**Chapter**

**Principles of food grain storage**

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1. **Introduction**

Food grains being an important part of the Indian vegetarian diet have become one of the main nutrients for people. Grain production has been steadily increasing due to advancement in production technology but improper storage results in high losses in grains. The rapidly increasing human population and the climatic changes that may cause unpredictable losses compel us to find a solution to the question about how we can use our resources in a better and effective way. Grains are small, hard, dry seeds (with or without attached hulls) harvested for human food or animal feed and they have a shelf life just like any other food product. Shelf life is the length of time that [foods](https://en.wikipedia.org/wiki/Food), beverages and many other [perishable](https://en.wikipedia.org/wiki/Decomposition) items are given before they are considered unsuitable for sale, use, or [consumption](https://en.wikipedia.org/wiki/Eating). Shelf life is primarily determined by its moisture content and temperature. It is normally used through the time before use, and each operation or storage regime consumes a portion of the life. The basic objective of good and effective storage is to create the suitable environmental conditions which provide sufficient protection to the product to maintain its quality and its quantity thereby reducing the product and financial loss.

1. **Importance of Storage**

Good storage facilities are important to all the farmers in concerned with their household and community food security until the next harvest and commodities for sale can be held back. Storage procedures and processes differ for each grain and purpose. Grain stored on farms for seed or livestock feed is an important part of the farm income and protecting the grain from insect attack is an exercise in income protection. But considerable losses are noticed during grain storage. The extent of losses occurring after harvest and particularly during storage has been the subject of considerable speculation because of the difficulties of reaching accurate assessments of the amount being lost. It is generally accepted that assessment of storage loss is difficult, particularly in relation to the rural situation in developing countries and there is a need for assessing storage losses**.** Inappropriate grain storage solutions cause the product to decay so to be lost, decrease of product quality, decrease of storage time and thus increase of storage and labor costs. Therefore, grain storage is extremely important as far as product quality is concerned which otherwise results in both qualitative and quantitative losses.

This has been observed that quantitative and qualitative losses in stored food grains may occur due to physical (abiotic), biological (biotic), chemical (breakdown of produce and pesticides) and engineering (structural and mechanical, aspects) factors. Grain temperature and moisture are the two important factors which affect the rate of metabolism, growth, development, reproduction and general behavior of stored grain insect pests and fungi. Within this scope, storing grains in predictable good conditions for a sufficient amount of time will contribute significantly to the world economy in terms of efficiency**.** Following are the losses observed due to inappropriate grain storage.

**2.1 Quantitative losses**

Quantitative loss is a physical loss of substance as shown by a reduction in weight or volume. It is the form of loss that can most readily be measured and valued. In commercial storage, weight is the important factor sometimes leading to malpractices such as adulteration with water, stones and earth to make up the deficiency. In many instances, weight loss may go undetected as the trader sells by volume. These types of losses occur due to various factors. It may be due to reduced moisture content easily recognized by a shrinkage factor. Insects, rodents, birds etc. feeds on the product resulting in weight loss but these weight losses are not always apparent. On average, losses due to insects are reported to be in the range of 10-20% of stored grains, but at times may be as high as 30%. The damage created by insects on the grain can affect the farmers because their grain may lose value for marketing, consumption or planting. In fact, insects cause the highest loss of grain. These insect pests inflict their damage on stored products mainly by direct feeding.

**2.2 Qualitative loss**

Nutritional loss and loss of seed are both aspects of quality losses. Qualitative loss is more difficult to assess and is perhaps best recognized through comparison with well-defined standards. Losses of this type can be nutritional, chemical, through contamination with toxic moulds or foreign matter. Foreign matter may be in the form of insect fragments, grass, rodent hairs and excrete; weed seeds, parts of plants, earth, stones, glass, etc. results in loss of quality. Generally quality is assessed and products graded on the basis of appearance, shape, size, etc. but smell and flavour are sometimes included. General contamination can result in many ways and shows up in the form of insect fragments, rodent hairs, excreta and urine, as well as dust and other materials that enter the product through human mishandling. Pests that selectively eat a part of the food-stuff (such as the nutritious germ of the grain) will reduce the value of the food-stuff as a whole. Also, there is the loss of vitamins through the action of sunlight and temperature. Chemical changes are particularly common in fatty foods through the development of rancidity. Aflatoxin (a toxic substance) producing moulds like *Aspergillus niger* can grow on many products which pose a long-term health risk.

1. **Storage requirements for food grains**

Nearly all grains are stored before they are finally processed and consumed. The storage period may be for few weeks or upto a year or more, on the farm or at marketing and shipping points. Inadequate storage and conditioning facilities or their complete absence contribute to substantial losses every year.

Traditionally, grains are harvested and stored with varying amounts of excess moisture except in arid regions where grains like wheat are often harvested and stored with a moisture content of less than 9% (wb). However, many of the dry regions have monsoon season of high humidity causing an increase in moisture in stored grains unless protected from humid air. In any case, mold development and insect attack are in proportion to the excess moisture and temperature at which the grain is stored.

Protection of stored grains from weather, rodents and birds can be obtained by proper construction of the storage bins or containers but this does not apply to the other destructive agents except in air tight storage which can be made to exclude insects and mites as well. The activity of these is greatly influenced by:

* Moisture
* Temperature
* Oxygen in the stored atmosphere.
  1. **Moisture**

This is perhaps the most important single factor in the development of molds, bacteria, insects and mites assuming that temperature is at a satisfactory level. Moisture content is important and essential for their growth. A sufficient reduction in moisture has been and still is the universal method of making grain safe for storage. Generally, a reduction of moisture to 11-13% in most grains is sufficient for all organisms except insects. For insects, the moisture content should be reduced to less than 9%. The moisture content should be equilibrated with the atmospheric relative humidity of around 70-75%. If a cereal grain is to be stored for a long period, its moisture content should be below 12%.

* 1. **Temperature**

It is the next most important factor along with grain moisture and equilibrium relative humidity which is in equilibrium with the grain moisture varied with the temperature. For considering temperature for the safe storage system, the following important points should be kept in mind:

1. Mites do not develop below 5°C and insects below 15°C.
2. Most of the storage fungi do not develop below 0°C.
3. The effect of temperature on an organism can be correlated with the amount of moisture content.

When the grain temperature rises around 20°C, it starts getting infested easily with insects and microorganisms and at the same time, its rate of respiration becomes rapid with the expense of chemical constituents. If sufficient moisture is present and temperature conditions are favorable, grains will germinate. Enzymes and microorganisms also become active and the value of grain becomes impaired due to mold growth. Under certain conditions, this is often accompanied by development of toxicity in the form of mycotoxins. Microorganisms are minute living organisms like bacteria, yeasts and molds. Enzymes are special proteins that are built up in the living plant and animal tissue for the purpose of accelerating the chemical reactions necessary to life. If only enzymes are active, the process is described as autolysis. If both enzymes and microorganisms are active, then disintegration is described as decay.

**3.3 Oxygen in the stored atmosphere**

Like grain, micro-organisms and insects are living organisms that need oxygen. Oxygen and carbon dioxide of inter granular environment influences the respiration of the grain and consequently also the rate of deterioration and heating. Majority of the fungi are storage aerobes. They fail to sporulate, their spores fail to germinate and their mycelium fails to grow when oxygen concentration is below a minimum which is well adequate for yeast growth. Storage of grain in places that are low in oxygen causes the death of insects, cessation of development of micro-organisms, and blockage, or slowing down, of the biochemical phenomena of grain degradation. This favors the conservation of grain but may affect its germinating power. Therefore, there is need to store these grains in hermetically sealed containers in which oxygen is removed. This is the basic principle of Controlled Air Storage. This type of storage results in retarding the growth of microorganisms. In early days, the level of oxygen was allowed to fall naturally but this method was very slow. But in modern practice, constant monitoring and adjustment of the CO2 and O2 levels within gas tight stores or containers is done to inhibit the growth of microorganisms and insects.

# Principles of Storage

The main aim of grain storage is to prevent the spoilage of grain. This is not done directly but indirectly through the control of moisture and air movements and by preventing the attack by microorganisms, insects and rodents. Food losses during storage are the result of physical, chemical and biological damage. Food spoilage predominates often in the areas of high rainfall and humidity. These conditions are ideal for the development of micro-organisms and insects which cause high levels of deterioration of crops in store. The management objective during the storage period is to reduce the metabolic activity to such a low level that the grain mass is sufficiently stable with minimum deterioration. In order to reduce the amount of food grains lost, the environment in the store needs to be controlled so as to lower the possibility of:

* Physical damage through crushing, breaking, etc.
* Chemical damage through rancidity development and flavour changes, etc.
* Biological damage by insects, rodents and micro-organisms. Much of the damage to stored grains by insect pests is done directly to the kernels. Their larvae destroy many times their own weight of food during their growth period. They frequently cause grain to heat resulting in a musty odor. Degree of damage depends on three factors namely:
* Moisture content of the stored grains
* Temperature inside the storage place, and
* Oxygen level, besides food supply and human activities.

It has been established that most insects do not thrive below 9% moisture content of the grains. So, it is essential that before grains are put into storage, the moisture level should be 8% and absorption of the moisture from the air should be prevented. Higher temperature favors the multiplication of insects, hence the inside storage temperature should be maintained low. Oxygen content inside the container under air-tight conditions also has a deciding influence on the infestation of grains and multiplication of insects.

Good storage thereby involves controlling the factors, like temperature, moisture, light, pests and hygiene. The two alternative methods are:

* Reduction of moisture content to a safe level and cooling of the grain.
* Modification of the atmospheric conditions of the storage system.

# 4.1 Temperature

This is the most important ecological condition required for grain storage.

**4.1.1 Effect on respiration**

Grains are biologically active and respire during storage. One of the products of respiration is heat and reducing the temperature of the crop can help to eliminate the rate of respiration, thereby increasing the storage life by decreasing the possibility of germination. It has been observed that the rate of respiration of grain increases with the temperature until inhibitions of vital process begin. Respiration whether of seeds, moulds or insects depends upon chemical reactions and is, therefore, accelerated by an increase in temperature until it is limited by such factors as the thermal inactivation of enzymes which are involved, exhaustion of the substrate, limitation of oxygen supply or accumulation of inhibitory concentration of carbon dioxide. Improper maintenance of storage temperature can result in biological and chemical damage to the food stuff being stored.

Appropriate control over temperature results in preventing both physical and chemical damage. Physical damage involves melting of fats in the products at high temperatures and crystallization of sugars in sweet foods at low temperatures. Temperature also controls chemical damage. The speed of chemical change in a food depends upon the temperature and the food's moisture content. A 10°C rise in temperature causes an approximately two-fold increase in the rate of reaction. Thus, cold storage will retard such changes as fat oxidation and vitamin loss. Many dried food grains benefit from even a small reduction in their storage temperature, and cool and dry conditions can greatly reduce the rate of development of brown discoloration and off-flavors. Direct temperature control is not usually possible, so other measures, particularly reducing the moisture content of the stored produce are necessary.

**4.1.2 Effect on micro-organisms, mites and insect activity**

Temperature is one of the most important factors which exert a profound impact on the rate of metabolism, growth, development, reproduction and distribution of pests and micro-organisms. There are many ways by which stored products may become infested. They include placing clean products in the infested storage, placing infested products in clean storage, by mixing infested with uninfested materials, through the use of already infested container, and through the use of infested transportation facilities such as trucks, etc. Infestation may, also arise from natural sources. These may include nests of birds and rodents, the hiding and bedding places of animals, etc. The optimum temperature for most of the insects lies between 29.4-32.20°C. Under Indian conditions some of the mites develop faster if the temperature is between 18-22°C. The micro-organisms differ in their thermal requirements and are commonly classified as Psychrophiles, Mesophiles, and Thermophiles on the basis of thermal classification. Micro-organisms grow faster as soon as temperature approaches their optimum. The required optimum temperatures for growth are: Psychrophiles: 10-20°C, Mesophiles: 25-40°C and Thermophiles: 50- 60°C.

**4.2 Moisture**

One of the most critical physiological factors in successful grain storage is the moisture content of the crop. High moisture content leads to storage problems because it encourages fungal and insect problems, respiration and germination. However, moisture content in the growing crop is naturally high and only starts to decrease as the crop reaches maturity and the grains are drying. In their natural state, the seeds would have a period of dormancy and then germinate either when re-wetted by rain or as a result of naturally adequate moisture content.

Temperature and moisture are the main factors which speed up most chemical reactions (increase with increasing temperature) particularly if some quantity of moisture is there. The food grains which contain moisture of other biological materials keep better under refrigeration (low temperature) than at high temperatures. Moisture is by far the most important factor to bring about deterioration of grains in storage. If the grain moisture content is maintained at low level, say 9-10 % clean grain can be stored for many years.

In food grains, there is a fairly well-defined relationship between moisture content of grain and relative humidity of the environment. The food grain moisture is due course tends to come in equilibrium with the humidity of the air. Thus, the amount of moisture fluctuates according to the temperature and relative humidity of the surrounding air. The rate at which the grain will lose or gain moisture generally depends upon its condition, type of grain and the extent to which it is exposed. However, the moisture keeps varying according to the changes in the environment.

All micro-organisms, including moulds, require moisture to survive and multiply. If the moisture content in a product that is to be stored is low, micro-organisms will be unable to grow, provided that the moisture inside the storage structure is also kept low. Moisture should therefore be prevented from entering the store.

**4.2.1 Effect on insect activity**

For majority of storage insect pests, moisture content below 10% is not adequate for normal activity and development. Insect infestation tends to increase with increase of moisture content above 10% up to a certain limit. Generally, insect activity is rapid at relative humidities in excess of 75%. One of the most remarkable features about the storage insect pests is that some of them can live in products having very low moisture content. However, a certain minimum moisture level is needed and this varies considerably for different species. Insects that live in food having low moisture content exhibits a remarkable ability to consume and utilize water and are certainly well adapted for the products in which they live. It has been known that weevils are attracted to moisture. The moisture content has to be in excess of 12% if rapid multiplication of weevils is required.

**4.2.2 Effect on micro-organisms**

Water contributes to the chemical and physical structures of micro-organisms. Moisture has a great effect on development of fungi, bacteria and yeast etc. Micro-organisms are classified as hydrophytes (minimum requirements is 90% or more relative humidity (RH), mesophytes (minimum requirements is 80 to 90% RH) and xerophytes (less than 80% RH) on the basis of their minimum moisture requirement for growth. Bacteria require higher moisture level for growth in grains and grain products. But if micro-organisms are present in food, then they results in discoloration, loss in viability, heating and induct bio-chemical changes besides production of various toxins which are very harmful to human beings. Therefore, it is essential that all food-stuffs are below their safe moisture content before they enter the store; the safe moisture content is to some extent related to the required storage time. Moisture levels above the safe moisture context can be tolerated if only short storage times are required.

Condensation of moisture can cause storage problems. If the walls of a store are cooled below their dew point by low night temperature, condensation can occur and increase the moisture content in the layers of the produce. The sitting and the ventilation of the store is extremely important.

**4.3** **Light**

Generally, the stored product insects seek secluded places and keep well hidden. Stored product insects reaction to light is more varied. Few are attracted towards light while most of the insects avoid it preferring a subdued light or darkness. Different stages of the same species react differently. A stack of gunny bags kept in dark places and most concealed parts, are found to be more severely attacked than those which are exposed to light. Therefore, this should be given proper attention to reduce grain spoilage.

* 1. **Insects and chemical residues**

Good hygiene is an essential component of insect control in stored grain. Other options for insect control include:

* Cooling grain with aeration
* Treating storages and equipment with inert dusts or residual chemicals
* Treating grain with inert dusts or residual chemicals
* Treating infested grain with dichlorvos
* Fumigation with phosphine
* Controlled atmosphere treatment (e.g. carbon dioxide)

Good hygiene combined with automatically controlled aeration is sufficient for some growers to maintain grain quality without using any residual treatment. Fumigation with phosphine leaves minimal residues provided tablet formulations are not mixed with the grain. Check with buyers before spraying grain with insecticides. Spraying with insecticides or fumigating minimizes insect problems but leaves chemical residues ingrain which breakdown with time. Presence of residues and their concentration affects acceptability of the grain to markets. Some markets prefer grain without residues. Grain buyers will not knowingly accept grain treated at rates higher than those specified on the label or within specific withholding period. Fumigate the bin as soon as the grain is poured in and thereafter 4-5 weeks later this treatment may be repeated. Inspect the grain frequently but at least one a month by taking samples. Re-fumigate, if an insect infestation is discovered. It is already known that the susceptibility of stored grain insect pests to fumigants is influenced by various factors viz., temperature, carbon-dioxide, oxygen, nutrition, population density, pre-fumigation starvation, post-fumigation starvation, relative humidity, sub-lethal fumigation, repeated fumigation, presence or absence and nature of commodities to be fumigated, affect of age, sex of insects, respiration etc. Hence, the success or failure of fumigation operations depends upon these factors.

Cracked grain and foreign material in excessive amounts can also be considered to be an important factor in storage especially as for providing favorable conditions for the development of the non-boring type of stored grain insect popularly known as bran and fungus beetles. These do not develop readily in clean grain but feed primarily on grain dust, broken kernels, moulds, etc. It is extremely difficult to fumigate grain which has a high percentage of broken grains and foreign materials.

* 1. **Inspect grain frequently during storage**

Stored grain should be inspected frequently. Insect or mould activity gives a distinct odor to air moved through the grain. By operating the aeration system and smelling the air coming through the grain, storage problems can be detected. Any ‘hot spots’ should be cooled as soon as possible by aeration. If the problem is due to insect activity, the grain should be fumigated.

* 1. **Storage capacity**

Different grains have different densities and settle to different angles in the bulk pile. As well, the angle changes with the moisture content. The grain also settles during the storage. The storage capacity of grains is determined by using flat pads. When working out with the volume of grain stacked on the flat pad, angle of repose must be known for each grain. The angle of repose will increase for wet grain and may also vary depending on grain quality and its admixture content.

* 1. **Grain storage facilities**

Bin and storage facilities also play an important role in determining the quality of the stored grain. There is a range of grain storage facilities which can be used for on-farm grain storage. They all vary in their cost and length of time they will be used for storage. Managing stored grains and seed requires the use of various techniques to ensure the quality of the product entering the storage facility does not deteriorate over time. These techniques include: the use of sanitation, storing sound, dry grain, managing temperature and aeration, using chemical protectants, regular sampling, and the use of fumigation. A regular monitoring program should be continued until the grain leaves the storage facility. Storage facilities should be inspected regularly for deterioration of any type. Proper storage moisture varies depending on type of seed, length of storage and storage conditions. The duration of storage is of vital importance in deciding the most appropriate storage practice. Thus, storage can be classified into the following categories.

# 4.7.1 Transit storage

This is the shortest-term storage where the grain is being transported from one place to another or where some kind of rotation is practiced so that the old stock moves out as the fresh stock comes in. Many of the Government godowns, godowns at seaports and godowns of retailers are examples of transit storage. Transit storage has been maintained in a variety of sheds available on an emergency basis, from time immemorial. In these sheds, bag storage has generally been practiced with the bags arranged in stacks.

**4.7.2 Short-term storage**

This type of storage is practiced by cultivators who generally like to store their seed grain from harvest to sowing and food grains from harvest to harvest. Storage structures generally use for short-term are bukhari, kothar, morai, etc., which are examples of non-airtight bulk storage. From ancient times grain has been stored in India in bulk in mud bins. These earthen structures of various shapes and sizes provide the easiest and most economic methods for the storage of grains under rural conditions in India. However, in this type of storage, one often finds the grains infested with insects. In some places rats also pose a serious problem since they easily cut through the mud walls. In some wet regions of the country, grains are also found to be affected by the high humidity conditions. As a result, the loss of food grains in storage is often quite considerable. Listed below are some of the short-term storage facilities together with sources of information available on their construction and use. Two types of short-term storages are:

* Steel mesh silos
* Plastic covered bunker storage and ground dumps.

**4.7.3 Long-term storage**

This type of storage is for long periods as required by large-scale trade stockist and Government agencies desiring to keep buffer stocks or maintain food banks. For long-term storage, careful planning and implementation of the storage practices is required. Prior to the storage of grain, it should be thoroughly dried as the moisture content of the grain is the most vital factor for safe storage. Grain can be dried in the sun but it is highly advisable that a suitable grain dryer be provided for each storage godown. Air-tight bulk storage is best if the stock has to be maintained on a long-term basis. It is generally in the form of modem silos above ground or as airtight moisture-proof underground pits. Large-sized structures constructed on the basis of the Pus a bin will also serve well for long-term storage. Such storage structures housed in storage godowns are permanent means of long-term storage. The cost of such storage is quite cheap in the long run. Two types of long-term storage are:

* Prefabricated steel silos and grain sheds
* Underground pits

Sealed air-tight storage provides a cheap method of insect pest control. Due to the respiration of the stored product and of any insects present, oxygen is used and carbon dioxide is formed, which results in the death of insect pests. In order to accelerate this process, a lit candle can be placed in a tin at the top of the silo just before closing it. The burning candle quickly uses a great deal of the oxygen present. It is important to fill the silo to the top, as the oxygen present is then used up faster. Another main advantage of air-tight storage is the fact that moist outside air cannot enter the silo. But important disadvantage of air-tight storage is that further drying of the produce in the store is impossible. Therefore, the crop needs to be well dried before placing in the store.

# Harvesting and transportation facilities

Crops left standing un-harvested start to show diminishing quantitative and qualitative returns through shatter losses and attacks by insects, mould, birds and rodents. It is therefore important to complete harvesting as soon as possible. The grains must be checked in the field before harvest to make sure that the grains are free from insects and diseases. The harvesting and transporting implement must be cleaned before a new crop is harvested. The grains must be harvested and threshed to avoid any breakage of grains, because broken grain will not store well. The threshing yards which are free from insect infestation should be used. The grains should be spread over plastic sheets or cemented floor while drying, otherwise it will pick up the moisture from the ground. The grains should be kept cool and dry between the time of harvest and storage. Therefore, in all situations, grain must be harvested in a timely manner before shattering, pre harvest sprouting and weathering to minimize pre-harvest losses.

* 1. **Cleaning and grading**

Before storage, the grains should be cleaned and graded. Harvested grain (threshed/shelled/dried) needs further processing to get rid of various types of undesirable matters like inert material, decorticated seeds, damaged seeds etc. Cleaning and grading results in reduced bulk of material, high value products, safe and longer storage, more turn out of better-quality milled products. These practices allow the growers to reduce the level of defects in their grain following harvest. Moreover, they help in enhancing the probability of grain meeting the required specifications and attracting a premium price. Cleaning is normally carried out with the purpose of removal of weeds and other contaminants. Unclean grain contains small amounts of straw, weed seeds and dirt, which not only decrease the value of food-grains but also cause the grains to deteriorate during storage. Therefore, store only that grain which is clean devoid of dirt-dust foreign matter, broken grains and with not more that 11% of moisture. Clean up and dispose all waste grain, feed and stray seeds/grains that have accumulated around the storage bins. In addition, it is necessary to remove dust and contaminants, which can include insects, and vegetable material, such as bits of straw and chaff and weed seeds. These will fill up pore spaces within the crop, inhibiting air movement and adding to any possible spoilage problems. The crop must therefore be clean.

* 1. **Good housekeeping practices**

It is an effective sanitation programme and this is the simplest and best technology to prevent storage losses. To ensure good grain handling facilities engage in a variety of activities to control the accumulation of grain dust, good housekeeping practices are very essential. Good housekeeping practices include:

* Check moisture content before storing any grain. Do not store any grain with high moisture content as this result in heating and rotting of stored grain.
* Never add new grain onto old grain.
* Prior to filling the storage bin, clean the bin thoroughly.
* Use shovels, brooms etc. to clean out all the grains.
* Check outside and under the bin for grain that may have leaked out, if any is found, clean it up.
* Make sure that the roof is in good repair.
* Get rid of rats and mice by using proper traps and other methods approved to rid the rodents from the bin area.
* Be certain to clean behind partitions, between walls and clean out cracks and crevices.
  1. **HACCP**

HACCP stands for Hazard Analysis Critical Control Point. It is s system of food safety assurance based on the prevention of food and feed safety problems and adopted by the food and feed industry as the most effective means of controlling food-borne safety issues. It can be used at all stages of the food/feed supply chain from primary production to final product use. The legal requirement for HACCP also applies to animal feed and therefore to crops intended for feed. In practical terms this means that HACCP is not required for normal on-farm crop production activities, including grain storage. The principles of HACCP are, however, still advantageous for determining risks in grain storage. The HACCP system also requires that hazard identification is

correct and that control measures are suitable and can be effectively managed. The good practices will help in providing the evidence that a grain store HACCP is technically correct.

* 1. **Controlled atmosphere storage (CAS) and Modified atmosphere storage (MAS)**

Both these techniques are nowadays widely used in grain storage. In CA storage, the levels of carbon dioxide, oxygen and nitrogen in the storage room are monitored. CA storage combined with refrigeration reduces respiration and delays yellowing and quality changes. However, the tolerance of individual varieties of horticulture crops needs to be considered. Commercial application of CA storage is limited only to few crops. The technologies involved in CA storage are complicated and sophisticated. While in MA storage, the respiration of the commodity is allowed to reach a desirable low level of oxygen and high level of carbon dioxide inside a closed chamber, container etc. and gases are maintained at these levels. Both the systems are best used with refrigerated storage involving manipulation of carbon dioxide, oxygen and nitrogen. Other gases such as ethylene, acetylene and propylene are also considered.

* 1. **Sampling stored grain**

When products arrive at the storage centres and during warehousing, it is important to check their quality and state of conservation. It is practically impossible to analyze all the batches. Therefore, a representative sample of the total product must be taken, from which the appropriate analyses can be made. To obtain a representative sample, several primary samples must be taken: once they have been gathered and mixed together in a clean receptacle, they constitute the global sample on which the necessary tests will be made. If the global sample is too big, it must be divided up to obtain a smaller, but still representative, sample. Methods of taking samples differ depending on whether products are delivered or stored in bags or in bulk. Collect samples from the areas where insects and mould are most likely to establish first. These areas are generally around openings- hatches, doors, aeration fan inlets, filling and emptying points. The most common place for insects and mould in a silo is at the top, just below the surface of the peak of grain. This is because it’s the last place aeration cooling or drying reaches, it’s exposed to the sun heating the headspace, condensation from the headspace and provides easy access for insects through the top lid, inspection hole or vents.

Bins should be inspected on a regular basis for insects, hot spots, mold growth or any "off odor.” Bins should be easily accessible and all unloading equipment should be turned off. Be aware of any pesticides applied to the grain, undissipated fumigants, bridged grain, grain dusts, and high temperatures.

Sampling once a month until the store is empty, coupled with records of grain consumption and disposal will enable an accurate estimate of the losses over the season to be obtained. When such an intense sampling system cannot be undertaken, at least three samples need to be taken:

* At the time of storage.
* Approximately halfway through.
* About a month before the store is emptied.

These samples should be taken from the whole store to determine the pattern of infestation. Sampling throughout the store causes grain to move and changes the pattern of infestation within the store so should not be used if a monthly sampling routine is operated. It is however necessary if samples are to be taken on very few occasions.

* 1. **Monitoring regularly**

Failing to monitor the grain conditions throughout the storage period is a big mistake that many producers make. Regular inspection should be carried out if mold and insect activity are to be detected early. The methods of monitoring will vary with the time of year, initial condition of the grain etc. Generally, grain should be inspected at least once a month during spring, summer and fall. It is very important to carry out this inspection is summers because grain is being held at higher temperatures and aeration conditions are less favorable during rest of the year. Temperatures should be checked and recorded during each inspection. An accurate moisture tester is required to determine the actual moisture content. Bins should be monitored to look for any leaks or condensation on bin roof, condensation on grain surface etc. Any problems that are found need to be evaluated and corrected as soon as possible. This may include methods like aeration, drying, fumigation etc.

* 1. **Seed germination and testing germination rates on retained seed**

Storing grain at the optimum temperature and moisture content not only reduces the risk of mould and insects but it maintains grain quality and germination. Stored grain deteriorates with time under any conditions, but poor storage conditions accelerate the deterioration process markedly. If keeping grain for seed, a germination test and seed count test performed a month after harvest can help guide how much seed needs to be kept to achieve acceptable populations. If the germination test at this stage is poor, it might pay to buy in seed. If germination is satisfactory, use that to guide how much extra seed to keep, adding an allowance for all the other factors that will reduce germination and seed establishment.

* 1. **Eliminate spout lines**

Spout lines are the areas within the stored grains where the density of stored material is higher due to increased levels of small weed seeds and broken kernels. These particles tend to accumulate in centre of the grain forming a core that is difficult for forced air to penetrate. Therefore, elimination of spoutlines by cleaning the grain prior to binning or using a spreader device is important. High moisture weed seeds commonly collect in spout lines and mold problems often start at these sites. The best way to check for spout lines is to sense changes in the force required as one push a probe through the edge of the grain into the centre.

* 1. **Use of storage structures**

The facilities that house stored materials for the purpose of preserving their qualities are called storage structures. The selection of storage structures depends on the production level, cultural practices, and the climatic conditions. Basically, storage structures are classified as traditional and modern storage structures. Traditional storage structures include: ground or pit storage and cellers and caves. Pit storage is very commonly followed to the hills, in the snow bound areas etc. The pits may be covered with pucca or kuccha and lined with straw or leaves; the produce is then covered with straw followed by thin layer of soil. The cellers are sophisticated type of below ground storage. The caves are also the natural shelters available under big rocks. Modern storage structures are mostly used for medium or long term and medium or large-scale storage. These include: Improved crib, Ware house, Silo/ Bin, Controlled atmosphere storage system, Refrigeration, Cold storage, Evaporative coolant system (ECS) and Hermetic and nitrogen storage systems. Refrigerated storage is a well-established technology widely used for storing horticulture crops all over the world. Essentially, all crops can benefit by being stored at a suitable low temperature which extends the storage life and preserves quality.

* 1. **Proper sanitation practices**

Sanitation is an overlooked component of safe and effective grain storage. Grains stored on the farm have limited shelf life due to molds, insects and other microorganisms. Therefore, proper sanitation before harvesting helps in minimizing the chance of problems occurs during storage. These sanitary practices will include:

* Inspect the storage bin roof and sides inside and outside for cracks, rust etc.
* Repair all leaks and holes to prevent water and rodent damage.
* Place a light inside the storage bin to look for any cracks or holes.
* Remove old grain from grain carts, combines etc. for harvesting, transporting or handling grain.
* Remove any spilled grain, weeds etc. to reduce insect infestation.
* Remove all debris from fans, aeration ducts etc.
* After cleaning and repairing storage bins, sanitize the walls.
  1. **Dealing with Global insect resistance problem**

In this method, insecticides are applied in combination. Insect infestation is prevented by treating grain as it is moved into storage with one of three approved insecticides like Chlorpyrifos-methyl, Malathion and Pirimiphos-methyl. Therefore, optimizing dosage rates and controls all species in a likely pest complex. This method will not allow accelerated development of resistance to insecticides.

* 1. **Use of technically trained hierarchy**

Only such persons who know the implications of grain storage need to be given the charge of grain storage. Moreover, personal hygiene of the person dealing with grain storage is also very important. This involves the concept of GMP (Good Manufacturing Practices) which includes:

* Personnel
* Training and supervision
* Facilities and installation
* Storage and distribution
* Pest control
* Code
* Control and quality guarantee
* Production, operation and process
* Cleaning and Sanitation

The awareness of the persons dealing with grain storage, training and awareness programme will guarantee necessary results.

* 1. **Phosphine fumigation technology**

Phosphine remains the single-most relied upon fumigant to control stored grain pests in Australian grain-production systems but continued misuse is resulting in poor insect control and developing resistance in key pest species. An important new development recently introduced by the Common Wealth Stored Grain Research Laboratory in Australia (Common Wealth Scientific and Industrial Research Organization, Canberra, Australia) is the use of Phosphine in gas form. Phosphine is applied in gas cylinders mixed with carbon dioxide acting as carrier. This technology is beneficial in grain storage but it is quite expensive.

1. **Maintaining food grain quality in storage**

This has been reported that up to 10 million tonnes of food-grains are lost each year in India through faulty storage techniques. If saved, it would have been more than enough to meet any world food deficit. It has been estimated that 10% loss in storage may be sufficient enough to feed 72 million people. The large stocks of grain in storage pose various problems which are unique and quite different from those of smaller lots. Therefore, adequate attention must be paid in the large-scale storage of food-grains. To minimize the storage losses, some practices for large scale storage of food grains has been developed.

* 1. **Moisture**

High moisture grain should not be stored long term. Accepted moisture limits for trading and storage of grains (Table 1) are generally below the limits at which moulds develop. Moisture moves around inside a silo. Daily and seasonal temperature changes near the silo walls set up air movements that carry moisture to the coolest parts of the grain. Pockets of high moisture grain (e.g. Grain harvested early in the season, late at night, early in the morning or soon after rain) or inclusion of green leaf material with the grain can affect the quality of grain in storage because of moisture movement. No food grains with moisture content higher than the safe acceptable level should be accepted for storage. Dry the moist grain before storage because it respires more quickly and gives off more heat and moisture, which encourages build of insect population and mould growth and hot spots develop in bulk grains. At all times, the moisture content of the grain should continue to remain low enough do that not to allow any fungal/bacterial growth.

**Table 1. Upper moisture limits for trading and storage of grains based on National Agricultural Commodities Marketing Association Standards.**

|  |  |
| --- | --- |
| **Grain** | **Moisture limit (% dry weight)** |
| Sunflower | 9 |
| Barley(malting), faba beans,  Mungbean, oats | 12 |
| Barley(feed), wheat | 12.5 |
| Chickpea, pigeonpea, soybean | 13 |
| Sorghum | 13.5 |
| Maize | 14 |

Aeration is a process of cooling a grain bulk by passing large quantities of untreated air of suitable temperature and humidity, so that the grain in storage remains in an acceptable condition for long periods. Aeration reduces grain temperatures to minimize mould growth and insect/mite activity. It maintains the grain quality and provides more uniform grain temperatures to prevent convection air movement and moisture transfer. Fumigants may also be distributed by aeration fans. Aeration will slow the rate of spoilage of high moisture grain but if the moisture is more than two or three percent above the limits in Table 1, it should be dried before long term storage. Early harvesting of grain at high moistures produces higher quality and higher yields of grain but those advantages are lost unless aeration and drying are used to minimize losses in storage.

Stored grains have relatively low thermal conductivity. Daily temperature changes have a very small effect upon grain temperatures, and even seasonal changes from summer to winter are likely to cause pronounced grain temperature variation only in most exposed part of a large grain bulk. The aeration equalizes the temperature of the grain thus arresting multiplication of insect and mould activities as well as moisture migration. Grain aeration is more properly considered as a preventive rather than a remedial measure.

Hot air drying is necessary to maintain the quality of high moisture grain. However, holding grain at too high a temperature for too long in the dryer will reduce grain quality. Operate the equipment according to specifications of the dryer manufacture. Using higher flow rates is a safer way to speed up drying than increasing temperature.

Selling grain at a moisture content below that allowed by market results in economic loss. Grain loses approximately 1.2 % of its weight for every 1% of moisture content reduction. For example, selling grain with 9% moisture content when upto 12% is allowed means a loss of about 3.6% of the value.

* 1. **Temperature**

Aeration will markedly reduce grain temperature and so minimizes the grain spoilage of grain quality. Aeration will also even out temperature differences that result in moisture migration from warmer top cooler patches in the grain. A white finish on the silo will also contribute to a reduction in temperature. Insects and moulds impair the quality of grain directly by their feeding and development and indirectly through generation of heat and moisture. High temperatures and moisture favor development of insects and moulds. Development of insects is limited by temperatures below 15°C and by moisture below 9% in cereal grains. Development of moulds is limited by temperatures below 10°C and by moisture below 13% in cereal grains.

**6. Conclusions**

Grain production has been steadily increasing due to advancement in production technology but improper storage results in high losses in grains. Grain temperature and moisture are the two important factors which affect the rate of metabolism, growth, development, reproduction and general behavior of stored grain insect pests and fungi and results in qualitative and quantitative losses. Storage procedures and processes differ for each grain and purpose but inappropriate storage solutions cause the product to decay so to be lost, decrease of product quality, decrease of storage time and thus increase of storage and labor costs. Grain storage can be enhanced by controlling temperature, moisture, oxygen and by applying various techniques like aeration, drying, use of fumigants, insecticides etc. Therefore, storing grains in predictable good conditions for a sufficient amount of time will contribute significantly to the world economy in terms of efficiency.