security. In rural households, extra supply of rice is stored together with that for own consumption for conversion into cash in time of need. This is in lieu of selling the paddy outright and putting the money in the bank which may be strange to the farm household;

(c) Seeds for the next season. A rice farmer would normally select seeds from the standing crop and store it properly and sometimes differently from the method used for paddy for own consumption. This additional or special care is aimed at maintaining seed viability or high percentage of germination;

(d) Expecting a better price for paddy or rice. For a marginal farmer, the timing of sale of stored paddy or rice is not as much

for a better price as for the need for money. For a merchant such as a wholesaler, trader, retailer, or rice mill owner, some rice stocks may be earmarked for sale during lean months (during low supply of staple as a certain period before harvest time) to get a better price. However, when a rice supply crisis occurs, such merchant may not be allowed to hoard the stocks and may be compelled by the government to sell not at the ideal time and at a certain regulated price;

Table 3.7.1, Annex 3.7 describes the different storage facilities.

Farmers store their paddy in traditional and non-traditional structures primarily for food security until the next harvest. Also, as a source of cash during emergencies, for seeds, for future increase in price of paddy during the lean months, and for anticipated future festivities. Paddy retained for storage are sun-dried several times and cleaned before loading to the storage containers. Although farmers do not have moisture meters, they know by experience the dryness of the grain appropriate for storage. Grain dryness is determined by pressing hard a bunch of grains on the hand and/or biting

several grains to determine hardness. Usually, a fully dried grain is hard. Paddy is usually stored with 14 percent moisture content or lower. Storage containers are checked, cleaned and repaired if necessary, before loading the grain. Paddy is stored until the next harvest season or for 6-12 months.

Very few farmers apply insecticide on food grains before or during storage, probably due to small quantity stored and relatively short storage duration. Grain used for seed requires different treatments. It must be well-dried to about 12 percent m.c.; cleaned to remove all immature and empty grains; mixed with insecticide powder; and stored preferably in a sealed container. Any available insecticide dust applied at the proper dosage rate will be satisfactory. The main causes of loss in storage are rodents, moulds due to moisture, mites, insects, spillage, and sometimes theft. Losses in farm storage have been estimated to reach up to 6.2 percent.

In some countries, agricultural co-operatives are formed by farmers to handle their marketing problems and make available loans in cash or kind intended for farm inputs including household supplies. Paddy acquired from co-operative members (as deposit or purchase) and purchased from non-

members are processed, stored, and marketed as paddy or milled rice. Facilities such as rice mills, drying pavements, mechanical dryers, warehouses, transport, and other accessories are made available. Because of their wide community operations and established operating systems dealing directly with the farmers, co-operatives are usually effective and beneficial as a purchasing and marketing arm.

Paddy is usually stored in bags which are stacked inside warehouses. Some are stored in bulk using bins or silo associated with the drying and milling operations. Fumigation, aeration and the maintenance of clean warehouses are considered good warehouse management practices.

Co-operatives help the public sector in making grains available to the consumers and in maintaining a stable price of the commodity between the producers and the consumers.

Private traders operate mainly for profit. They have drying facilities such as concrete pavements and mechanical dryers, rice mills, warehouses, and transport facilities. Paddy is purchased dried, stored, processed and marketed

as paddy or milled rice. Paddy/milled rice are stored in bags stacked inside a warehouse. Storage is usually less than six months and depends upon rapid turnover for more profit or, in some cases to pass on the problems leading to losses and costs to the consumers. With this kind of operation, they do not have the incentives or facilities for disinfestation. Warehouses of poor design and low construction standards built at minimum cost are often not suitable for proper management and storage of food grain for food security.

Public agencies are involved in processing up to about 30 percent of paddy produced in the country. The storage structures used vary from bulk pile to fairly advanced systems of modern structures conforming to good warehousing practices. These practices include monitoring and maintaining temperature of the grain, waterproofing, insulation, rat and bird proofing and regular pest control. Causes of losses on the public sector storage are insect, rodents, birds, moisture (moulds), theft and pilferage. Except for theft and pilferage, losses of up to 6.6 percent was assessed due to these factors.

The methods and storage structures used in the public sector vary and are adapted to existing conditions, available resources and technology adopted in

the country. Grains are stored in bags and bulk with each having comparative advantages and disadvantages.

The Indian Grain Storage Institute having developed 95 designs of improved farm level storage structures with various capacities. The Institute also devised a code of scientific storage practices suited to farm level storage and measures to improve on traditional storage structures used by Indian farmers. The propagation of scientific storage practices was being undertaken by the Central Save Grain Teams in collaboration with the State Governments (Bansal, 1986).

Storage structures used for paddy are listed in Table 3.7.2, Annex 3.7. Storage structures used by farmers in the different rice producing countries vary depending upon materials available, technology accepted and practised, weather conditions and availability of non-traditional materials in the area.

Recent advances in long-term cereal storage include the hermetic or sealed storage and controlled atmosphere storage (CAST). As the name implies, the containers in hermetic or sealed storage are made airtight after storing the

cleaned and dried grain. Oxygen will be depleted inside the storage container to the point where growth of insects, moulds, and fungi are restricted. In CAST, the air inside the sealed storage containers is replaced by modified atmosphere that is insecticides, prevents mould growth and quality deterioration of the commodity. The modified atmosphere inside the storage containers can either be: (a) low- oxygen atmosphere generated by purging with nitrogen; (b) low-oxygen atmosphere produced and maintained by the combustion of hydrocarbon fuels or (c) high-carbon dioxide atmosphere (35-80 percent). Although hermetic or sealed storage and CAST are effective in long term preservation of cereals, it is not popular in developing countries because of its cost, technology required and associated equipment needed to use the method.

Stored paddy is lost due to moisture (moulds and fungi), vertebrate pests (rodents and birds), insects, mites, spillage and possibly theft or pilferage.

Paddy is a living, hygroscopic, and biological food materials that respire at a rate dependent upon its moisture content and surrounding conditions. Respiration rate increases with moisture content of the grain. Heat, a by-

product of respiration, is released in the process and retained in the grain mass because of the insulating effect of the rice husk. High moisture content will increase respiration rate, heat evolved and ultimately grain temperature which leads to deterioration. Also, high moisture makes the grain soft and susceptible to insect attack and mould growth resulting in increased grain loss. Loss due to vertebrate pests (rodents and birds) is possible only when their access to the grain is possible. Insect eggs or adults already in the grain prior to storage, adults in the crevices inside the container or openings in the container are the means by which insects gain access to the stored grain.

The above factors must be carefully considered in storing paddy. Grain for storage must be well cleaned and appropriately dried. Moisture content of 14 percent can be stored up to six months depending upon the container and surrounding conditions. Lower grain moisture content than 12 percent is appropriate for storage of more than six months. Storage containers must be free from large and small openings to prevent vertebrate pests and insects to gain access to the stored grain. It must be located in a cool dry place with minimal temperature variation within the container to prevent moisture migration within the stored grains. Paddy exposed to damp or very humid

conditions absorbs moisture increasing its moisture content and resulting in shortened storage life.

Majority of the storage containers used by farmers (open top woven bamboo or straw baskets with or without mud/dung plaster and jute or propylene bags) do not conform with the above criteria for good storage because moisture, pests and insects can easily gain access to the stored grain. Farmers do not usually consider storage losses significant because of the short duration of storage. Grain is consumed before infestation is discernible. Woven bamboo or straw basket with mud/dung plaster on both sides provided with cover to seal insect passage, and metallic drums or GI bins, if available, is recommended for on-farm storage. Any other structure that can satisfy the above criteria can be used particularly if materials and technology is locally available.

Bag storage is used by all sectors in storing paddy for both short and long duration although it does not conform to the above criteria. It is recommended that this method be used for short duration of up to three months and when grain is stored longer, frequent inspection for any sign of

rodent, insect, heating and mould on the stored grain. Necessary steps should be applied to remove the cause of grain loss, that is, plugging possible entries of vertebrate pests, fumigation to kill insect infestation and aeration or re-drying of grain. In addition to cleaning and drying of the grain to about 12 percent, bags must be cleaned and treated to kill hiding insects. Bags must be piled on dunnage with provision for aeration or free air circulation.

Bulk storage in silos made of bricks, concrete, metal or mud straw (China) is commonly practised by the public sector and sometimes by the co-operatives and commercial millers. It is recommended that when this system is used for any length of storage, associated auxiliary equipment to dry, aerate, transfer, transport and monitor the temperature of the grain inside the silos must be made available. Regular inspection of the grain and fumigation if insect infestation is observed must be done.

In addition to the above recommendations, the surrounding and the inside areas of the warehouse must be regularly cleaned. Also, the warehouse and storage containers must be fumigated before the seasons' harvest is stored.

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