RICE

Post-harvest Operations

INPhO - Post-harvest Compendium

Food and Agriculture Organization of the United Nations

RICE: Post-harvest Operations

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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.

1.1 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.

1.2 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.

1.3 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.

1.4 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.

1.5 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

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.

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 of 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.

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

3. Overall losses

Postproduction losses of rice can be quantitative or physical which means a reduction in weight or volume of the final usable product from the potential yield or harvestable paddy. The losses can also be qualitative which means a reduction in value of the usable product due to the physical and chemical changes which diminish the grain size, cause poor appearance, taste, aroma, cleanliness due to admixtures or contaminants and chemical residues and other factors which the consumers of the product will otherwise undervalue or the grain standards authorities will degrade resulting in low demand for the product, low price or rejection and declaration as unfit for consumption by human or animal.

Losses are incurred in pre-harvest and post-harvest processing operations consisting of harvesting, threshing, cleaning, drying, storage, transportation and milling. The flow chart of loss components of each operation are shown in Figure 4.0.1, Annex 4.0 F. The theoretical estimated losses of rice incurred in each operation are shown in Table 4.0.1, Annex 4.0 T.

Values of loss percentages for the different post-harvest operations by method in each operation in China, Indonesia, and the Philippines are respectively shown in Table 4.0.2, Table 4.0.3 and Table 4.0.4, Annex 4.0 T. Losses of rice within the post-harvest system in the developing countries of Asia, West Africa and Latin America are shown in Table 4.0.5, Annex 4.0 T.

The percentages of loss components incurred in different methods of harvesting, threshing, and storage in Zheijang, China during 1987-1989 have been documented by Ren-yong et al., 1990 and values are given in Figure 4.0.2, Figure 4.0.3, Figure 4.0.4, and Figure 4.0.5, Annex 4.0 F.

The following summarises the wrong practices in each major field operation and processing activity lead to physical grain losses:

(a) Pre-harvesting

1. Planting varieties with admixtures of red rice, which are highly shattering, have low resistance to lodging and uneven maturity dates;

2. Poor weed, rodent and bird pest controls;

3. Harvesting too early or too late of the variety maturity date.

(b) Harvesting

1. Missing the secondary tiller panicles because harvesting by sickle of lowland rice is done by cutting the straw about 60 cm above the ground;

2. Delay in harvesting causing shattering losses during harvesting and transporting and handling of the harvested crop before threshing;

(c) Threshing

1. When threshing manually by beating the harvested crop against a wooden plank, some more rice grains remain in the threshed crop. In some countries, these bundles are threshed once again by treading with animal;

2. Rice grains scatter around when lifting the small bundles just before the manual threshing above;

3. Some grains stick to the mud floor and cannot be recovered;

4. Birds and domestic fowls feed on the grains.

Summary notes on field operations The following are some choices of technology which is characterised by the degree by which grain could be lost. Manually beating the panicles on a drum or wood block will shatter grains and needs a wide threshing mat. A portable manual threshing platform enclosed by cloth or plastic sheet or fine net will contain shattering. A pedal-operated thresher increases threshing productivity and minimises shattering losses. An engine-powered axial-flow thresher combines threshing and cleaning in most designs but inefficient designs could lead to non-thorough separating and cleaning functions. An engine-powered stripper harvester combines harvesting and threshing and minimises handling losses but can lead to substantial grain losses if the crop is lodged and the field is wet and has poor trafficability.

(d) Drying

1. Grains shatter from the stalks or spill out of the grain bags during transport and handling;

2. During sundrying, birds and domestic fowls feed on the grains; grains spill outside the drying area;

3. Overdrying the grain, especially when sundrying by traditional method;

4. Delayed drying or no grain aeration which causes stackburning.

(e) Storage

1. Stored grain is attacked by insect, rodent and bird pests due to inadequate protection;

2. Storing for long term, grain with moisture content above 14 percent or storing grain with moisture content of 18 percent longer than two weeks under ambient conditions;

3. Theft and pilferage in grain warehouses.

The farmers in Lao PDR store paddy in bags or in bulk on a roofed elevated platform with removable stairs and supported by six posts. The walls are made of woven or pounded bamboo mat or slats. Rodents are kept out by enveloping each post by a galvanised iron sheet cone guard or a circular horizontal wooden plate barrier.

(f) Milling

1. Improper adjustments of milling equipment;

2. Spillage in traditional hand pounding methods;

3. Under or over-dried paddy.

Summary notes on off-field operations. Sundrying, the most widely used drying method for home-consumed rice by farming families in developing countries, needs concrete pavement facilities. Table 4.0.6, Annex 4.0 T gives values of losses in drying and storage.

Insect pests can not only cause physical losses but also affect the nutritive value of stored rice. Table 4.0.7, Annex 4.0 T gives the estimated losses in samples infested by *Sitophilus oryzae*.

The theoretical milling recovery is 71-73 percent, depending upon the variety of rice. In a well -operated modern mill, it is possible to obtain a milling recovery of 68-70 percent from a good variety of paddy.

Milling losses can be reduced by adopting small-scale modern rubber roll sheller and introducing parboiling of paddy before milling. The suggested mill for village level is cleaner ---- rubber roll sheller --- horizontal abrasive polisher. This combination is expected to give 66 percent milling recovery.

4. Pest control.

The estimated grain losses in storage due to pest infestation account for some 0.35 - 4.55 percent out of the total estimated grain losses in the post-harvest system of 2.63 - 31.3 percent. An insect population attains pest status through invasion, ecological changes and economic changes.

Invasion. The development of international trade has contributed greatly to the widespread habitat of insect pests. It is therefore important that the strict quarantine be part of the pest control system in a country.

Ecological change. The use of wide spectrum pesticides has reduced the population of natural enemies such as predators and parasites of major rice storage pests. The conditions therefore become more favourable to the rapid multiplication of major pests.

Socio-economic changes. The economic threshold is determined by market value of the grain, cost of control measures and consumer habits and taste. The rice damaged by a certain insignificant pest may lessen in value because of reduced tolerance of people for such condition of the commodity. The pest therefore becomes a significant or serious pest, although its population density did not change.

4.1 Relative status of major pest species

A pest is major if it is found in great number or in abundance. The rice weevil and the flour beetle are examples of such pest. A pest is minor if it is found in small number. A pest is primary if it attacks undamaged or sound grain, completes its development in it and initiates a chain of events in which other insects, fungi or bacteria feed on the damaged grain. The rice weevil is a primary pest. A pest is secondary if it attacks grain damaged or processed mechanically by grinding, milling, and handling or by the action of primary pests. The flour beetle, saw-toothed grain beetle and the rice moth are secondary pests.

4.1.1 Details of each major pest

(See Table 5.2.1, Annex 5.2).

4.2 Pest Control

Pesticide residues. (See Table 5.3.1, Annex 5.3).

Integrated pest management (IPM).

IPM is the use of all available tactics in a program to manage pest problems and minimise economic damage and environmental side effects (NAPHIRE, 1997). It involves the integration of biological, chemical and physical methods ones to control pests as well as other suitable and compatible to the system to keep the pest population at a level that will not cause any economic damage. The IPM program is built around the concepts of efficient warehouse design, high standard hygiene, minimum use of insecticides, use of methods that obtain as complete kill as practical and thorough inspection program.

The warehouse or storage structure at any level or size should protect the grain from water and moisture, keep the pests out or given no access for entry, facilitate loading and unloading, and be conveniently sited for handling and transport. A high standard of cleanliness and strict hygiene will prevent the build-up of damaging pest population by denying the pests of food and reduce the residual populations of insects and rodents in grain stores, surroundings and machinery. The program will also avoid seeding of clean grain with insects and infestation of adjacent stores as well as reveal possible structural weaknesses and paths ingress of water and soil moisture into the store.

The restriction of the use of pesticides to combinations with other control methods will enhance the oval effectiveness of the pest control program. Such restriction will help in reducing the potentially harmful residues, selection for resistance, environmental hazards and cost of treatment.

The complete kill is important in delaying population build-up and in reducing the rate of selection for resistance. Proper fumigation will control established infestations and in combination with barrier sprays of residual insecticides, will protect the grains against re-infestation.

Inspection and sampling activities are the means to obtain accurate qualitative information and data on the status of infestation of the grain. A pest and damage monitoring system is important in the overall efficiency of the pest control measures.

Elements of IPM

There are four basic elements of IPM, namely, natural control, economic levels, sampling and insect biology and ecology.

Naturally occurring growth suppressive factors may be utilised. The gas composition may be manipulated to hinder the growth and development of the pest

The economic threshold level (ETL) rather than the calendar-based application of pesticides will minimise the use of harmful chemicals and maximise the use of no-chemical methods of control.

The status of pest infestation, damage, level of losses and the population of beneficial insects and population trends of the harmful ones are determined by sampling which is a tool to apply ETL.

The knowledge of the biology and ecology is essential in utilising effectively the above three elements.

Components of IPM

The following components are utilised in the practice of IPM:

Biological control. The pest is controlled by a parasitoid, a predator or a pathogen to manipulate the reproductive processes, behaviour, feeding and other biotic aspects of the pest. A parasitoid resides and feeds on the host pest itself which eventually dies. An example is *Anisopteromalus calandrae* a small wasp which feeds on the beetle larvae of *Sitophilus spp*. and *Rhyzopherta spp.* A predator kills and feeds on one or more hosts and seldom resides or rides on them. A pathogen is a disease-causing organism, which is normally targeted specific and harmless to non-target organisms. It is easy and cheap to culture. Pheromones are chemical messages released by organisms to influence the behaviour (usually sexual) of the other organisms of the same species. Pheromones may be employed as attractant to prevent mating of the target species by misleading them. Host resistance to insect attack makes use of the natural built-in protection. For example, it is more advantageous to store rice as paddy than as milled rice because of the protective husk. Some varieties may have degree of tightness of the husk, which make them either susceptible or resistant to certain pest species. The use of sterile insects may be effective but it is resisted by those concerned. Neem (Azadirachta indica) leaves are used as insect repellent in the grain store in Indian households.

The constraints on the potential use of biological control of stored grain pests have been cited as follows:

(a) Predators, parasites and sterile insects found among the grains are themselves contaminants;

(b) Chemicals used to treat grains in store are toxic also to the beneficial insects;

(c) Predators and parasite attacks on pests are usually limited to the superficial layers of the large bulk of the stored grain;

(d) Pathogens do not thrive well in conditions of grain stored according to the recommended practices;

(e) Consumer rejection of the pathogen-contaminated rice.

Physical control. The physical method of controlling pests in storage includes the following:

(a) Hygiene and physical removal of infestation nuclei, including commodity residues, secondary or unproductive primary hosts for field pests. Cleaning should involve brushing and washing and disposal of all residues containing or supporting live insects. The rice mill machinery and premises are always a potential hosts of insects and should be cleaned regularly with special efforts made before any long gaps in operation to prevent the old and new resident pests from multiplying before the next milling season comes.

(b) Physical exclusion of the pests from the stored grain in the form of hermitic and controlled atmosphere storage requires gas tightness to be effective. Gas tightness through sealing is effective not only in keeping insects out but also in fumigation, single-treatment controlled atmosphere and heat disinfestation.

(c) Drying hinders the attack of most insects and fungi on the stored grain.

(d) Cold ambient temperatures during harvest and storage reduce the activities of insects. Refrigeration is the alternative in places like the tropics to take advantage of the effect of low temperature on insect pests.

(e) Aeration with cold ambient air as a means of effectively controlling pests in cold and temperate climates will not be as effective in semi-tropical and tropical conditions where temperatures are above 15 to 18^{o}C required to prevent rapid increase of insect population. However, aeration of the grain bulk can be effective in preventing local hot or wet spots, which favour insect growth and development.

(f) Hermetic (airtight) storage confines the grain inside a sealed enclosure wherein the respiration of the grain and the associated insects and fungi will deplete the oxygen and replace it with lethal amounts of carbon dioxide generated by them. The process is simple, self-regulating, and requires no added pesticides, inert gas or energy inputs. Maintenance of the hermetic seal of the storage structure and moisture migration are problems involved in this method. Studies of the use of plastic enclosure for outdoor storage intended to be used by farmers' co-operatives and small-scale traders and millers were conducted by NAPHIRE (1997) in collaboration with the Commonwealth Scientific and International Research Organisation (CSIRO) of Australia and the Agricultural Research Organisation (ARO) of Israel. Results indicated that paddy at 14 percent moisture content could be stored for three months without being damaged. The locally available nylon fibre-reinforced polyvinyl chloride (PVC) plastic material of thickness 0.60 mm could be used for five years. The capacity of the heat-welded enclosure was 6 tons of paddy. The volcani cube (Israel) made of PVC food grade liner of 0.83 mm thickness and closed by polyurethane zipper, could be made for capacities of 5, 10 and 20 tons of paddy. The volcani cube could be re-used and last for 10 years provided that it is cleaned and properly stored after each use.

(g) Controlled atmosphere which although similar in form to hermetic storage, is different from it in that the carbon dioxide gas is supplied from the outside. Storage period could last from 9 to 16 months. No risks of toxic chemical residues are present.

(h) Inert dusts in the form of ground rock or wood ash have been used to control insects in subsistence level grain storage systems. They may be used at rates above 30 percent of the weight of the grain. Dusts made of silica aerogels, various clays, diatomaceous earth, activated carbon, pyrophylite and a number of other silicates kill insects by absorbing or abrading the waxy layer from their cuticle causing desiccation and death. Dusts do not eliminate the residue problem although they are not toxic. They are unpleasant to handle. Promising inert dusts for on-farm storage in developing countries are the low-cost and easily applied silica aerogels and the diatomaceous earth as they are not toxic.

(i) Physical shock and disturbance can kill insects due to physical stress and damage due to handling and processing of the grain.

(j) Artificial light regimes can affect the photoperiodic responses and mating of insects. However, the potential for response by insects to visible, ultraviolet and infrared radiation for control has yet to be realised.

Chemical control. Chemical control methods have the advantage of effectiveness, simplicity, versatility, low cost and immediate availability. However, synthetic insecticides must be regarded as adjunct to good warehouse management, to reinforce hygiene and sanitation, to enhance effectiveness of available storage facilities, and to complement physical methods. It is not intended to replace good warehouse keeping or regular inspection for infestation or deterioration. The main types of insecticide treatment are as follows:

(a) Structural treatment (residual spray application). The surfaces of warehouses, storage bins, transport vehicles and other structures and machinery are sprayed with chemical which will not only kill the insects directly hit by the spray but will also leave a deposit on the treated surface which will be toxic to walking insects. Spraying may be done during the cleaning of the storage facilities before intake of new stocks or along with fumigation or spraying of stock in storage. The residual deposit decays with time and its effectiveness depends on the chemical and the climatic conditions prevailing.

(b) Space treatment. Fogging or space spraying is intended to control flying insects not controlled by the residual spray and those coming into the storage warehouse. Spraying is done usually at dusk hen insects are most active. Chemicals with knockdown action such as pyrethrin, lindane, and dichlorvos aerosols and strips or smoke or fog are used in space spraying. Dichlorvos plastic strips hung inside the warehouse at a density of 1 strip /30 cubic meters of space will be effective for flying moths.

(c) Grain protectants. These insecticides will prevent infestation when applied on grains. It is intended for light infestation only at the time of treatment and is not a substitute for fumigation in case of heavy infestation. In general, it should be avoided as it may accelerate the selection of resistant strains. The choice of insecticides to use is quite limited, as safety should be a prime consideration. Studies by Sayaboc, et al., 1996, of resistance of major insect pests to pyrethroids and organophosphates, revealed high resistance of the lesser grain borer *(Rhyzoperhta dominica)* to phosphine, in contrast to the low resistance of flour beetle *(Tribolium castaneum)* and susceptibility of rice weevil (*Sitophilus oryzae*).

(d) Surface spraying. The insecticide is applied on the surfaces of bulk grain or bags of grain. Examples are pyrethrum synergized with piperonyl butoxide, pirimiphos-mythl, chlopyrifos-methyl, tetrachlorvinphos, fenithrothion and metacrifas at about 1 to 2 percent concentration.

(e) Fumigation. A fumigant is a volatile pesticide, which exerts toxic action in the gaseous or vapour phase. The most common fumigants used world-wide are methyl bromide and phosphine. Fumigation is effective because of thoroughness of application but fumigants used to control pests are generally toxic to humans and plants; may be corrosive, flammable, leave harmful residues and produce offensive odours. In application, it is best to monitor the atmosphere inside the warehouse with appropriate test equipment and the threshold limit value should conform with that recommended by the American Conference of Government Industrial Hygienists (1983-1984). The most common deficiency in fumigation is the neglect of hygiene and stock management resulting in the necessity of frequent fumigation and consequently, the hazards of excessive bromide residue accumulation in the grain. Phosphine complements the use of methyl bromide, especially in vertical storage, Sayaboc et al., (1996) found that the use of 2 g phosphine per ton of grain at seven-day exposure time will effectively control insects at all their life stages. Other fumigants, which are used occasionally, are hydrogen cyanide, carbon disulfidem ethylene dibromide, chloropicrin, methyl chloride and carbon tetrachloride. A tolerance value of 0.1 ppm expressed as PH_3 , is recommended in international trade of cereals.

Two or more components of pest control can be combined in an integrated program. However, in a storage ecosystem, hygiene and good warehouse management are basic requirements and the IPM system is but supplementary. The combination of two or more of the following practices will constitute an effective pest control program.

(a) Improved harvesting and threshing techniques;

(b) Judicious use of insecticides;

(c) Use of ambient aeration and refrigerated aeration;

(d) Atmospheric gas modification;

(e) Thermal disinfestation;

(f) Irradiation techniques;

(g) Insect resistant packaging;

(h) Insect growth regulators;

(i) Biological control;

(j) Use of resistant varieties.

5. Economic and social considerations

The straightforward method by which farmers can add value to the paddy is by drying it to a marketable moisture content. In most of the tropics the equivalent moisture content is 14 percent wet basis. When paddy is dripping wet as in the case when harvest time occurs during monsoon rain and a series of cloudy days will likely follow the rainy days, it is critical that the moisture content of the paddy be reduced to skin dry condition within 24 hours after harvest. An interim safe moisture content is 18 percent for a 2-week storage under dry and protected conditions or at most 20 percent for a few days storage with occasional stirring and aeration. The choice of how far down the moisture content should go depends on the urgency of reducing the moisture content of the bulk of the grain to a safe moisture level. A flash dryer will remedy the situation on an emergency basis. This moisture content will at least be a first aid in saving the paddy from deterioration and will give the farmer enough time to organise and implement a drying system or sundrying depending upon his resources. Under most circumstances however, the farmer will opt to sell the paddy at a low price to a trader or rice mill because the small holder is generally averse to risks. The alternative is government action to provide drying and storage facilities at strategic areas. This is what the grain agencies like BULOG in Indonesia and the NFA in the Philippines are doing to a limited extent. These government agencies also encourage the formation of farmers' co-operatives in rice milling with drying facilities.

For very small holders, the problem of saving the wet grain harvested during the monsoon rains needs to be solved. Even if there were a government facility for drying paddy, the small quantity and most often the cost of transporting the paddy becomes an additional financial burden which the marginal farmer will not likely take. An option is to aerate the small amount of paddy by piling it into small heaps to expose as much surface area of the grain to the atmosphere and prevent heating up of the bulk due to microbial action and grain respiration. This procedure will require frequent turning over of the grain. A meticulous farmer will even scoop out the thin upper layer of each heap to form another heap, which is drier than the grain beneath and at the bottom especially with an initially dripping wet grain. If available, a manually or pedal-operated blower or engine-powered blower used for field winnowing may be used to increase the aeration process. A household electric fan will also be useful and in fact being used by farmers. It is best to have the bottom of the heap to be resting on a fine mesh net on a platform with slatted floor to increase underneath aeration and to drain any gravity moisture from the grain heap. These are emergency measures for the small holder and will be impractical or will require much labour or space for a commercial scale operation. Nevertheless, in the absence of drying facilities the above procedure can be adopted as an emergency measure or first instance solution until favourable sundrying weather comes.

The rising cost and non-availability of labour due to increasing employment opportunities in industry in some developing countries, particularly in Asia, has increased the adoption of mechanisation of rice production and post-harvest operations. The small size of fields, however, limit the powered machines to pedestrian tractors and machinery which also determine the scale and method of operations in harvesting, threshing, in-field handling and field-to-road paddy and straw transport of paddy.

Unless major policy directions leading to more efficient field operations than in the small-sized fields are instituted, the field operations in harvesting and threshing will likely remain as it is for a long time although small-scale powered machines will increasingly be utilised. One of such policy directions is the land reformation and consolidation as has been done to some degree in Japan and in Taiwan, province of China. Due to increasing demand for small-scale machinery mainly for custom service operations by small village entrepreneurs, the local manufacturing industry has been progressing and gradually increasing the quality of farm machines as well making them more affordable than before. In most developing countries, the power unit, the small engine ranging from 5 to 10 kW, remains as an imported item and is a major high cost component of a machine. However, a given engine may be used for a variety of small machines ranging from land preparation, crop establishment and care, irrigation, harvesting, threshing, transport, drying, and perhaps, in-field hulling of paddy. An increased support in rice production and post-harvest machinery research and development as well as agricultural and industrial extension will eventually lead to minimised post-harvest losses and reduced costs. Improved timeliness and efficiency of operations resulting from appropriate machinery and its proper maintenance will redound to the benefit of the small holders.

The use of combines as a step towards mechanisation has had a forward linkage with post-harvest operations. The large volume of paddy being turned over to the processing plants in a short time has put pressure on the drying and storage facilities in Thailand, a major exporter of rice. Large capacity dryers are now being manufactured locally and have large demand, at least for the present. Because of lack of incentives for the farmer to dry paddy, the drying operation will continue to be an adjunct operation of rice milling and will take place at the rice mill site using mechanical dryers combined with mechanised sundrying whenever feasible because of its low cost especially due to free, albeit unreliable (during rainy season) heat energy. Sundrying with complementary mechanical drying will be a main drying operation to take advantage of the sun's free heat energy and the environmental friendly feature of the technology. Mechanised and precision-controlled sundrying (still a neglected area for technological innovations, though sundrying is widely used) in combination with artificial or forced-heated air-drying is a pertinent subject of research and development now and in the future.

The concept of increasing the income of small holders through value-adding in paddy or engaging in primary post-harvest operations at the farm level remains a question under the present system of low incentives or non-recognition of such added value either by design and necessity or by trade practices in most developing countries. The farmer will have larger margin of profit and therefore incentive if he dries paddy during the wet season. Only a few farmers will recognise and adopt this concept, as some sort of drying facilities will be needed. A government campaign and assistance will perhaps make more farmers adopt the value-adding concept rationalising that social benefits will accrue in terms of lessened post-harvest losses, better grain quality and self-sufficiency in the staple. Perhaps the more easily adopted technology is to make the production and field harvest and post-harvest operations of threshing, handling and transport more efficient through better infrastructures and this is also normally a government initiative and at best a community action.

5.1 General overview

Once the rice crop has produced the grains approaching the potential yield for the variety under a given cultural practice, soil and climatic conditions as well as a set of inputs and other factors in production, the actual amount of grain finally retrieved from the plant after all stages of processing does not normally match that yield. There are numerous ways by which that yield already in the plant could be lost and so does the opportunity for it to be of use as food or something else. This situation occurs because there are many steps to be taken in bringing that yield from the plant to the rice bowl. Each step in the production and processing entails a certain degree of reduction depending upon the technology used and the care given to prevent or minimise losses. The rice crop losses are reported as lumped as percentage of the yield per hectare.

The post-harvest operations begin at harvest and ends at the storage of the milled rice. The range of processes discussed here does not consider the costs and losses in delivery of the rice to wholesalers and retailers from the rice mill, in cooking, and finally in serving the rice food in the plate or bowl of the consumer.

The grain losses in the field may be incurred during pre-harvest period and at harvest time. Normally, the longer the harvested grain is left in the field, the higher the chances of incurring grain quality deterioration and spoilage due to weather, stackburning and delays in drying as well as physical loss due to rodents, pilferage, and other causes. Depending on whether the variety is shattering or non-shattering, field losses of the grain may be small or large even if the rice crop is still standing. Wind, rain and degree of maturity of the crop can have a large effect on the magnitude of such losses for a given variety.

5.2 Major problems

Harvesting and threshing are major problems in field operations while drying of the paddy is critical as a post-harvest operation. Since milling is an industrial process which can easily be controlled inside a building, the problems related to this process are determined by the quality of the paddy received by the mill. The critical factor is the drying of the paddy immediately after harvest. In some developing countries, drying of the surplus paddy for the market is not normally carried out by the small-scale farmers. Wet or freshly harvested paddy is sold directly to traders or to the rice mills and rice milling co-operatives. Somehow, the farmers avoid the risk of crop deterioration by disposing off the crop immediately. The problem of drying is passed on to the trader or rice mill owner but the farmer gets a low price for the undried paddy. The bottlenecks in post-harvest processing should be solved using the systems approach.

In harvesting and threshing the quality of the harvested crop, the degree of losses incurred and the efficiency of the operations and hence, overall costs are affected by factors related to the weather, variety of the rice, and the technology used. Harvesting and threshing during the monsoon season bring about problems of wet and lodged crop, high moisture grain which is susceptible to spoilage due to fungal and microbial invasion, difficulty in threshing, grain handling and transport regardless whether the methods are mechanical or manual, and the critical need for immediate drying of the paddy. It is obvious that one problem in a process stage affects the quality and efficiency of the next stage and mitigating measures at that stage are needed. This chain reaction continues up to the milling process until the semi-final product, milled rice is produced.

The same problems appear to be magnified for small holders because of scarce resources to do mitigating measures like quick drying or transport to the market of wet paddy. They have lesser capability to absorb losses than the big landholders or commercial rice producers. They are forced to sell the paddy at very low price which may be the best thing to do under the circumstances to prevent greater losses, if not total loss.

5.3 Proposed improvements

The sale of the paddy, the final product from the farm, is the major if not only means by which the farmer, especially the small holder, can benefit from rice production. Straw, the only other by-product of rice production in the farm but has not been fully tapped by most farmers, except in places where it has market value as animal feed or thatch.

An increase in sales proceeds of means increased income. This increase in income can be achieved through increased quantity and improved quality of the product. Increased quantity is achieved through enhanced productivity of the cropping system and increased amount of production through improved production technologies as well as reduction of losses in the field. Improved quality of the paddy can be achieved essentially though variety selection in terms of eating quality, improved crop care (irrigation, pest and weed control), optimum harvesting time, and improved post-harvest processing. Field processing activities, including harvesting, threshing, cleaning and handling are more for retaining that quality or preventing grain deterioration rather than improving it.

Unfortunately, the small holder usually participates in the post-harvest processing stage only at harvesting, threshing and handling which may still be considered as the tail end of the farm production system because the product is considered as raw material and no value has been added so far. The concern is more of sustaining the quantity and the quality of the crop as produced, that is to add value and prevent the paddy from deteriorating.

The small holder does not have the capability or resources and the incentive (in many places) to do any further processing. Attempts by government extension services to promote drying at the farm level of paddy for sale have not been successful because the economic benefits for the farmers are not significant in terms of labour inputs and capital costs involved as well as the affordability to wait for higher prices of paddy. Any incentive from the paddy trading industry in terms of value or price increase given to the farmer to dry the paddy is usually very low, so that the farmer is forced to sell the wet paddy at a low price or else the paddy will deteriorate and will have zero or near zero value. The small holder family only dries the paddy retained at the household for immediate family consumption and for food and cash security at least until the next harvest.

After the field post-harvest procedures and activities have been optimised, such that production has been maximised, losses have been minimised, and the excellent quality of paddy have been attained, a possibility of the small holder increasing the cash income is an increased efficiency of the traders and millers of the traded rice in their operations and passing on part of the savings in costs to the small holder through better paddy prices. This is at best theoretical, as the traders and millers will likely keep the windfall from such efficiencies rather than share it with the producers or they are more likely to share such efficiencies to consumers. Only increased competition, increased market demand for rice or reducing supply by lowering production (indeed a counter-productive method) with no government intervention by importation of rice will increase the price of paddy.

Rice processing and trading co-operatives among farmers have been successful in many places in assuring farmers a fair price for their paddy and enabling them to get benefits from the processed and traded rice by virtue of their share of ownership of the processing facilities and the business. This strategy has been promoted by governments but is beset by problems of lack of management skills and capital investment costs. While there are success cases, there are also failures of attempts to organise and sustain rice processing co-operatives.

Perhaps an effective strategy is to empower the farmers to process the paddy (at least partly) in the farm by hulling it and trading the brown rice for further processing by the rice milling co-operatives or the private commercial mills. Brown rice can have a separate path leading to a niche market among the health-conscious consumers is developed countries. This alternative will entail not only innovative approaches to the technology but also changes in the pattern of field production, trading, storage and consumption of rice.

The reduction of field losses in harvesting and threshing can increase the profits of the small holder. Shifting from the manual to the proven efficient mechanical method of harvesting will greatly reduce harvest losses. The fast rate of harvesting and threshing enables a timely removal of the grain from the field which may be critical during the monsoon season. Drying the crop by the small holder aimed at increasing value of the paddy has not been a popular activity because of the low returns from the drying process. However, very wet paddy resulting from a rainy harvesting and threshing episode, will command a low price unless it is dried properly. In such a case the margin of profit may be high as the choice could be between a total loss or no profit and reduced profit due additional expenses in drying. Small portable axial-flow threshers which have been originally designed by IRRI are now being manufactured and distributed locally in many developing countries. Pedal-operated threshers have been accepted in the terraced fields in the highlands because of their portability and affordable costs, especially if made locally.

In Myanmar, the system of mechanical threshing has increased in popularity among farmers because of the significant benefits derived from their use. From observations in the adoption of mechanical technologies such as mechanical threshers in developing countries, the custom operation by a local entrepreneur who buys the machine such as a thresher, appear to be a popular and fast process. Custom services in threshing and cleaning of paddy benefit the farmer because of the faster output and cheaper rates. The system spares the farmer the investment and operational costs of the machine and may not be viable from the ownership consideration. The utilisation of the rice husk as domestic cooking fuel has increased in popularity in Myanmar perhaps because of the aggressive manufacturing and marketing by a local fabricator of a Vietnam-designed rice husk stove which has been modified by IRRI.

5.4 How has the introduction of the improved technology affected income/responsibilities between genders?

In most small rice farms in developing countries, women play a major role not only in production but also in post-production operations. In many countries, women are involved in or do most of the manual harvesting, threshing, winnowing, handling and sundrying drying. The men do the hauling and operate any powered machine if it is used while the women act as helpers.

In general, postproduction technology development and transfer programmes have been carried out on the assumption that the technology is either sex-neutral or that men are the main users and decision-makers. This assumption is often incorrect because women and other household members have quite different technology needs than men because of their different knowledge, experiences and skills, physique, stamina, etc.

Women workers are usually the first ones to be affected by a new technology introduced to improve processing. A powered machine will immediately displace women or relegate them into lesser tasks as helpers as the men take over the machine, be it a power tiller-mounted harvester or an engine-operated thresher. A pedal-operated thresher, however, fits the physique of women and is therefore accepted as a labour-saving device where mostly women do traditional harvesting and threshing.

Sundrying of paddy for household consumption is also a traditional task of women. Men do assist in the handling of the bags or containers. Since mechanical or forced heated air-drying is usually done by rice traders and millers, women are not much affected by such technology.

Most rural women in developing countries are traditionally responsible for pounding rice using the mortar and pestle or the beam hammer/pounder (*dheki*). Where the steel huller mills have been introduced, these traditional methods fade away. In most cases the substitution has been beneficial to the women because of the great relief from the arduous work or otherwise, because their family income has contracted. Sometimes, the change has given them the opportunity to explore other means of income generation, a luxury they could ill afford because their time is being used up by the major family obligation of milling rice which is just one of their several domestic tasks. At the worst perhaps, the displacement of women from their income generation of hand-pounding of rice for sale in the community (a marginal micro-enterprise at that), is temporary as some well-to-do community consumers would still prefer the pounded rather than the milled rice during the transition stage. With a small rice mill, such as IRRI micro-mill modified from a Chinese design, a women's group in the Philippines was able to increase income and obtain the bran for animal feed. The milling micro-enterprise was easily patronised by the villagers who were spared the time and effort to go to the far commercial rice mill to have their paddy milled. In effect, the introduction of the technology on a pilot basis has given economic and social benefits.

In a rural appraisal on the roles of the different household members in the postproduction of rice and other crops in Isabela and Quirino provinces in the Philippines, the following activities of women were observed (Paris and Duff, 1989):

Harvesting. Performing this task varied according to the culture and economic need of the family. In one village, men dominated harvesting because they were considered fast workers and could stand tougher jobs (exposure to sun or rain for long periods while at work). In another village of another province, harvesting was dominated by women and children (8-14 years old) because they were available or left behind during the harvest period as the men folk did the land preparation immediately after harvesting their own fields or worked as hired labour. In some cases, men looked for harvesting/threshing jobs in neighbouring villages where payment was in the form of in-kind share of the harvest which was larger than wage or contract work paid for in cash.

Threshing. Mechanical threshers were adopted because of their efficiency, less grain loss and immediate recovery of the threshed grain within the day compared with hand threshing which must be closely supervised by the farmer-owner to control losses and technical pilferage (not threshing thoroughly to give more yield to gleaners who are relatives of the threshing labourers). Mechanical threshing was dominated by the crewmen of the hired thresher. They performed the feeding of the harvested rice, bagging the threshed grain, sewing the bags and stacking them at the threshing site. Other men did the in-field and field-to-road transport as well as loading on the transport vehicle, consisting of animal-drawn sled or cart or motorised tricycles, trailers pulled by small tractors, jeepneys, pick-up trucks and lorries which were usually hired by the buyer of the harvested paddy. Depending upon the distance, the transport job was paid for separately from harvesting.

Gleaning. Women and children, usually the relatives of the hired labour for the threshing operation, tried to recover grains from the straw or threshing yard. Landless and marginal farmers sometimes did gleaning to augment family income. Each gleaner could recover about 25 kg of paddy in a day.

Hauling. Men usually dominated this job, which required strength and stamina. Women assisted in lifting the bag onto the shoulder or head of the men.

Drying. When sundrying the grain, men did the hauling, loading and unloading on the drying floor while the women and children took turns in spreading, stirring and watching over the grains to be dried. They also assisted the men in bagging and loading of the grains at the end of the drying period.

Storing. Most of the grains were sold immediately to the buyer. Only about 800 to 1500 kg were stored per farm household per season. Storage could be in bulk or in sacks in one corner of the house, in bamboo baskets or wooden boxes. Sometimes the grain was stored in a warehouse which could be a separate shed or an extension of the house with galvanised sheet roofing and wooden or concrete walls and floors.

Marketing. In one village, farmers sold their paddy in buying stations located outside the village from where they could obtain cash payments and loans and farm inputs. In another far-away village, buyers pick up the grains using big trucks to ensure payment from farmers who obtained loans or advanced payments from them. Both the father and the mother decided on the volume and price of the grain to be marketed but the mother usually managed and kept the proceeds after marketing.

The above observations in the post-harvest operations for rice may vary from country to country, depending upon the culture. However, in most developing countries in Asia, women do share a major portion of the labour inputs in such operations.

In the northern mountain provinces or Lao PDR where exchange of labour is still practised, especially in subsistence level farming in the slash and burn cultivation of rice, the whole handling job from harvesting to storage is done without any cash payments - only food and drinks and return labour. Women usually perform the hauling and piling of the harvested stalks to the threshing site, and the cleaning or winnowing operation. Some women participate in the actual threshing operation itself, which is predominated by men.

Custom threshing operation by engine-powered threshers is becoming popular in extensive lowland rice areas near urban centres.

In Bhutan, women haul the harvested stalks to the house and if the grain shatters due to over maturity or varietal characteristic, losses are incurred at various actions such as in lifting, carrying and laying down the harvested bundle.

In the Philippines, women had greater than 50 percent involvement in post-harvest activities, mainly in sundrying and marketing. Women were significant participants in the disposal of output, specifically in marketing decisions such as where and when to sell and what selling price. Women contributed 17 percent and 26 percent of the family labour used in harvesting of wet and dry season rice, respectively. They contributed 16 percent and 19 percent in total post-harvest activities.

Few alternative employment opportunities or rural industries existed to absorb the displaced labour at the time the machines were introduced. Caution should be exercised in introducing any labour-displacing technology such as mechanical harvesters in a labour-surplus, low-wage environment.

Decisions on which type of rice mill is to be used for milling the family grain are often made by women, especially when they are involved in backyard swine production. While increasing milling recovery of such rice mills, the reduced bran-rice mixture and brokens decreases the value of the by-product as animal feed, an important feed in backyard swine production in the Philippines.

Any intervention, which eliminates the Engleberg type rice mill or improve it to increase the milling recovery, will bring about socio-economic problems and choice of any other alternatives. Using other feed ingredients such as crop residues to reduce the rice bran requirements is a potential solution to the problem.

The decline in demand for female labour adversely affects the category of rural women at risk- those belonging to landless householders or without sufficient land to support their families. This situation aggravated further when the female is head of a household with children. With the introduction of small power threshers in the early 1980s, the time spent by women in harvesting and threshing decreased from 8 h/ha in 1975 to 3 h/ha in 1980. On the other hand, use of portable threshers decreased turn-around time for rice production and enabled farmers to grow two crops of direct seeded rice in a year.

In Bangladesh, rural women are responsible for most post-harvest operations, particularly processing which is a carried out near or on their homesteads. Rural electrification stimulated the rapid spread of small, inexpensive, electrically-driven mechanical rice mills in the early 1970s. By 1979, about 23-26 percent of total rice production was machine-milled and labour productivity was substantially higher (5.6 t/man-day) for machine milling compared to the manually operated *dheki* mill (0.2 t/man-day).

The improved mills have benefited farm families by reducing the participation of female household labour in this arduous task and by lowering the cost of hired labour. The mills also increased milled rice output and reduced processing losses. It was estimated that household labour for husking declined from 58 percent to 55 percent and hired labour from 32 percent to 16 percent.

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