Post Harvest Technology

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"Nature does the Business and Man is merely the Manager"

Whole plant utilization methods and the preparation of value added products from the available agricultural biomass are important, both for enhancing income and for ensuring good nutritional and consumer acceptance priorities. Low cost drying, storage and marketing technology not only demand non-renewable source of energy but also prevent quantitative and qualitative damage to the agricultural products. Technology should be developed for the value added products from the agricultural products in order to better return to farmers.

Equally vital is developing post-harvest technologies including processing of agricultural commodities, production of value added products, more efficient utilization of by-products and cost reduction in production and processing technologies. All these would necessitate interdisciplinary scientific efforts.

There are ample opportunities in international agriculture and trade participation. Entry into this area will call for market research, genetic manipulation of crops and livestock to suit the varying requirements of the export market.

Stability in agricultural production to mitigate the effects of natural calamities will have to be achieved. Research on crop-weather interactions and on long and short term weather forecasting will help in developing technology to cope with the situation.

Post Harvest Technology (PHT) is central to the preservation of quality and the reduce of damage and wastage in the movement of fresh produce from the grower to the consumer and cover all those processes that fresh produce may undergo, either separately or in combination, throughout this journey.

Post Harvest Technology includes processes such as:

1. Cleaning,
2. Grading (for quality and size),
3. Trimming/Preparation,
4. Weighing,
5. Packing,
6. Cooling,

7. Transportation.

With the obvious of transport, the majority of these operations usually take place either within, or adjacent to a central pack-house where they can be properly supervised and controller. Preliminary operations may take place in the field but for enterprises of any reasonable size or larger co-operative ventures receiving produce from growers, a central pack-house confers many advantages.

HARVESTING AND STORAGE

Post-harvest operations are assuming importance due to higher yields subsistence farming was practiced, harvesting was easy and storage was not a problem as less quantity on final produce was available. Due to introduction of modern technology, yield levels have substantially increased resulting in marketable surplus which has to be stored till prices are favourable for sale. With increases in irrigation facilities and easy availability of fertilizers, intensive cropping is being practiced. Harvesting assumes considerable importance because the crop has to be harvested as early as possible to make way for another crop. Harvesting time may also coincide with heavy rainfall or severe cyclones and floods. Suitable technology is, therefore, necessary for reducing the harvesting time and safe storage at farm level.

The post-harvest losses are estimated to be about 25 per cent. Important operations carried out after harvesting the crop are threshing, drying, storage, and processing.

HARVESTING

Removal of entire plants or economic parts after maturity from the field is called harvesting. Portion of the stem that is left that is left on the field is known as stubble. The economic product may be grain, seed, leaf or entire plant.

Time of Harvesting

If the crop is harvested early, the produce contains high moisture and more immature grains. The yields will be low due to unfilled grains with high moisture are prone to primary infestation of pests. The quality of grain as well as germination percentage is reduced. Late harvesting results in shattering of grains, germination even before harvesting during rainy season and breakage during processing. Hence, harvesting at correct time is essential to get good quality grains and higher yield.

Crops can be harvested at physiological maturity or at harvest maturity. Crop is considered to be at physiological maturity when the translocation of photosynthates is stopped to economic part. In other words, physiological maturity refers to a development stage after which no further increases in dry matter occurs in the economic part. In cereals, moisture content of grains is very high during milking stage and it gradually decreases due to accumulation of photosynthates. The moisture content falls steeply from 40 per cent to 20 per cent which is an indication of attaining physiological maturity. At this stage, translocation of carbohydrates is stopped due to formation of abscission layer between rachis and grain. The attainment of physiological maturity can be seen from external symptoms like black-layer formation in sorghum and maize, bleaching of peduncle beneath the ear in some varieties of pearl millet, turning of green pods to brown colour in pulses etc. (Table 4.1). Black layer formation near sorghum grain attachment coincides closely with the cut-off assimilate translocation.

Table 4.1: External symptoms of physiological maturity of some field crops.

Crop	**Symptoms**
Wheat	Complete loss of green colour from the glumes occurring 1.6 days before physiological maturity. Centre spike are used as indicator grains.
Barley	Loss of green colour from the glumes or from peduncle
Maize	Black layer in the placenta region of corn kernels
Sorghum	Black layer formation in the placental region of grain
Pearl millet	Appearance of bleached peduncle in some varieties
Soybean	Loss of green colour from leaves
Red gram	Green pods turning brown, about 25 days after flowering

Harvest maturity generally occurs seven days after physiological maturity. The important processes during this period are lost of moisture from the plants. The general symptoms of harvest-maturity are yellowing of leaves, drying of grains or pods (Table 4.2). Crop is harvested at physiological maturity when there is need to vacate the field for sowing another crop. Under all other situations, it is advisable to follow harvest-maturity.

Time of harvesting can be known approximately by the duration of crop. As the maturity depends on climate, maturity symptoms are good indicators for deciding the time for harvesting. Criteria for harvesting are presented in Table 4.3. Calculation of the degree-days is another approach for predicting the harvesting date.

Table 4.2: Harvest-maturity symptoms of some important crops

Crop	**Symptoms**
Rice	Hard and yellow coloured grains
Wheat	Yellowing of spikelets
Sorghum	Yellow coloured ears with hard grains
Pearl millet & Foxtail millet	Compact ears, on pressing hard seeds come out
Finger millet	Brown coloured ears with hard grains
Pulses	Brown coloured pods with hard seeds inside pods
Groundnut	Pods turn dark from light colour. Dark coloured patches inside the shell. Kernels are red or pink. On pressing the kernels, oil observed on fingers.
Sugarcane	Leaves turn yellow, sucrose content more than 10 per cent and brix reading more than 18 per cent.
Tobacco	Leaves slightly yellow in colour, specks appear on the leaves

Table 4.3: Criteria for harvesting crops

Crops	**Criteria for harvesting**
Rice	32 days after flowering Green grains not more than four to nine per cent

	Per cent of milky grains less than 20 per cent Moisture content of grains less than 20 per cent 80 per cent panicles straw coloured and grains in lower portion of panicle in hard dough stage. At least five hills are to be studied at maturity.
Sorghum	40 days after flowing Grain moisture content less than 28 per cent
Pearl millet	28 to 35 days after flowering
Maize	Less than 22 to 25 per cent moisture in grain Husk colour turns pale brown 25 to 30 days after tasselling
Wheat	About 15 per cent moisture in grain Grains in hard dough stage
Sugarcane	The ratio of brix between top and bottom part of cane nearly on one. Brix 18 to 20 per cent Sucrose 15 per cent
Red gram	35-40 days after flowing 80-85 per cent pods turn brown
Black gram and Green gram	Pods turn brown or balck
Cotton	Bolls fully opened.

Determination of harvesting date is easier for determinate crops and difficult for indeterminate crops. At a given time, the indeterminate plants contain flower, immature and mature pods or fruits. If the harvesting is delayed for the sake of immature pods, mature pods may shatter. If harvested earlier, the yield is less due to several immature pods. The problem can be can be overcome by: (1) harvesting pods or ears when 75 per cent of them are mature, or (2) periodical harvesting or picking of pods, or (3) inducing uniform maturity by spraying paraquat or sodium salt.

For deciding harvesting date of fodder crops, additional aspects have to be considered. They are: toxins present in the crop, nutritive value, purpose of harvest (whether for stall feeding or for storage) and single or multi cut. When toxins are present, they are generally, high in early stage. Durrin present in sorghum is high up 30 days after sowing. The nutritive value of fodder crop, especially protein content, decreases and fibre content increases with the advancement age of the crop. Around 75 per cent of nitrogen requirement is used by grasses during vegetative stage. Subsequently, nitrogen is redistributed to the growing points and is diluted due to addition of dry matter. Nitrogen content in fodder grasses varies from 2 to 3 per cent in the initial stages and 0.5 to 0.75 per cent at flowering. Thus protein content is high in fodder grasses during early stages. The time of harvesting also depends on the purpose for harvesting. For stall feeding, crop is harvested when protein content is high and also when the fodder is succulent and leafy. Harvesting is delayed by a few more days to get more dry matter if the purpose is hay making. Good quality silage with long preservative characters is obtained when fodder contains more carbohydrates and less protein at the time of harvest. Crops with rationing ability are harvested at periodical intervals while others are harvested as a single cut. For multi-cut crop, stubble height is important. Fodder grasses regenerate well when the stubble is left with at least two nodes above ground level. The stubble height may be 5 to 15 cm depending on the inter-nodal length of the stem. In fodder trees, the stubble height has to be around one metre for convenience in harvesting at subsequent cuts. At the time of first cutting, at least two active leaves have to be left for quick regeneration.

Grazing by the animals in pasture is another method of harvesting of forage crop. Continuous, rotational and rational grazing are the three important methods of grazing. Continuous grazing is allowing the livestock on the pasture throughout the growing season. This system of grazing requires less labour and animal performance is good. Uneven grazing is the important disadvantage in this system. The livestock tend to return to the new growth that is succulent and palatable and do not feed on more mature material. Rotational grazing system is one in which the field is divided into several sub-units and animals allowed to graze in sub-units one after another. The carrying capacity is 10 to 20 per cent more over continuous grazing, but cost on labour and fencing are high. Rational grazing, also known as strip grazing, represents the most intensive grazing system. The idea is to provide a day's ration for the herd and then to a fresh supply of forage the next day. This system may provide 15 to 40 per cent yield increase over the rotational system, but more labour is required in this system. Soilage which is cutting grass and stall feeding is not a grazing system, but it is an alternative to grazing.

Method of Harvesting

Harvesting is done either manually or by mechanical means. In manual harvesting, sickle is the most important tool. The sickle has to be sharp, curved and serrated for efficient harvesting. The other tool used for the harvesting is knife especially for harvesting of plants with woody stems.

When there is a labour shortage or in periods of peak labour demand when planting and harvesting coincides or for quicker harvesting, mechanical methods are adopted. Combine harvester or simply combines are used for harvesting. Combines perform several operations: cuts the crop, separates the grain from straw, cleans it from chaff and transports grains to the storage tank. The combine reaps two to nine rows at a time depending on its size and is equipped with 8 to10 HP engine. The cutting operation is done by reciprocating type of cutter bar operating at a speed of 800 to 900 stokes per minute. The cut portion of the crop is transferred to conveyor belt or platform with the help of a reel. Threshing cylinders operating at a peripheral speed of 800 to 1200 strokes/minute are used for threshing. Grain and chaff are separated with the help of blowers.

Harvesting of crops is done by several ways depending on the crop. Cutting of the crop with sickles leaving small stubbles near the ground is the common method of harvesting. This method is followed in crops whose maturity is almost uniform and occurs at a time. In indeterminate plants, harvesting is done at intervals as the economic comes to maturity at different periods. Pods or fruits are picked at periodical intervals. Harvesting green gram, black gram, cotton etc., is known as picking and is done at 15 days interval.

Problems of Harvesting

Problems in harvesting occur especially when it coincides with heavy rain or cyclones. The crop may be submerged and the seeds may start germinating on the plant itself. These problems are common in monsoon season crops especially rice in south India can be overcome by growing dormant varieties. Most of the rice varieties have few days of dormancy. The other way of saving the crop is by spraying 500 litres/ha of 25 per cent salt solution which hastens maturity by 8 days.

When the economic product is under ground, harvesting is difficult if the soil dries due to lack of rain. Running blade harrows may help to some extent to loosen the soil. Groundnut is harvested by running heavy blade harrows (Pedda guntaka) with two pairs of animals. Tractor drawn sweep cultivators (with inverted 'V' shaped blades) are also used to harvest groundnut.

THRESHING AND WINNOWING

Separating fruits or seeds from the plants or ears is called threshing. In cereals, straw and grain are separated and in pulses seeds are separated from the pods. Threshing is followed by winnowing. Separating grain or seed from chaff is known as winnowing. Wind power is used to separate husk and grain since husk is lighter than grain or seed. Threshing is done immediately after harvest of the crop or it may be done at a later stage.

Threshing of cereals, millets and few pulses are done mainly by beating against stones or any other hard material or by beating with mallets or by treading under the feet of cattle or tractor tyres. Some threshers lie Olpad thresher. Japanese rotary paddy thresher, rollers etc., are also used. Rollers made of stones are used to thresh grains from ears of sorghum, pearl millet, with a thickness of about 20 cm. The roller is pulled with the help of a pair of bullocks over the circular path of ears. The repeated rolling separates the seed from the ears.

Olpad thresher is used for threshing wheat, barley, oats etc. It consists of 20 circular discs each 45 cm in diameter and 3 mm thickness placed 15 cm apart in three rows. The threshed is run by a pair of bullocks over the dried crop spread in a circular path on the threshing floor.

Japanese paddy thresher consists of a threshing drum, driving mechanism and a supporting frame. The main part of the machine is a wooden drum with peg-teeth all around its circumference. The diameter of the drum is about 43 cm and width may vary from 40 to 76 cm. The thresher is operated by a single person with the help of a pedal. Threshing of paddy is done by holding the bundle of sheaves against the teeth of the revolving drum.

DRYING

Moisture content of grain at the time of harvesting of crops is about 18 to 20 per cent. Moisture content for safe storage is 14 per cent for most of the crops. Drying is a process by which moisture content from grain is reduced to safe limit. Drying process is basically the transfer of heat by converting the water in grain to vapour and transferring it to the atmosphere.

Drying is done either by using solar energy or by artificial heating. In case of sun drying, the produce is spread on hard floor or threshing yard, around 10 cm thickness, and is allowed to dry by heat supplied by the sun. The produce is stirred at two hourly intervals to have uniform and quick drying. In general, four to five days of sun drying is required for different produce to bring the moisture to a safe level. In tropical regions, one-day drying under full sunshine throughout the day brings down grain moisture content of rice from 24 per cent to 14 per cent. Though sun-drying is cheaper, there are some problems. The grains that are the upper layers develop fissures due to uneven sun-drying resulting in broken grains. However, this problem can be over come by repeated stirring. Sun drying needs large area and more labour for spreading, stirring and collecting the produce. Weather also may not permit timely drying. With high crop intensity and period bound varieties, crops have to be harvested even in wet season and sun-drying is difficult under cloudy and humid-filled weather. High moisture in grain and also high humidity in the atmosphere are caused sprouting and moulding of grain. In rice, this problem can be overcome by mixing powdered common salt of 5 kg/100 kg of grain. The salt absorbs water from the grain and salt solution flows out of the heap of grain. This treatment prevents heating and subsequent damage to the produce. Another way of storing wet paddy is by mixing paddy husk which helps in storage for about seven days. The produce is dried subsequently when condition are favourable. Artificial drying uses stem to dry the produce. It can be done at any time of the year, but is expensive.

STORAGE

Harvesting of crops is seasonal, but consumption of the food grains is continuous. The market value of the produce is generally low at harvesting time. There is, therefore, necessity to store the produce for different periods. The different categories of agricultural produce needing storage are food grains, oilseeds, seeds and fodder.

Storage of Foodgrains and Oilseeds

Storage Losses

During storage, food grains are subjected to several losses. The losses due to different pests during storage are estimated to be about 6.5 per cent. These pests are insects (2.55 per cent), rodents (2.50 per cent), birds (0.85 per cent) and fungus and other microorganisms (0.68 per cent). Respiratory losses occur which depend on moisture content of grain. At 13 per cent grain moisture the respiratory losses (in g/kg/year) are: wheat and rice 0.98, sorghum 1.76 and maize 2.92. At high moisture level of 17 per cent, these losses are 20.52, 30.78, 28.08 and 41.04 g/kg/year respectively for the above crops.

In addition to loss in quantity, quality of food grains is also affected in storage. The quality losses depend on duration of storage and place of storage. Protein and free amino nitrogen contents decrease in rice and sorghum. Aflatoxin levels are higher in sorghum than in rice. Quality losses are more in the produce stored in coastal areas compared to inland areas due to higher humidity in coastal areas.

Factors Affecting Storage

Several factors that influence the storage of food grains are moisture content, quality of produce, climate and storage conditions.

The most important factor deciding the storability of the produce is moisture content of grains. Higher moisture content of grains results in severe attack of insects and microorganisms in addition to heating and germination. Grains with high moisture respire at higher rate than dry seeds. When the moist seeds are stored, the moisture from upper layers moves downwards and deterioration of grains in lower layer takes place. Insects obtain water needed for their body from the food material they eat. Moist seeds are amenable for easy biting or chewing by insects. Due to this, grains with high moisture are proneto higher insect attack then dry seeds. Sometimes moist grains may even germinate and become unfit for consumption. Moisture content for safe storage of grains of most crops is about 14 per cent (Table 4.4).

Table 4.4: Moisture content of grains for safe storage

Crop	Moisture content (%)
Paddy, raw rice	14
Parboiled rice	15

Wheat, barley, maize, sorghum, pearl millet, finger, Millet and pulses	12
Coriander, Chillies, fenugreek	10
Groundnut pods, rape and mustard	6

Early harvested crop contains ill-filled and shriveled grains. Mechanical harvesting through combines often results in higher proportion of broken grains. Shrivelled and broken grains are the predisposing causes for insect attack. Among the climatic factors, temperature, light and relative humidity are important factors influencing storage of food grains. Respiration of grains increases with increase in temperature. In addition, temperature influences metabolism, growth, development, reproduction, behavior and distribution of insects. Insect development is generally limited below 10^{o}C and above 45^{o}C. Light influences movement, ovipositor and development of stored grain pests. For example, most of the rice storage insects show photonegative response. Darkness is necessary for egg laying. Grains are hygroscopic and absorb moisture from the atmosphere. Under high relative humidity, moisture content of grain increases. Tropical climate, in which the temperature and relative humidity are relatively high, is favourable for the growth and multiplication of insects. Because of favourable condition throughout the year, pest problem is continuous and high in tropical regions compared to temperate regions.

Local storage structures fail to provide complete grain protection from insects. In general, these structures are nor moisture proof. These storage structures do not permit effective disinfection procedures. Gunny bags are more prone to insect infestation of the grain than bulk structures. Storage period is a vital factor which affects insect infestation. In rural India, the procedure is stored for a period of 3 to 9 months i.e., from harvest to next sowing. Longer the storage period, higher is the insect infestation. Grain characters like husk, seed coat, hardness of grain, presence or absence of hair etc., also influence infestation.

SOURCES AND KINDS OF INSECT INFESTATION

Storage structures ear the main source of infestation. Old storage structures that are used repeatedly for storage purpose contain higher number and various types of insects. Threshing floors and grain carriers like carts, trucks, ships, railway wagons etc., contribute to the spread of insect infestation. The infestation of grains by storage pests via post-harvest operations, threshing and drying is called horizontal infestation. Spread of the infestation from the top layers of bulk stored grains to lower layers is called vertical infestation. Storage insects have a tendency to lay their eggs on any type of surface structures, bags or dunnage. The infestation through these sources is called latent infestation. Infestation of insects from one commodity to another due to another due to storing in the same place is known as cross infestation.

STORAGE FACILITIES

Food grains and oil seeds are stored either in bags or in bulk. The storage of produce in bags is called bag storage and without bagging, it is bulk storage. The storage facility whether it is meant for bulk or bag storage has to satisfy certain conditions: (1) Protection of gain from excessive moisture, insects and rodents, (2) provision of safety and convenience while moving grain in or out of storage, (3) facilities for inspecting the grain without removal from storage, (4) provision for controlled aeration, and (5) provision for making sufficiently airtight for fumigation.

While considering storage facility, the basic decision is about the way the grain is to be handled i.e., whether the bulk or in bags. This decisions dependent upon three considerations namely: the type of grain, the likely period of storage and whether the facility is meant exclusively for a particular grain or different grains. Any food grain, except rice, pearl millet and broken pulse (dal) can be held in bulk. Food grains stored in bags are relatively more susceptible to damage by pests. Under most suitable dry conditions, grain has been held in bags in India in a satisfactory condition up to two years. In coastal areas, deterioration is faster and grain can be held in bulk for a period varying between 8 to 12 months. On the other hand, grains held in bulk can be stored practically without damage for periods up to five years irrespective of the location.

Holding grain in bulk in underground facility has been in use in India for centuries. The produce can be stored for periods up to two years. Wheat, paddy, sorghum, finger millet are restored underground. These structures are simple underground dug-cut varying in sizes to hold from a small quantity up to 500 tonnes. The pits are lined with straw before being filled so that moisture from walls and bottom does not damage the grain. After the pit is filled, straw is spread over the grain and the topped with a layer of soil. In some places the sides of storage facility is sealed with stones and cement. It is cheaper to store food grains underground than above ground. However, grains stored underground have poor appearance and musty smell.

Several types of above ground storage structures are available in India. Small rectangular sheds with brick walls and with dimensions ranging from a few to 10 m^2 are used for holding paddy, wheat, barley, Bengal gram and sorghum in various parts of India. These are known as *Kothas*. Farmers store food grains ranging from 0.5 to 15 t in receptacles which are fabricated from locally available materials. The storage period may be two seasons or one or two years. The structures vary in size, shape and material from which they are prepared. The structures are used for bulk storage. These structures may be rectangular huge baskets made with bamboo or round earthen bins.

Bins made of steel, aluminium, R.C.C. are used for storage of grains outside the house. These bins are fire and moisture proof. The capacity ranges from 1 to 10 t. Soils are huge bins made with steel, aluminium or concrete. Steel and aluminium bins are invariably circular. The capacity of each silo ranges 500 to 4,000 t. A silo has facilities for loading and unloading grain.

Godowns are the most common structures for above ground bag storage. All conceivable types of sheds have been used for holding bagged grain in storage. The godowns constructed by Food Corporation of India and Warehousing Corporation have all the facilities for fumigation, providing aeration and are rat proof. Each of these godowns can hold 5,000 t of bagged food grains.

Out of the total food grain production, more than 70 per cent is with the farmer and rest is stored by government organization like Central storage in these corporations is in two ways: covered storage and open storage or CAP (Covered and Plinth) storage. In the converted storage, the produce is stored as bulk in silo or in bags inside godowns. When storage space in godowns is not sufficient, food grains are stored in the open and this method of storage is known as CAP storage. CAP stands for cover and plinth. Abandoned airstrips or roads or open spaces in the warehouse are used for storing the produce. Crates are placed on floor, mats are spread on the crates, and finally bags are placed over the crates. The stacks are build in the form of domes. As a protection against rain, the stacks are covered with thick black polythene covers and the cover is tied to the stack with the help of plastic ropes.

PRINCIPLES OF STORAGE

Dunnage, stacking and pest control are three important aspects of storage. Dunnage is any material like crates, mats, wooden beams, stones which are placed over the ground and below the bags so as to avoid direct contact of grains with the floor and for providing aeration. Wooden crates provide sufficient space between floor and produce and allow free air circulation. If the bags are placed on the floor itself, moisture from the top layers migrates to lower layers and accumulates at the bottom as there is no escape. This process causes caking up, charring and development of heat in lower layers of the stack. It is advisable to spread mats on crates before placing the bags. The mats do not allow spilled grains to fall on the ground and avoid attracting insects. The second important aspect of storage is stacking. In case of bag storage, stacking is done up to 13 bags high. The stack should be brought to pyramidal shape.

Several pests attack the produce during storage. They can be controlled by adopting different methods of pest control like prevention, spraying and fumigation. Moisture content of grain and pest intensity are directly related. Pest attack can be reduced by through drying of the produce to a safe moisture limit. Gunny bags and dunnage material has to be thoroughly cleaned before using them so as to get rid of eggs and pupae of insects. Godowns or storehouses have to be kept clean by sweeping periodically so as to avoid pest build up. When the pest population increases, spraying with insecticides is done on the walls of godowns, alleyways and bags. The insecticides for spraying should have low mammalian toxicity. The chemicals recommended are malathion and dichlorovas (DDVP). When the pest population can not be controlled by spraying and major pests are more than two per kg of sample, fumigation is resorted to. The pest is killed by the poisonous gas released from the fumigant. Generally, fumigation is done with aluminium phosphide or methyl bromide. Aluminium phosphide tablets are placed at different heights on the bags at 2 tablets/t of the produce and the stack is covered with gas proof cover. The tablets absorb moisture from the atmosphere and release phosphine gas which kills the insects. When methyl bromide is used for fumigation in bulk storage, 3 to 5 ml of chemical for 100 kg of produce is placed in glass tubes and the container is closed. The volatile gas released into the container kills the pests.

STORAGE OF WET GRAINS

Due to un-seasonal rains, cyclones etc., crop may get drenched in rain at the time of harvest or immediately after harvest. The moisture content of the grain is high and susceptible to heavy losses due to germination, fungal and insect attack. Sun-drying is not possible and artificial driers are not available with Indian farmers. A possible short term alternative is to store the moist grain in modified atmosphere containing higher carbon dioxide and lower oxygen than normal air. This can be done by filling the containers to three-fourth of their capacity and sealing the containers to make them air tight. These conditions produce modified atmosphere in the containers with 20 per cent carbon dioxide and one per cent oxygen within one week due to respiration of the grain and microbial population. Wet paddy can be stored by this method for a few weeks until sun-drying facilities become available.

Panicles of rice, when drenched in rain water, are dipped in five per cent sodium chloride (common salt) solution before threshing. The grains thus obtained can be stored in ordinary gunny bags for 10 days without drying. Wet paddy can also be stored for about two months by mixing powdered salt at five per cent to the heap.

STORAGE OF SEEDS

Germination and vigour are the highest when seeds first reach physiological maturity. Thereafter, deterioration sets in and moves gradually to loss of viability. Deterioration can not be reversed or eliminated, once it has occurred. All seeds in a lot do not have the same life span. They age and dye at different rates over a period of tie. Differential rates of deterioration result in storage of seed lots in three distinct phases. (1) a period of high viability in which relatively litter deterioration occurs; (2) a relatively short period in which germination declines sharply to low levels; (3) a relatively slower rate of decline until all seeds are dead. Good storage seeks to minimize deterioration and prolons the first phase in which little loss of viability occurs.

CAUSES FOR DETERIORATION

Such deteriorate in the field prior to harvest under unfavourable weather conditions, primarily due to rain, high moisture and high humidity or both. Hot dry weather with inadequate soil moisture during seed maturation also causes deterioration. Seeds which have begun to deteriorate in the field usually do not store well.

Most plants flower and produce seeds over several days, weeks or months. Consequently, not all seeds on a plant mature at the same time. Commercial seeds are harvested when maximum yield of mature seeds can be obtained. Thus, each lot may contain both mature and immature seeds. Immature seeds that are smaller than normal size, wrinkled or shriveled do not store well. Delayed harvesting also causes reduction in viability. In the rainy season, rice seeds harvested 25 days after 50 per cent flowering have viability for longer periods than seed harvested at later dates.

Mechanically injured seed have reduced storability. Damage to seeds during harvest is influenced by seed size, seed shape, firmness of seed coat and seed moisture content. Damaged seeds not only deteriorate faster, but are also more susceptible to storage fungi and treatment damage. Seeds of grasses which are harvested with glumes still surrounding seeds are not subjected to damage. Very dry seeds are susceptible to physical injury. Drying too slowly after harvesting can permit heat accumulation, resulting in decreased viability. Drying too rapidly or at too high temperature can damage seeds and reduce storage life. Most of the seeds shoule not be dried at a temperature above 38^{o}C. Storage life of seeds decreases as storage temperature increases. Harrington’s thumb rule states that for every 5^{o}C increases in storage temperature, the lifespan of seeds decreases by half within a temperature range of 0 to 50^{o}C. High moisture seeds are more susceptible in damage from high temperature.

The most damaging single influence on storage life is by high seed moisture. As moisture content increases, rate of seed deterioration increases. Harrington’s thumb rule states that for seeds of 5 to 14 per cent moisture content, each one per cent reduction in moisture content approximately doubles seed storage life. High moisture seeds deteriorate faster and are more susceptible to damage from extreme temperature, fumigation, storage fungi, insect heating and mechanical injury.

Exposure to high atmospheric relative humidity also increases seed moisture content. Seeds are hygroscopic and absorb moisture from humidity. Conversely, they lose moisture to the air under low relative humidity. Exchange of moisture with the surrounding air affects seed moisture content until it reaches equilibrium with atmospheric relative humidity. Equilibrium moisture content varies with different crop seeds. It is lower for oily seeds than for starchy seeds.

Storage fungi, primarily *Aspergillus* and *Pencillium* species occur almost universally and may attack seed stored at relative humidity of 65 to 100 per cent. When seed moisture content or atmospheric relative humidity is high, storage fungi can grow rapidly and may damage seed and cause heating. ‘Hot spot’ damage to bulk stored seed is usually caused by insect of fungal activity in small areas where high moisture content has built up. All crop seeds are not equally susceptible to fungi. Cereal seeds are very susceptible, while some vegetable seeds seem to be more resistant.

Insects cause serious damage to seeds stored at moisture content higher than nine per cent. Insects attack endosperm or embryo in addition to other parts of grain. Rats, mice and birds eat seeds, damage bags, scatter, mix and contaminate seeds.

Some crop seeds, by inheritance, remain viable for long periods while other have a short storage life. Based on longevity, seeds are grouped as short-lived and long-lived seeds (10 or more than 10 years). Groundnut, soybean, onion and lettuce seeds have naturally short life span, while many legume seeds, especially those with hard impermeable seed coats survive relatively longer periods. Many short-lived seeds can not be dried to a low moisture content or be subjected to temperature below freezing. Long-lived seeds survive best under low temperature and low humidity conditions.

SEED STORAGE

Seed deterioration, as well as insect and fungi activity is reduced by lowering temperature and moisture content (and correspondingly relative humidity). The longer the storage, the lower should be the temperature and moisture content. At lower temperatures, seed of higher moisture content can be safely stored, at lower moisture content; seed can be safely stored at higher temperatures. These apply to reasonable storage periods and reducing only one does not result in maximum potential seed storage life.

PROVIDING SAFE STORAGE CONDITIONS

Seed can be safely stored if the storage is designed, equipped and managed to provide the required dry, cool, protective conditions. Seeds can be protected from moisture and high relative humidity by suitable package or the storage facility. Lower temperatures can be maintained by the storage facility. Moisture control requires protecting dried seed from moisture and high relative humidity. Methods include:

1. Keeping short term non-conditioned storage as dry as possible,
2. Lowering storage humidity by ventilating a well constructed non-conditioned storage when ambient relative humidity is low,
3. Placing low moisture seeds in a vapour proofed storage when relative humidity is very low and keeping the storage sealed to prevent entry of moisture,
4. Dehumidifying the air inside a completely vapour proof storage, and
5. Packing very dry seeds in hermetically sealed vapour proof containers.

KINDS OF STORAGE

Seeds are stored either in bulk or in bags or other packages. Bulk storage is common for short term storage of large amounts of seed awaiting processing. In temperature climates, processed seed is also sometimes stored in bulk for short periods. Many designs and sizes of bins, tanks etc., are used. Seeds are frequently dried in such bulk storage units. In tropical climates, wide temperature differences which occur between outside air and the bulk seed mass and at different points within the mass, result in moisture migration. Moisture accumulates in spots until dangerous levels are reached and seeds deteriorate rapidly. Deterioration spreads through the seed mass as more heat and moisture are generated. Under humid tropical conditions, short term storage of bulk seed may be used but adequate mechanical aeration or drying must be incorporated and properly used to keep the seeds uniformly dry and cool. According to storage is especially constructed to create a sealed space in which lower relative humidity by dehumidifiers. Temperature and relative humidity are reduced as required for the seed crop and storage period. For non-conditional storage, only suitable building design and construction is adopted with no special equipment except ventilation fans. Non-conditioned storage is used for most short term storage of seeds and is adequate for very dry seeds sealed in vapour proof packages.

If seeds in vapour porous packages are taken from cold storage into warm humid outside air, seed temperature may be below the dew point of the air. When this occurs, moisture from the air condenses on the seed, seed moisture increases and the seeds lose viability rapidly. This can be prevented by:

1. Packaging seeds in vapour tight packages for cold storage, or
2. Quickly moving seeds in vapour package from cold storage into a dehumidified room at ambient temperature for storage until seeds warm up to outside temperatures, or
3. Removing all seeds from a cold dehumidified storage at about the same time, stopping the cooling equipment and operating only the dehumidifier until seeds warm up to outside temperatures.

Being hygroscopic, seeds gain moisture from atmospheric relative humidity. If seeds are hermetically sealed in vapour proof packages, water vapour of the outside air can not enter the packages. Thus, seed moisture content does not change regardless of ambient humidity. Very dry seeds in vapour proof packages can be stored for two to four years in good non-conditioned storages at reduced storage construction and operation costs. Packing very dry seeds in vapour tight containers appear to hold much promise as a low cost, simple means of protecting seed viability during both storage and transport, especially under humid tropical conditions and where adequate storage facilities are not available. The packaged seeds are not affected by outside relative humidity and being very dry, the seeds can withstand reasonably higher temperatures. Also there are no moisture problems in taking seeds out of cold storage.

Moisture content of seed sealed in vapour proof package must be considerably lower than for non-vapour proof packages. There is no exchange of water vapour between air outside and inside the packages and seed moisture content determines equilibrium relative humidity of air sealed inside the package. For example, air inside a vapour proof bag of cron (*Zea mays*. L) seeds at 13 per cent moisture will equilibrate at about 65 per cent relative humidity. At this relative humidity, fungi are active and insects can multiply. These conditions create additional moisture and heat and seeds deteriorate rapidly. In general, seeds can be safely sealed in vapour proof packages if their moisture content is low enough to be in equilibrium with approximately 30 to 35 per cent relative humidity.

Vapour tight bags for larger amounts of seeds may be made of solid thick films of polyethylene (10 gauge or more), polyester, or plastics with similar vapour transmission characteristics. Multi-wall paper or other laminations which include suitable layers of plastic film, asphalt/aluminium foil, aluminium foil/plastic etc., are also used. The bags must either be heat sealed or of volve-pack design with the volve properly sealed. Sewn bags are not vapour proof as water vapour will enter through holes left by the sewing machine needle.

Some bag materials are not vapour proof, but are vapour resistant to varying degrees i.e., they do not prevent entry of vapour, but have a slow rate of vapour transmission. These include bags of woven plastic threads with only a thin film of sold plastic sewn multi-wall bags, multi-wall bags of materials of higher vapour transmission rates etc. These bags keep seed moisture lower and longer than storage in porous bags, but seeds slowly increase in moisture under high ambient relative humidity. When seed moisture reaches higher levels inside such bags, vapour can not escape readily and seeds deteriorate rapidly. Careful management is necessary when such bags are used.

Small quantities of vegetable and flower seeds may be packed in heat sealed vapour proof bags, pouches, or packets of suitable polyethylene, polyester, laminated aluminium plastic, cellophane, plastic, etc. Sealed tin cans, gasket metal cans, gasket sealed glass jars and sealed rigid plastic containers may also be used. Paper packets and friction sealed tin cans are not vapour tight Due to increased susceptibility of low moisture seeds to mechanical injury, vapour proof seed bags must be handled gently.

STORAGE MANAGEMENT

Even with the best storage facilities, seeds deteriorate if management is inadequate. Contamination is prevented by storing the seeds in bags that are in good condition and by avoiding spillage. Bags should be placed in proper lots with clear labels. Keeping properly dried seeds in cool place minimizes damage by storage fungi and insects. The storage facility and surrounding area are kept clean to reduce food and cover for the pests. Insects and other pests are controlled by suitable pest control programmes which include fumigation, seed treatment, space sprays, residual surface spray and poison baits. Chemicals, feeds, fuels, fertilizers etc., should not be stored along with seeds.

STACKING MANAGEMENT

Properly dried bagged seed may be stacked to sufficient storage heights (12 to 13 bags high) without weight or pressure damage to seed at the bottom. Falling or dropping of bags from the stack may result in mechanical injury to seeds. Bags should be removed from stacks by conveyor or by hand carrying but never by dropping. Poor ventilation, especially when the floor has no vapour barrier, results in air convection currents due to temperature differences within the storage structure. This causes moisture movement within the storage and relative humidity of cooler air near the floor increases. It results in increased moisture content and rapid deterioration of seed at the bottom of stacks. Good stacking management includes: (1) Provision of proper ventilation around seeds, stacking only on pallets or crates with at least 10 cm open space between stacks and walls and 50 to 60 cm above stacks, and (2) provision of adequate aisle space so that storage operations do not damage bags and also to facilitate inspection.

STORAGE FODDER

Green, nutritious and palatable fodder is necessary throughout the year for good milk and meat production, but it is not available round the year due to adverse climatic conditions. Shortage of fodder is necessary during summer in south India and during winter in north India due to very high and low temperatures respectively. In addition, shortage of irrigation water makes fodder production difficult in summer in south India. To overcome this problem, green fodder is stored mainly as hay and silage.

HAY

Hay is any forage crop cut before dead ripe stage and dried for storage. Straw of cereal and millet crops is the most commonly fed fodder to the cattle in India. As these crops are harvested at dead ripe stage, carbohydrates and proteins are less in shoots to re-translocation to grain. In addition, more lignin accumulates in the stem. Straw is, therefore, less nutritious and palatable than hay.

High quality hay is made from fine stemmed legumes and grasses cut at the right stage of growth and dried carefully to avoid loss of nutrients. Good quality hay should be leafy, pliable, and green in colour with characteristics pleasant smell and aroma. Hay should be free from mould, dust and weeds. Hay made from mixed herbage of grass and legume is highly nutritious and palatable. Hay can be made from any grass or leguminous fodder crop. However, certain crops are more suitable than others. Forage plants that are best suited for hay making are thin stemmed, leafy and those that remain sufficiently nutritious and palatable even after drying. Bermuda grass (*Cynodon dactylon*) is one of the best grasses for hay and it is equivalent to timothy grass (*Setaria sphacelata*) of western countries. Other grasses that are suitable for hay making are Arjuna grass (*Cenchrus ciliaris*). *Dicathium annulatum*, *Echinochloa colona*, and *Eleusine flagelligera*. Oats, maize and sorghum can also be made into good hay but maize and sorghum are most suitable for silage making. Legumes are less suitable for hay making though these hays are more nutrients. Leaf shedding during drying and curing process is considerable in legumes. Leaves constitute half of the green material and contain 75 per cent of the protein. They are rich in vitamins, phosphorus and calcium. Though most of the leguminous fodder crops are prone to leaf shedding, cowpea is less susceptible; lablab and *Pillipesara* are moderately susceptible and berseem and *shaftal* are highly susceptible. Time of harvesting is important for obtaining good quality hay. For most of the grasses, 50 per cent flowering is the most suitable time for harvesting for hay making. Leguminous fodder has to be cut at full bloom stage (Table 4.5).

Table 4.5: Optimum time of harvesting for hay making

Crop	**Time of harvesting**
Grasses, clover, Lucerne	Early bloom to full bloom
Cereals	Soft dough to medium dough stage
Soybean	Pod half grown
Cowpea	First pod maturity

Hay making involves two important processes: drying and curing. The crop is dried to 25 per cent moisture or less with as little loss of leaves, green colour and nutrient as possible. Curing losses are small when drying is rapid. The crop is cut, spread in the field in thin layers and allowed to dry for one or two days. Later, it is dried under shade to avoid loss of carotene or green matter. It can be done by spreading partially dried fodder in thick layers under shade of tress or in covered yards. It is repeatedly turned for uniform drying. Crushing helps in quick drying of fodder with thick stems. Artificial drying, if available helps in quick drying and minimum loss of fodder. Curing takes place when the dried fodder is stacked. Excess moisture at the time of heaping causes heating up resulting in loss of carbohydrates, carotene and reduced protein digestibility.

Loss of fodder and feeding value is unavoidable in hay making. When hay is dried in the open field, a minimum loss of 10 per cent in feeding value occurs. During curing, carotene starts to degrade due to oxidation. Under normal conditions, dry mater loss in field drying of hay may be 10 to 25 per cent. In wet weather conditions, leaching, bleaching and leaf shedding may account for losses up to 40 to 60 per cent.

SILAGE

Silage is product formed by the fermentation of green fodder stored under anaerobic conditions. Fermentation occurs during the first two or three months. During this process of fermentation, acids are formed and these aid to preserve the fodder for 12 to 18 months. The process of making silage is known as ensiling. In humid regions, subjected to frequent rains, ensiling is easier than hay making. Nutrient losses are less in silage making than hay making.

Among several crops, maize is the most suitable for silage making. Maize silage is easy to make, palatable and can be preserved in good condition for several years. Fodder yield from maize is higher than most of the other crops. Sorghum (both sweet and non-sweet types) and Sudan grass are also well suited for silage. Grasses or mixture of grasses can make good silage. When properly made, grass silage is not only palatable and highly nutritious, but also has an agreeable smell and high carotene content. A mixture of grass also has an agreeable smell and high carotene content. A mixture of grass and legume makes good silage. Forage legumes such as Lucerne, cowpea, sunnhemp and *Pillipesara* can also be used for making silage.

The principle in making silage is to keep the green fodder material tightly packed in impervious containers, excluding air as much as possible. Ensilage can be done either in towers, iron silo earthern pits. The large iron silos can hold about 100 tonnes of green fodder. Earthern pits or trenches are dug on elevated place where water table is below 3.7 m from the surface. The pits are 2.4 to 3.0 m wide and of variable lengths depending on the quantity of fodder to be stored. One cubic metre storage space is necessary to pack 400 kg of green fodder. Small sized pits should be wider at the top and narrower at the bottom. The shape of the pits should be wider at the top and narrower at the bottom. The shape of the pit helps in packing fodder tightly against sides and bottom and it also prevents the soil from caving. The slope of the side walls has to be more for light and loose soil. Packing can not be done compactly in earthern pits compared to silos and so earthern pits require were space for the same amount of fodder. Before filling pits, fodder should be chopped (10 to 13 mm size) for easy and proper packing. When the crop is too succulent, it should be allowed to wilt to reduce moisture content. Coarse straw is used as lining material at sides and bottom. The chopped material is placed in the pit, layer by layer and trampled. Preservatives are sprinkled over each layer. Filling is dome so as to 0.9 to 1.2 m above the ground level. The top of the pit is made into a dome so as to drain rain water. Finally, straw is covered over the green fodder and sealed with thick layer of wet mud, preferably of clay soil. The material sinks on settling and cracks develop subsequently. These cracks are sealed periodically with wet mud to avoid entry of water.

After packing green fodder in the pit, respiration continues for some time due to the presence of oxygen in some packets. Aerobic bacteria, yeast and moulds are active and use up the oxygen within four to five hours. During this process, carbon dioxide is released and temperature increases. By the fourth day, temperature rises to about 29 to 40^{o}C. Due to anaerobic conditions, the activity of anaerobic bacteria increases and act on carbohydrates forming carbon dioxide, lactic acid, butyric acid, propionic acid and small quantities of alcohol.

Carbohydrates	Anaerobic	**Under low moisture**
		Acetic acid (CH_3COOH)
$C_6H_{12}O_6$	Bacteria	Lactic acid ($CH_3CHOHCOOH$)
		Under high moisture
		Propionic acid (CH_3CH_2COOH)

		Butyric acid ($CH_3CH_2CH_2COOH$)

Two types of fermentation processes known as lactic acid and butyric acid fermentation occur depending on the conditions under which fermentation occurs. Lactic acid fermentation is desirable and it occurs when the moisture content of fodder is 55 to 75 per cent with sufficient sugars in plant juice. Glucose and fructose, the major carbohydrate sources for fermentation, are required at a minimum level of six to seven per cent on dry weight basis. At these levels, fermentation provides pH lower than 4.0. The organisms responsible are *Lactobacilli* and *Streptococci*. If the acids rise to about one per cent at the initial stage itself, the silage will be of good quality as lactic acid checks undesirable organisms. Butyric acid type of fermentation occurs when the fodder is wet with high protein and under cold conditions. The bacteria responsible are *Clostridium* sp. This silage has a disagreeable odour and is not relished by cattle. Preventations are added to the silage to inhibit butyric acid type of fermentation by reducing pH or by the addition of carbohydrates or by both. Substances such as molasses, cereal grains, citrus pulp etc., act as preservations by adding carbohydrates to the fodder (Table 4.6). Sodium metabisulphate at 400 t/100 kg of fodder modifies fermentation process and reduces objectionable odour.

Table 4.6: Quantities of preservatives to be added per 100 kg green fodder

Silage material	**Preservative or additives**
Grasses alone	2.7 to 3.6 kg of molasses or
	4.5 kg of citrus pulp or beet pulp or
	4.5 kg to 6.8 kg of kibblet or broken cereal grains
Legumes or Grasses	3.6 kg of molasses or
	4.5 kg citrus pulp or beet pulp or
	6.8 to 9.0 kg of broken cereal grains
Legumes alone	3.6 to 4.5 kg molasses or
	6.8 kg of citrus or beet pulp or
	6.8 to 11.3 kg of broken cereal grains

Good quality silage should be green, fruity with pleasing taste and without moulds, slimyness and objectionable odour. It should be uniform in colour and moisture content. Dark brown colour indicates excessive heating. Good quality silage should have pH less than 4.5, low ammonia content, little or no butyric acid and 3 to 13 per cent lactic acid. To obtain good quality silage, the crop has to be harvested at proper stage, moisture content to be 55 to 75 per cent at the time of ensiling, carbohydrate content high and entry of air avoided.

Loss of nutrients is unavoidable in ensiling. Silage can be a substitute for green fodder but not equal to it. When plant material with high moisture content is ensiled in large size silos of 100 t capacity, exudation of plant sap occurs at the bottom of silos due to the weight of the material. This loss may range from 3 to 10 per cent of green material. Carbohydrates are lost as carbon dioxide and organic acids due to respiration and fermentation. Loss of carotene and vitamin C occurs when the temperature during fermentation is high. Loss of dry matter from silage stored in earthen pits is due to spoilage in addition to respiration and fermentation.

"Through understanding of what, pray does all this world become understood, sir!

Mundaka Uppanisad, 1-1-1

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