Lecture notes on Grain storage
(M. Tech IInd Year)

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1. BACKGROUND

In the agrofood chain, harvesting is the stage between the phase of actual agricultural production and that of grain processing or, more broadly, treatment of the produce. Storage is the last stage of production. It is an interim stage in farm to processor chain.

"Storage" means the phase of the post-harvest system during which the products are kept in such a way as to guarantee food security other than during periods of agricultural production.

The main objectives of storage can be summed up as follows:

- *At the food level:* to permit deferred use (on an annual and multi-annual basis) of the agricultural products harvested;
- *At the agricultural level:* to ensure availability of seeds for the crop cycles to come;
- *At the agro-industrial level:* to guarantee regular and continuous supplies of raw materials for processing industries;
- *At the marketing level:* to balance the supply and demand of agricultural products, thereby stabilizing market prices.

In order to attain these general objectives, it is obviously necessary to adopt measures aimed at preserving the quality and quantity of the stored products over time. Some points to be considered are:

- Whether it is done by hand or with the help of machines, the harvest should generally not take place until the produce has reached its optimal maturity.
- After the harvest, it may be necessary to pre-dry the produce before the subsequent threshing or shelling operation.
- The grain must be cleaned and dried, so that it can be stored or undergo further processing.
- Grain can be stored in bulk or in bags, on the farms where it was produced, in collection centres, or with storage agencies.
- Finally, the grain is sent from the warehouses to markets for sale to consumers, to smallscale food-processors, or to agrofood industries.

The sequence and interactions of these operations contribute to the formation of a complex system called the post-harvest system.

Harvest
↓
Predrying
↓
Theshing/Shelling
↓
Precleaning
↓
Drying
↓
Cleaning and sorting
↓ ↓ ↓
Marketting Storage Processing

With an annual worldwide production estimated at more than two billion tons in 1992, grain crops provide the world's primary staple food. The FAO's Agricultural Engineering Service recognizes that dissemination of knowledge on appropriate grain storage facilities and techniques to its developing member nations remains very important.

The importance of grain storage as part of the marketing, distribution and food security system is well recognized. As early as 1971, the Group for Assistance on Systems relating to Grain After-harvest (GASGA), in which FAO participates, brought together experts and coordinated activities on research and development. In 1978, following the resolution of the UN General Assembly which called for the reduction of post-harvest losses, FAO launched the Special Action Program for Prevention of Food Losses (PFL). Since then more than 250 projects have been implemented world wide under this program.

1.1. TECHNOLOGIES AND PHASES OF THE POST-HARVEST SYSTEM FOR GRAIN

Post-harvest operations	*Traditional technologies*	*Intermediary technologies*	*Industrial technologies*
Harvest	Manual	Manual and mechanized	Mechanized
Pre-drying	Standing or in shocks	In cribs or in shocks	
Storage in the ear	In traditional	In cribs granaries	
Threshing	Manual	Mechanized	Mechanized
Pre-cleaning		Mechanized	Mechanized
Drying	Natural	Artificial	Artificial
Cleaning and sorting	Winnowing in the wind	Mechanized	Mechanized
Storage in grains	In traditional granaries	In bags or in bulk	In bags or in bulk
Processing	Manual	Mechanized	Mechanized

During recent years, as a result of privatization and liberalization of trade, the organization and management of grain storage has changed in many developing countries. This restructuring of the grain storage sector has created a demand for information and knowledge from the emerging private entrepreneurs operating in the storage sector. In the previous storage and distribution systems, functions such as collection, storage, regulation of supplies, food security and price control, were often entrusted to marketing boards. Skills have been developed, facilities have been installed and methods taught to their staff, often at high cost. These skills have now to be acquired by the new "actors" of the privatized storage and distribution system. To this end, FAO and GASGA have published a bulletin the purpose of which is to contribute to the transfer of knowledge on grain storage to persons involved in the storage of grain.

1.2. THE ROLE OF STORAGE IN THE ECONOMY

In most countries grains are among the most important staple foods. However they are produced on a seasonal basis, and in many places there is only one harvest a year, which itself may be subject to failure. This means that in order to feed the world's population, most of the global production of maize, wheat, rice, sorghum and millet must be held in storage for periods varying from one month up to more than a year. Grain storage therefore occupies a vital place in the economies of developed and developing countries alike.

The market for food grains is characterized by fairly stable demand throughout the year, and widely fluctuating supply. Generally speaking people's consumption of basic foods such as grains does not vary greatly from one season to another or from year to year. The demand for grain is 'inelastic', which means that large changes in the market price lead to relatively small changes in the amount of grains which people purchase.

Market supply, on the other hand, depends on the harvest of grains which is concentrated within a few months of the year in any one area, and can fluctuate widely from one year to the next depending on climatic conditions. New varieties that have shorter growing periods, and variation in climatic conditions and farming systems in different regions of a country, can help to even out the fluctuations in market supply. But even in a country such as Indonesia, which has diverse climatic and farming conditions and where 90 per cent of rice land is under short duration high yielding varieties, about 60 per cent of production is harvested within a three month period (Ellis et al. 1992).

The main function of storage in the economy is to even out fluctuations in market supply, both from one season to the next and from one year to the next, by taking produce off the market in surplus seasons, and releasing it back onto the market in lean seasons. This in turn smoothes out fluctuations in market prices. The desire to stabilize prices of basic foods is one of the major reasons why governments try to influence the amount of storage occurring, and often undertake storage themselves.

1.3. COSTS AND INCENTIVES TO STORE

Both producers and consumers benefit from stable prices, which reduce the uncertainties associated with planning farm investment and household expenditure. However storage involves costs, and the only way in which these costs can be recuperated is through a price spread. If storage is to be profitable, people who store grain must receive a price on sale which at least covers the costs of storing the grain since harvest. These include:

- The cost of the store itself (often a rental cost);
- Labor and supervision;
- Pest control;
- Storage and spillage losses; and
- Cost of capital invested in the grain.

In practice, the costs of storage depend on the commodity stored, on the type of storage system, and on unpredictable and variable factors such as pest incidence and climatic conditions. Storage costs also depend on the circumstances of the person, the business or the institution who is storing. The most variable component of storage costs is the cost of capital. For a small farmer or trader, capital may be scarce and costly, and their only access to loans may be from money lenders charging rates of 10% or more per month. On the other hand a Government Marketing Board may have preferential access to loans at low interest, at rates of as low as 10% per annum. There is, therefore, no single cost of storage.

In Nepal, more than 70% of the produce is stored by farmers. About 30% enters into the trade channel. The storage facilities are very primitive. About 7% is lost in handling and transportation alone with an additional 2-6% during storage. Depending on the specific grain, 64 to 96% of the seed is stored by farmers themselves. About 48 to 90% of the grains are stored by the farmers for future sale (when the price rises).

Families of the hills sustain themselves with their own production for about 225 days a year. Grain produced in Nepal is sufficient to feed its people. However, the real problem appears to be in the lack of transportation, distribution and management. According to FAO, underdeveloped countries lose 30-40% of produce. In Nepal, according to Rural Save Grain project (1983) post harvest losses were found to be 16%, 13.8%, and 14.6% for paddy, wheat and maize respectively. The losses of wheat, rice, and overall in the developed countries are <1%, ≈ 1.5%, and ≈ 5% respectively.

Estimates of the quantitative losses of rice for each stage in the post-harvest system in Southeast Asia.

Stage	Losses	
	Min.	Max.
Harvest	1%	3 %
Handling	2%	7%
Threshing	2 %	6 %
Drying	1%	5 %
Storage	2 %	6 %
Transport	2 %	10 %
Total	10%	37%

In many developing countries, overall post-harvest losses of cereals and grain legumes of about 10 to 15 percent are fairly common. In some regions of Africa and Latin America, higher rates are found: up to 50 percent of the quantities harvested.

Up to now, we do not have really reliable data on the true level of post-harvest losses. There are many reasons for this information gap:

- No universal mathematical methods exist for establishing a "model";
- The extent of losses may fluctuate considerably depending on weather conditions (rainy season, etc.), varieties, locations, etc.;
- Many national institutions deal negligently and superficially with the question of post harvest losses, considering it marginal in relation to the problems of agricultural production;
- It is difficult to make credible estimates of quantitative and qualitative losses, especially in situations where specific resources, strategies, and capabilities are all lacking;
- The lack of adequate permanent national organizations makes it impossible to monitor the extent of post-harvest losses.

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2. POST-HARVEST LOSSES

2.1. DEFINITION

Harvest is the operation of gathering the useful part or parts of the plant. It is a voluntary intervention by man, carried out at the time when all the nutrients have been developed and when the edible parts have reached the degree of maturity appropriate to the treatments to follow.

The expression "post-harvest losses" means a measurable quantitative and qualitative loss in a given product. These losses can occur during any of the various phases of the post-harvest system and may occur separately or together.

The main types of losses can be categorized as (i) weight loss (apparent and real weight loss), (ii) nutritional loss, (iii) quality loss, and (iv) viability loss.

I. WEIGHT LOSS

This is assessed by measuring the quantity lost under a period of investigation or period of storage. It may be subdivided into (a) apparent weight loss and (b) real weight loss. Apparent weight loss refers simply to weight loss during any post harvest under investigation. It does not account for the effect of moisture content, contamination and foreign material, respiration, combustion, etc. Real weight loss is calculated by making necessary corrections in the apparent weight (taking into account the losses due to pilferage, rodents, moisture content, respiration, etc.)

II. NUTRITIONAL LOSS

Any loss in weight of edible matter constitutes nutritional loss. For example, the endosperm can be eaten by the insect thereby reducing the nutrient.

III. QUALITY LOSS

This includes damaged grains, contaminants, rodent excretion, pesticide residues, insect parts, etc. This loss results in monetary and goodwill loss. Changes in biochemical composition (e.g. increase in free fatty acids, reduction in vitamin content, etc.) also cause quality loss.

IV. LOSS OF VIABILITY OF SEED

The germination capacity of the seed (% of seeds able to germinate in 3 days) and germination energy (% of germinated seeds observed after 7 days) may decrease. The germination energy is determined by assessing roots, shoots, abnormalities, etc., in seeds during germination.

2.2. FACTORS AFFECTING LOSS/SHELF LIFE

The main categories of factors that lead to loss are (i) socioeconomic factors and (ii) scientific factors. Each of these factors can be further broken down into sub-factors the summary of which is shown in the following page.

In Southeast Asia, temperature and moisture are the most important factors leading to huge amounts of grain loss because warm and moist condition is not suitable for grain storage.

2.2.1. EFFECT OF TEMPERATURE

Temperatures between 21 and 43℃ are favorable for microbial activity, insects, rodents and other organisms. Chemical reactions also speed up. If the humidity is low, this high temperature can be advantageously used for natural drying. Grains have capillary structures that lead to faster absorption and desorption of moisture. However, the RH is high in most part of Asia and this beneficial aspect of high temperature cannot be realized.

Factors affecting storage loss/shelf life

- (I) Scientific factors
  - (1) Physical
    - o Temperature
    - o Moisture
  - (2) Biological
    - o Properties of biomaterial, microorganisms
    - o Insects
    - o Rodents, birds, man
  - (3) Chemical
    - o Respiration
    - o Pesticide residues
  - (4) Engineering
    - (i) Structural
      - o Bag storage
      - o Bulk storage
    - (ii) Mechanical
      - o Conveying
      - o Application of pesticides
- (II) Farming and socioeconomic factors
  - (1) Financing
  - (2) Farming methods
    - o Traditional farming
    - o Developed farming
  - (3) Storage and marketing methods
    - o Small traders
    - o Food corporations

The produce contains certain amount of heat. When it is put in the storage, the heat is retained in the storage structure. Condensation occurs on the surface due to temperature fluctuation, altitude, etc. Condensation reflects a very poor condition of storage. Localized accumulation of moisture induces germination. The condition also becomes favorable for microbial proliferation.

Temperature is the determining factor in the development of all organisms and its effect is correlated with the amount of moisture present. The water holding capacity (WHC) of air increases as the temperature increases. For example, at 10℃ and 38℃, 1m^3 of air can hold 10g and 45g of water respectively. Under damp condition, grain respiration increases to the point where germination occurs. At temperatures above 66℃, germination as well as gluten value will be impaired.

Fungi have different rates of growth at different temperatures. Some can grow at 2℃ while some can grow even at 63℃. *Aspergillus* and *Penicillium* are the dominant grain fungi.

Insect development also speeds up with the increase in temperature (up to 42℃) but will eventually die on prolonged exposure. Temperatures below 15℃ retard insect reproduction and development and temperatures below 10℃ will cause death of most insects.

The status of storage is assessed by measuring temperature at different points in the grain mass. Increase in temperature above the initially stored temperature indicates deterioration. This may be due to grain respiration, microbial activity or insects. When the temperature reaches around 50℃ food grains are killed and respiration begins to stop. Increase in temperature above 50℃ is due to microorganisms. Further changes and destruction continue due to development of bacteria and fungi until a temperature of 70 to 80℃ is attained .

2.2.2. EFFECT OF MOISTURE

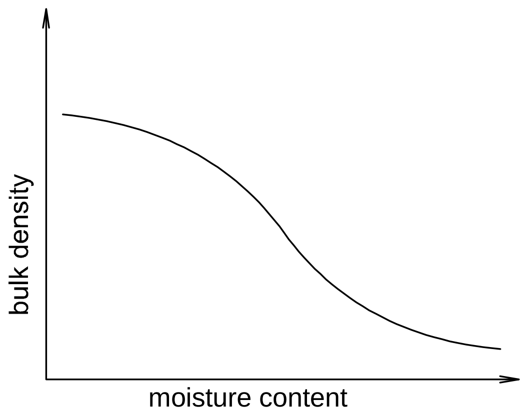
Moisture is the key to safe storage. Biological activities occur only if moisture is present, with minimum quantity for such activity varying with the microorganism concerned. Moisture determination is carried out on wet basis (industrial purpose) and dry basis (for research works) and this can be done using various physical and instrumental methods. The status of grain of grain with respect to moisture can be gathered also by measuring the bulk density of the grain. Bulk density is defined as the weight of grain in a fixed volume. Bulk density is related to storage space and is therefore a very important parameter in warehousing.

Bulk density decreases with the increase in moisture content. Grains have density greater than 1 (the density of water). When water enters the capillary, the net density therefore decreases.

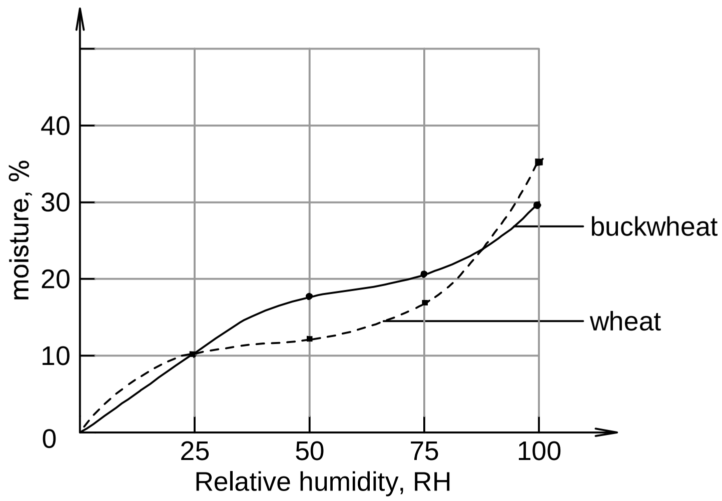
Grain with low moisture content has longer storage period without deterioration. Surface friction properties increase with increase in moisture content.

Moisture in grain is held in following forms: (i) absorbed water (held in capillary), (ii) adsorbed water (due to molecular attraction), and (iii) bound water.

In a broader sense, the term “sorbed water” is used to collectively represent both “adsorbed” and “absorbed” waters. This water is important in grain storage. Sorption characteristics are the inherent property of all seed grain bulk. Seed has a capillary colloidal structure. It can take up and hold moisture, air and vapor from ambient air. Sometimes, chemicals are also sorbed. Water is held by loose capillary system in absorption. In adsorption, water is held more firmly by molecular attraction. In some cases, the process is reversed and this is termed “desorption”.

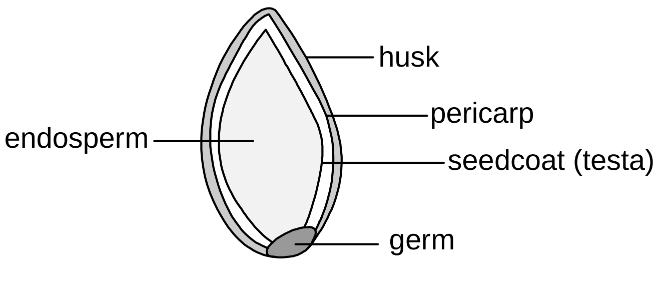


Grains sorb moisture or release moisture until equilibrium is reached. This particular moisture level is called equilibrium moisture content (EMC) and is generally between 7-36% (depending on RH). In most grains, increase in RH does not uniformly increase moisture content of the grain. At RH > 75, a slight increase leads to large increase in moisture content of stored grains.



Sorption is due to two main reasons, viz., (i) capillary porous colloidal structure, and (ii) porosity of grain bulk (grain-to-grain porosity). The macroporous and microporous grains have pore diameter of 10^{-2} – 10^{-4} cm and up to 10^{-7} cm respectively. The active surface area of pores is > 200,000 times greater than the grain surface area.

The lack of uniformity in the distribution of moisture in a grain bulk is an important factor in the initial attack by decay microorganisms. Due to different chemical composition and peculiar anatomical structure, distribution of moisture in grain will be different. Germ holds much water in all grains due to abundance of phospholipids and enzyme activity. Pericarp and husk contain second highest moisture content. Endosperm contains the least moisture content. The decay organisms attack where the moisture content is high.



2.2.2.1. MOISTURE MIGRATION

Moisture migrates heavily from germ. Testa layer is moisture impervious and is continuous except at the germ. Germ is nutritious and hence insects attack it first. The moisture variation within the stored bulk of grain occurs due to:

- Variation of adsorption capacity among the grains of differing size, shape, maturity, etc.
- Grain bulk harbors different organisms. They have differing rates of respiration, which in turn leads to moisture variation
- Condition of granary, storage, and materials
- Difference in thermal-moisture conductivity. The passage of moisture is analogous to transfer of heat along the gradient

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3. GRAIN DETERIORATION

Moisture and temperature play a major role in grain deterioration and all of these are interrelated.

For machine-processed corn, the mathematical relation is given by:

$$T = (T_R)(M_T)(M_M)(M_D)$$

Where,

T = Maximum storage life of corn related to moisture content, temperature and mechanical damage. The critical value of CO_2 evolution rate in corn is 7.4g CO_2 per kg of dry corn. This value represents 0.5% mass loss. Excess of this value leads to deterioration. Corn can be stored until 0.5% loss.

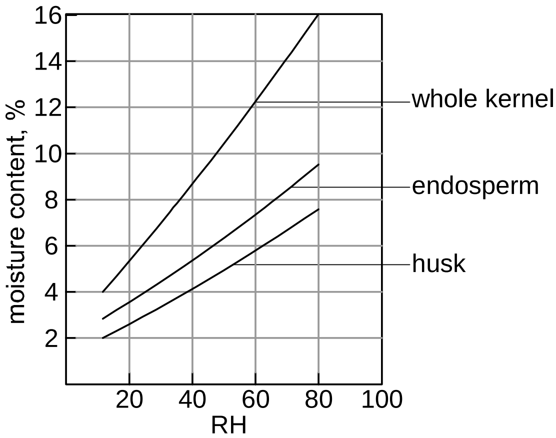
T_R = Time (in hour) for corn having 25% moisture and 30% mechanical damage stored at 15.6℃

M_T = Temperature multiplier. If $M_T = M_M = M_D = 1$, $T = T_R = 230$ hours

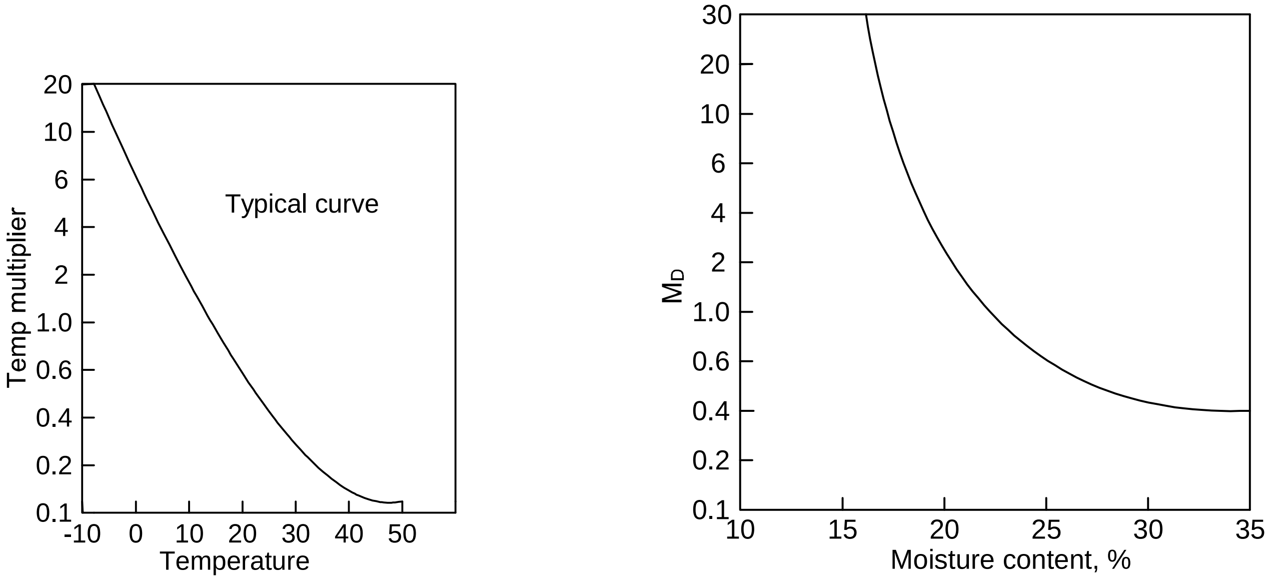
M_M = Moisture multiplier

M_D = Mechanical damage multiplier

If the required storage period is known and other relevant data are known, they can be used in the above equation to predict the storage condition (temperature, moisture, etc.) needed for storage. Likewise, if the storage condition is known, the maximum storage period can be calculated.



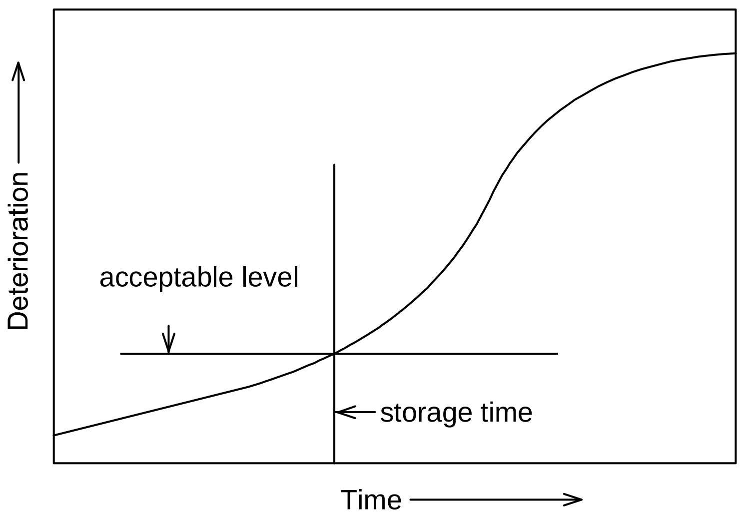
EMC of sunflower seed



Typical graphs for calculating shelf life of grains

3.1. DETERIORATION OF GRAIN BY RESPIRATION

Deterioration of grain increases with time. However, the relation is not linear (= the deterioration rate is not constant). Instead, the graph of deterioration against time gives a sigmoidal curve as shown below:



The respiration chemistry can be represented by the usual formula:

$$O_2 + C_6H_{12}O_6 \rightarrow 6CO_2 + 6H_2O + \text{energy } [32 + 180 \rightarrow 108 + 264 + 2{,}829 \text{ kJ heat}].$$

The type of food material being used in the respiration can be assessed by calculating *respiratory quotient*, *RQ*, which is defined as the ratio of moles of carbon dioxide produced to moles of oxygen consumed (i.e., mole of CO_2 /mole of O_2). The respiration is aerobic if *RQ* = 1. If the consumed O_2 is used for other processes, *RQ* < 1 (e.g., oxidation of lipids). RQ depends on different factors, such as grain species, process, air, moisture, temperature, silo storage, etc. For grain storage, the value of *RQ* (also denoted by *k*) should be greater than 1 so that a partially anaerobic condition prevails.

The free heat evolved per mole of glucose aerobically oxidized is 2,829 kJ. This heat must be dissipated. Grain, on the other hand, is an insulator, having a thermal conductivity of ≈ 0.15 W/m℃.

There is the possibility of formation of 'hot spot' in the grain. Hot spot results not only from the respiration of grain but also due to microorganisms, insects, etc. Heat accumulates in a localized area and causes serious problem. Convective mass flow occurs due to intergranular space (40-60% intergranular space or porosity). As a result, serious increase in temperature occurs. 2400kJ/kg heat is required to change water from liquid to gaseous form. If 1kg of water is generated by grain deterioration, the quantity of heat released is given by:

$$Q = (1000\text{g} \times 2{,}829 \text{ kJ}) / 108\text{g} = 26{,}100 \text{ kJ}$$

Dividing 26,100 by 2400 we get 10.9 times. Thus, deterioration of grains generate 10.9 times of heat needed to evaporate the water generated. This principle is used by farmers when piling harvested rice (along with straw). The raw rice on the stalk dries itself.

Dry matter of grain is used to produce heat to dry the stored grain and the material is stored in such a way that water can move away from the store.

Grains that are badly damaged by insects have greater protein than the sound counterpart. This is due to respiratory quotient

EXAMPLE

Grain protein = 7.5% (*RQ* = 0.71); carbohydrate = 90% (*RQ* = 1); fat = 2.5 (*RQ* = 0.83)%.

Using these values for calculating average *RQ*, we get:

$$1 \times 0.9 + 0.83 \times 0.075 + 0.71 \times 0.025 = 0.98$$

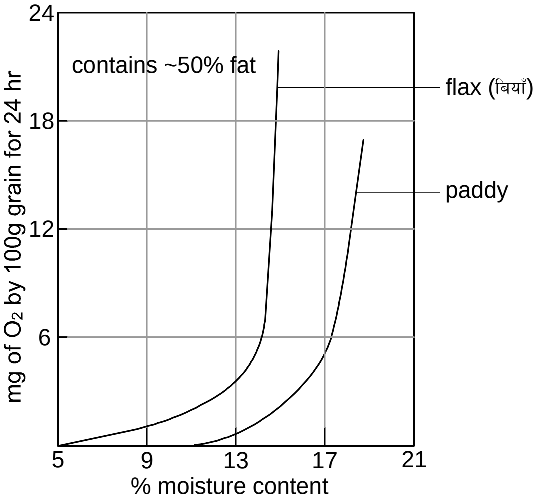
Using *RQ* = 0.98 for a given grain to compute the outputs of CO_2, H_2O and heat will not improve the accuracy of calculation because many microorganisms selectively attack carbohydrates before they do proteins. This leads to an increase in protein content in grains that have been damaged by microorganisms.

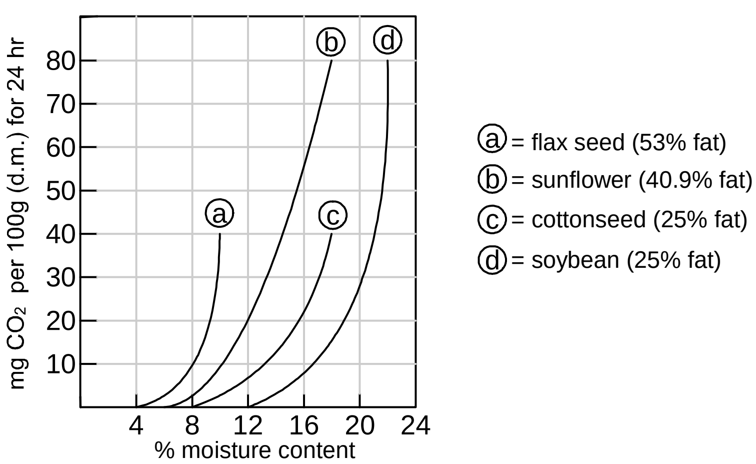
3.2. INTENSITY OF RESPIRATION OF STORED GRAINS

This depends on (i) moisture, (ii) temperature, and (iii) active ventilation/aeration

If moisture content is in the range 11-12%, respiration rate tends to zero or very low. At moisture content of 25-30% (along with ambient temperature and access to free air) the rate of respiration is high. The loss of dry mass will be around 0.05-0.2% in 24 hr. The following graphs show the relation of moisture content and the utilization/liberation of O_2/CO_2.

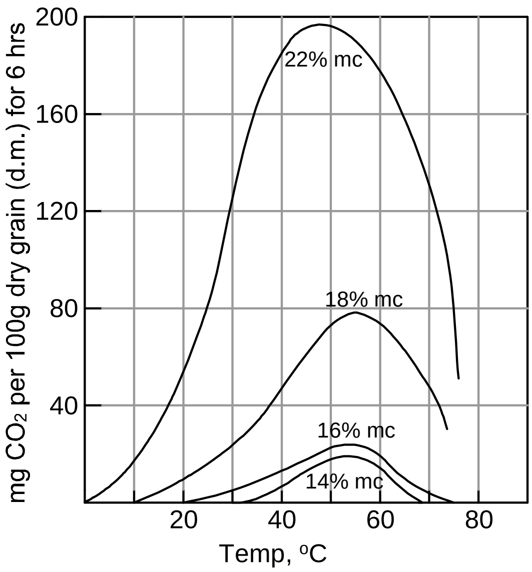
The relation of moisture content and respiration is a molecular phenomenon. At higher moisture levels, the solutes become more available for reaction due to increased mobility. The retardation of growth of microorganisms at low moisture levels is thus related to reduced dissolution and mobility of nutrients.

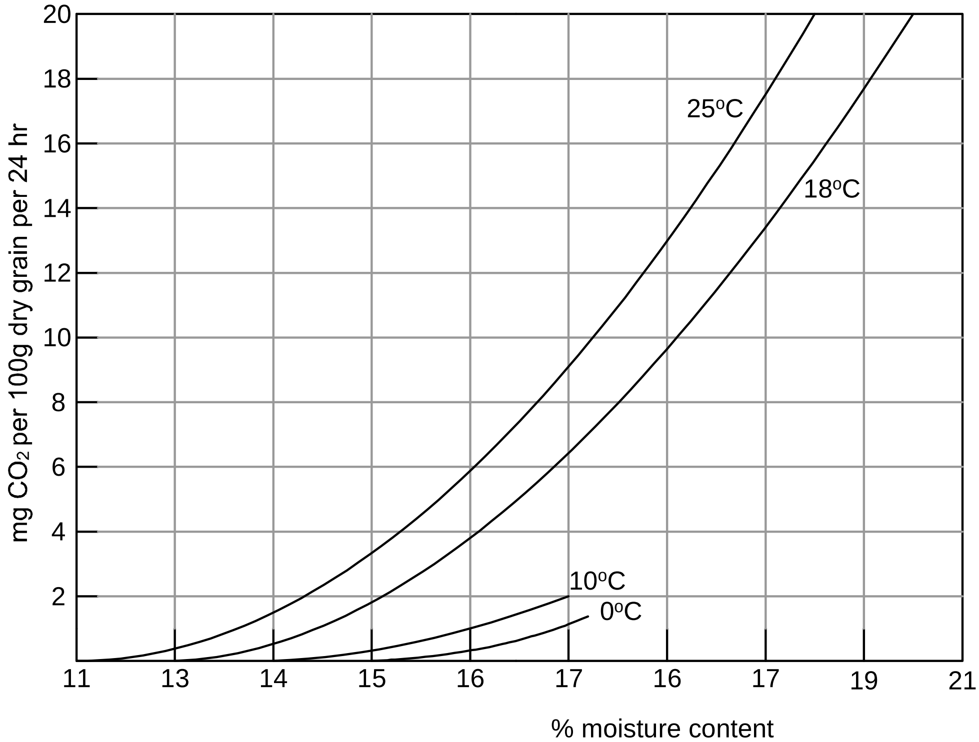




Respiration rate is also related to temperature. It increases with an increase in temperature up to 50-52℃. This temperature is the most reactive temp erature. The following graph depicts the relationship of respiration (CO_2 liberation), moisture content and temperature for grain.

It can be seen from graph that respiration falls off after about 50℃ because of gradual denaturation of cellular proteins. The respiration stops at around 70℃. The graph also shows that respiration is maximum at 22% moisture content. The rate decreases gradually as the moisture content decreases.





3.4. HOT SPOT FORMATION AND MOISTURE MIGRATION

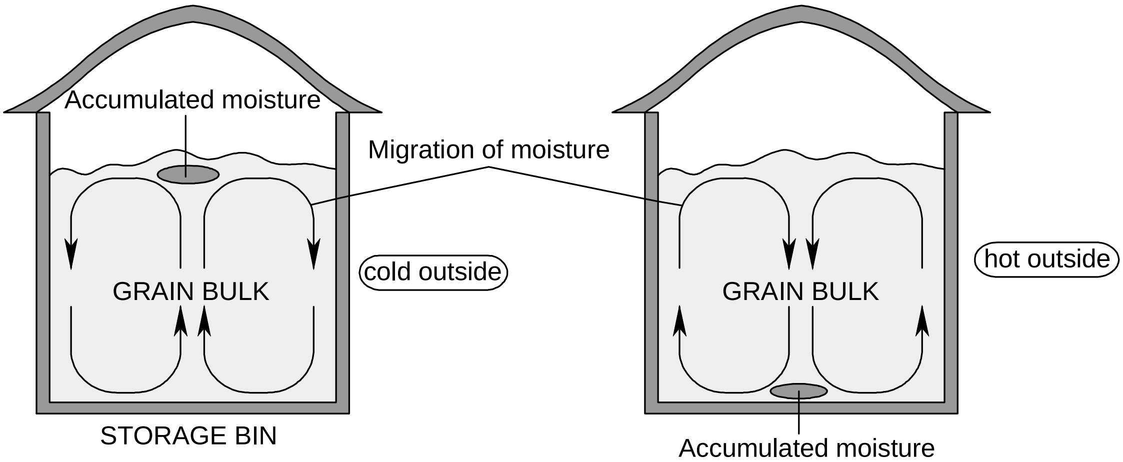
Grain bulk contains sound grains and impurities of different moisture contents. Moisture content may vary from lot to lot also. When such grain bulks (with varying moisture contents) are stored in containers or bins, higher moisture at any localized spot increases the rate of respiration. Insects and microorganisms also grow and respire. The storage fungi of importance are *Cladosporium*, *Penicillium*, and *Aspergillus*. Grains may also contain 'hidden insects'. Hidden insects refer to insect eggs present in the grain. Insects bore the grain and lay egg in the field itself. The eggs remain dormant but become active when the condition becomes favorable. The bacteria of importance in grain storage are mostly from the *Bacillus* genus, e.g., *Bacillus subtilis*.

Microorganisms are decomposers; insects are consumers and grain the producer.

The moisture travels to the drier areas and may condense on the cooler surface. Due to heat, active insects move further away. Inactive insects (e.g., pupa) die. The dislocated insects begin to respire in the next site again.

3.5. MOISTURE MIGRATION IN BULK UNDER COLD AND WARM CONDITION

Grains near the wall become cold if the external environment is cold. The moisture therefore migrates down (due to increased density) adjacent to the cold surface. The moisture then moves up along the central axis but only to be condensed at the top surface. The moisture continues to accumulate near the surface. This may lead to germination of grain. The moisture migration is more pronounced in larger bins. In the same light, moisture moves up along the walls under warm condition. It eventually goes down along the central axis and condenses at the bottom. This event produces grain cakes at the bottom of the bin. The following figures show how moisture migrates under cold and warm conditions.



3.6. AGENTS CAUSING DETERIORATION OF STORED GRAIN

The principal enemies of stored grain are micro-organisms, insects and rodents.

3.6.1. MICRO-ORGANISMS

- Micro-organisms (moulds, yeasts, bacteria) are biological agents present in the soil which, when transported by air or water, can contaminate products before, during and after the harvest.
- Their presence and growth cause severe changes in the nutritive value and the organoleptic features of grain (taste, smell).
- Furthermore, they are responsible for the alteration of important germinative properties of seeds (vigor and capacity to germinate) and, in the case of moulds, for the potential formation of dangerous poisons (mycotoxins).
- Impurities, and cracked or broken grains, foster the development of micro-organisms.
- Furthermore, temperature and humidity have a determining influence on the growth rate of these degradation agents.
- It has been observed that micro-organisms develop at temperatures between -8℃ and +80℃, when the relative humidity of the air is ove r 65%.

- On the contrary, atmospheres that are low in oxygen help check the development of these degradation agents.

3.6.2. INSECTS

- Insect infestations can occur either in the field, before the harvest, or in the places where products are stored.
- In some cases, these infestations are difficult to discern with the naked eye, since the damage is provoked by the larvae developing inside the grain.
- The insects most likely to infest stored products belong to the following families:
  - Coleoptera (beetle family, damage by larvae and adult insects);
  - Lepidoptera (moth family, damage only by larvae).
- Insects can be responsible for significant losses of product. Furthermore, their biological activity (waste production, respiration, etc.) compromises the quality and commercial value of the stored grain and fosters the development of micro-organisms.
- Insects can live and reproduce at temperatures between +15℃ and +35ºC.
- On the contrary, low humidity slows or even stops their development, and a low supply of oxygen rapidly kills them.

Some of the important species of insects recognized as pest insects of food grains, including pulses are given below:

Table. Important insect pests of tropical stored grains or grain products

COLEOPTERA:	ANOBIIDAE BOSTRICHIDAE BRUCHIDAE CUCUJIDAE CURCULIONIDAE DERMESTIDAE SILVANIDAE TENEBRIONIDAE	*Lasioderma serricorne* (F) *Rhyzopertha dominica* (F) *Prostephanus truncatus* (Horn). *Acanthoscelides obtectus* (Say) *Callosobruchus* spp. *Zabrotes subfasciatus* Boheman *Cryptolestes* spp. *Sitophilus oryzae* (L) *S. zeamais* Motschulsky *Trogoderma granarium* Everts *Dermestes* spp.
LEPIDOPTERA:	GELECHIIDAE PYRALIDAE	*Sitotroga cerealella* (Olivier) *Ephestia cautella* (Walker) P*lodia interpunctella* (Hubner) *Corcyra cephalonica* (Stainton)

3.6.3. RODENTS

There are more than 4000 species of mammals, of which about 1700 are rodents. However, not all of these rodent species are pests. About 150 species have been defined as a pest at some locality to some crop at some time or another, but only 20 could be termed important. Very few species indeed are regularly described as pests in the literature. In connection with post-harvest losses, the number of species occurring in and around human habitation drops to below 10.

- Rodents invade and multiply in or near storage places, where they can find an abundance of food.
- They cause serious damage not only to stored products but also to packaging and even to storage buildings.
- The principal rodents, those most common and likely to attack stored products, belong to the following species:
  - black rat, also called roof rat (*Rattus rattus*),

- brown or Norway rat, also called sewer rat (*Rattus norvegicus*),
- mouse (*Mus musculus*).

- Prolonged attacks by these pests inevitably results in serious quantitative losses of stored products.
- To these losses must be added those arising from the decrease in quality of the foodstuffs, caused by the filth (excrement, secretions) rodents leave behind in the stored products.
- This contamination is as important from the marketing standpoint as it is for hygiene and health. Indeed, rodents are often the vectors of serious diseases (rabies, leptospirosis).

4. PREPARATION OF GRAINS FOR STORAGE

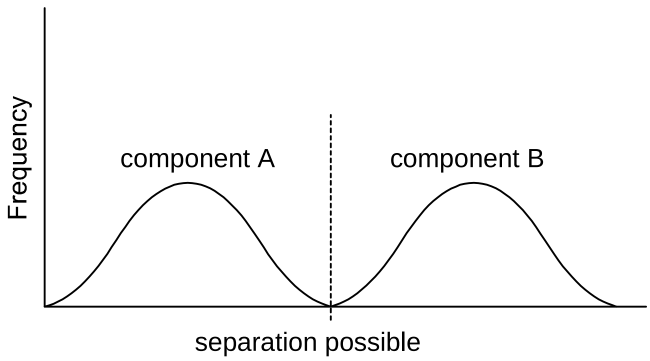
4.1. CLEANING

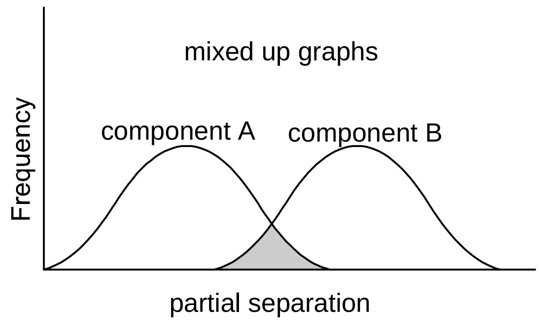
Harvested grain contains different types of foreign matters (vegetables, minerals, animal material, etc.). Foreign matters generally have higher moisture content than the grains. These impurities together with damaged and shrunken grains are called 'screening', 'dockage', or 'bestaz'. They must be removed before storing grains.

Impurities in the form of solid particles are separated from the fundamental grain by machine operation using the characteristics of impurities that differ from that of grain. Such properties are shape, size, sphericity, aerodynamic property, density, elastic property, friction property, magnetic property, electrostatic property, color, surface roughness, etc.

Density and size/shape are the most widely used characteristics for separating sound grains from dockage. If we construct a frequency distribution of the components present in the grain (including the grain) using a given characteristic, we can obtain any one of the graphs shown below. If the graphs are separate (component-wise) the grain can be separated by a given process based on that particular characteristic. If the graph mixes up, separation is only partial.

Stones and other particles that equal in sizes cannot by separated by screening for sizes. In such cases the density principle is used. Density difference helps separate heavy impurities. Some of the machines based on density difference are specific gravity table, stoner, etc.





4.1.1. SCREENING

Screening is the method of separating grain or seed into two or more fractions according to size/shape. Screening is most widely used for cleaning and separation. When the solid materials are dropped over a single screen, they are separated into two fractions. If the feed is passed through different sizes of sieves, it is separated into different fractions according to the opening (aperture) of the sieve.

Screen with air blast works satisfactorily for cleaning and sorting. Sieves are generally suspended in hangers and when the screen is oscillated by an eccentric unit they have a horizontal oscillating motion and at the same time a small vertical motion. These two motions cause the grain to attain downward motion whereby it is thoroughly stirred during the passage. The three main reason of giving motion to screen are:

1. Spreads material on the surface of sieve
2. Fine particles settle on the screen sub surface
3. Discharges oversized particles

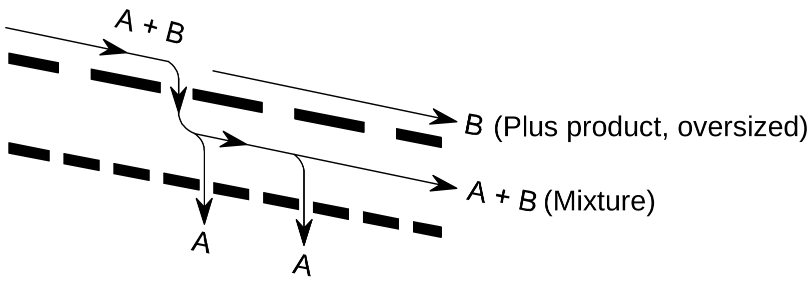
Shifters use cloth or synthetic threads while screens usually use metal wires. The unit for expressing the opening size of screen is usually '*millimeter*' while that of synthetic threads is '*number of holes per linear inch*'. 'Wire mesh' is the number of openings per linear inch counted from the center of any wire to exactly 1 inch distance. The opening can also be specified in millimeter.

Aperture is the minimum clear space between the edges of the opening screening surface. It is generally given in millimeter or inch. The opening area of a square mesh, *P* is given by:

$$P = (O^2 \times 100) / (O + D)^2 = (OM)^2 / 100$$

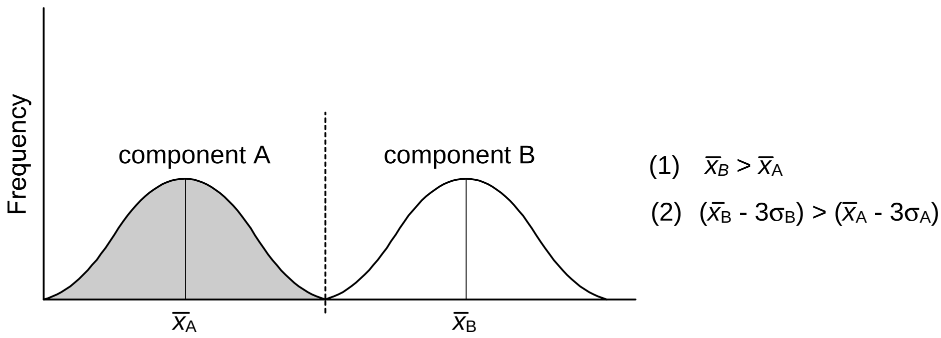
Where, P = opening area, %; D = wire diameter; M = mesh; O = aperture

Below is given the principle of separation based on size.

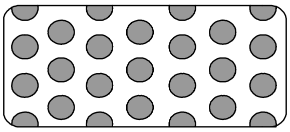


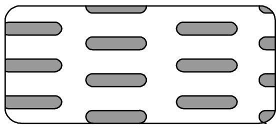
The condition of separation in screening is given by the figure in the following page.

The size and shape of perforation is chosen in relation to grain size and shape. Round hole perforation ≅ length of the grain. This arrangement removes large impurities. This system uses gyratory motion and is placed horizontal. Long slotted perforations are used to remove small seeds and small impurities. In this, separation occurs according to thickness (width) of the grain kernel. This system uses reciprocating motion and is placed inclined. The length of perforation ≅ length of grain. The diameter is variable.



Modern long-slotted systems have rexman motion. In this motion, gyratory as well as reciprocating motion is applied alternately (1 time gyratory followed next by reciprocating). The perforations are shown schematically in the following diagram.



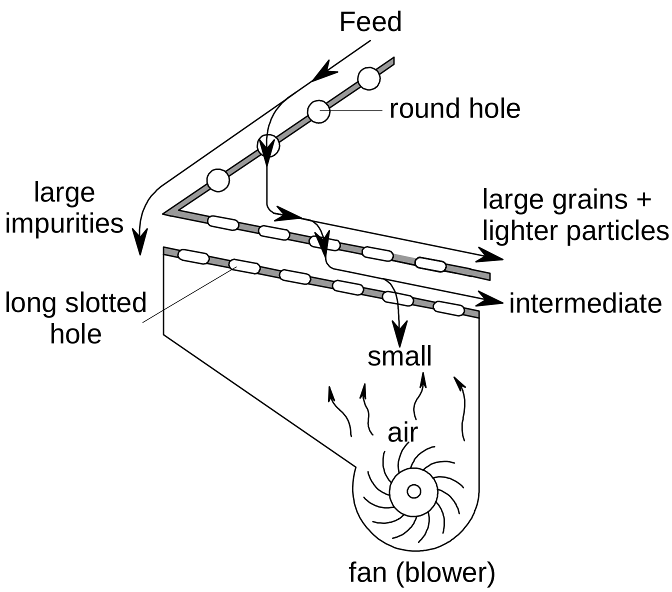


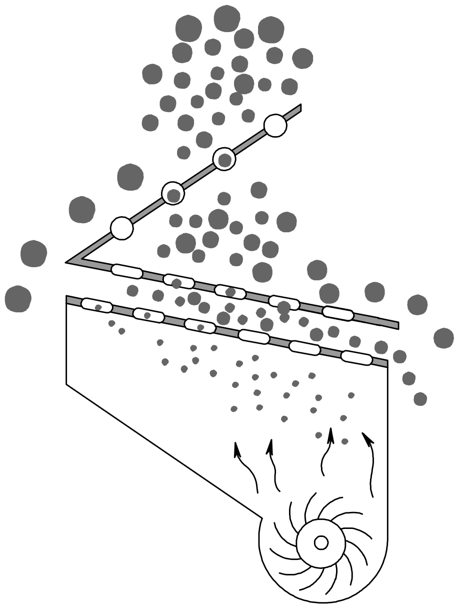
4.1.2. SEPARATION BASED ON DENSITY PRINCIPLE

PRINCIPLE

1. The characteristic of the grain → property to flow down in an inclined plane
2. Floatation of particles due to upward movement (countercurrent) of air
3. Heavy particles sink and contact the surface of screen. Light particles float and are free to move downwards.

The floatation approach is very widely used in grain cleaning. It is often used in conjunction with screens. The main part of the machine is triangle-shaped perforated desk. Motion of the table and the speed of the air must be controlled. See below the schematic diagram of separator based on density. A system that uses sieving as well floatation is shown below.



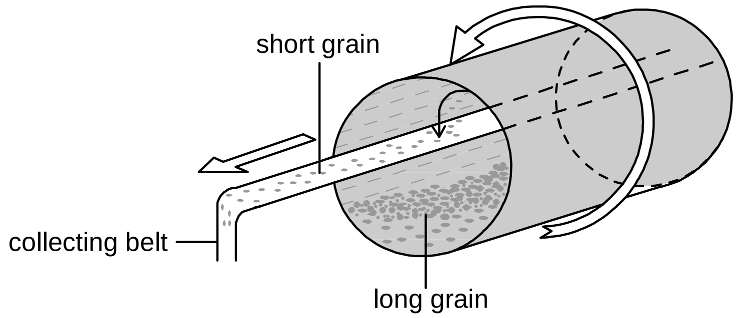


4.2. GRADING

Grading is an indispensable part of storage. It is generally done in trieur. Particles longer or shorter than the grain but similar in diameter can be separated from the grain by means of indented dish- or cylindrical trieur. The working part is indented (depressed).

Cylindrical trieur is used to separate brokens of rice. The cylinder rotates and impurities that are trapped in the indent are carried over a short distance before they fall off. Plump grains do not travel and instantly drop on to a screw conveyor or a belt, which slowly pushes them out. First, the grain is fed at the end of the cylindrical trieur. Short grains are picked up by the combined effect of fitting into the indent and centrifugal force. These grains are dropped in a separate adjustable trough in the cylinder near the top of the rotation. The indented surface is changeable to meet the requirement. The cylindrical trieur separates length-wise. Dish trieur separates thickness-wise.

The speed of operation and position of adjustable trough are very important. The machine is also called ‘cockle separator’. See the following figure for an idea.



4.2.1. GRAIN FLOW CHARACTERISTICS (FROM A HOPPER)

Two types of grain flow characteristics exist, viz., (i) mass flow, and (ii) funnel flow

4.2.1.1. MASS FLOW

If only sufficiently steep and surface coefficient of friction is less, then the flow channel expands from outlet outward along the wall of the hopper and bin and all the solids are in motion. It is characterized by entire mass movement towards the opening. Flow takes place in the wall and the central zone of the bin simultaneously. The material entered first comes out first. The advantages of this flow are:

- Less natural segregation
- Less internal friction
- Less crumbling

60-70% of grain drops out by mass flow, thereafter follows funnel flow. The disadvantage is that the lateral pressure is greater.

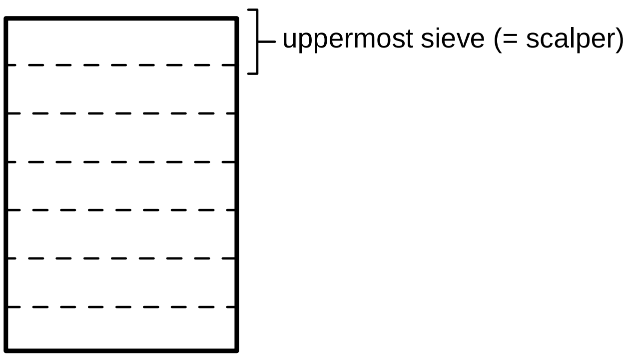
4.2.1.2. FUNNEL FLOW

Solid flows towards outlet in the form of canal or pipe which forms around the grain and grain surrounding. When hoppers are wide-angled and walls not smooth, first in first out does not occur. If the hopper is 30-40° it gives pipe flow.

The material entered first leaves last. The product in the dead zone may stay longer and pose high risk of deterioration. Funnel flow is used in coarse product.

4.2.2. ASPIRATORS

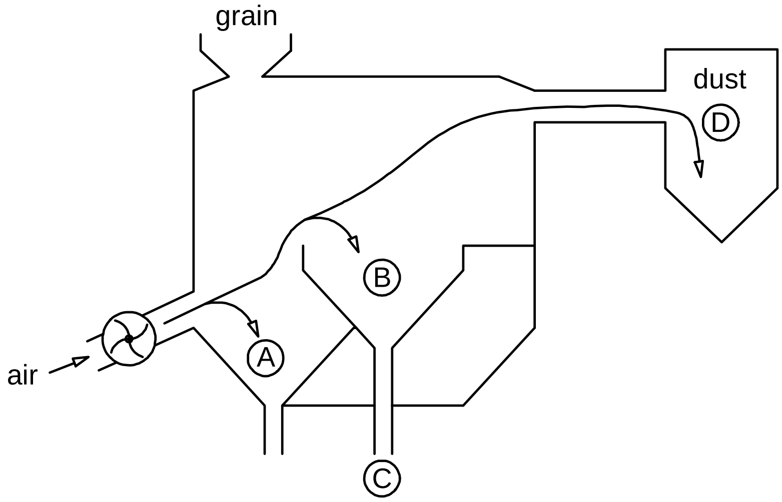
Aspirator is used to separate the lower density materials from grains in most cleaners and scalpers. Winnowing system also uses the principle of aspiration. Aspiration in a cleaner pulls or pushes air through the mass of moving grain. Sometimes, aspirator alone (without cleaner or scalpers) can also be used for special impurities, e.g., removal of husk from brown rice in mills. Arrangement of sieves in a typical aspirator is shown below.



4.2.3. REQUIREMENT IN AIR SEPARATION SYSTEM

1. Air flow system
2. Introduction of grain to air flow
3. Collection materials separately

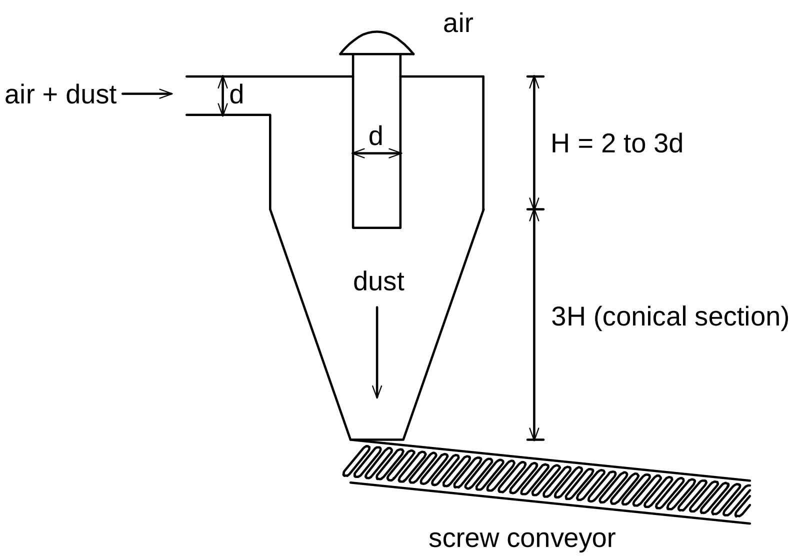
A schematic diagram of a very simple air separation system is given in the following figure.



Uncleaned paddy drops through the screen towards (A). At the same time air picks up the light particles and carries them to expansion area (B) where they are dropped through (C). Air movement carries the dust particles through (D). External fan or blower is used with this aspirator. Generally, aspirators are built as a part of grain cleaning system.

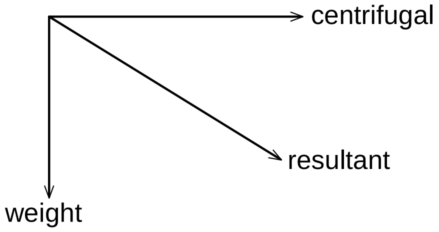
4.2.4. CYCLONE SEPARATOR

This is a device for collecting the end product in a process, commonly used for the collection of dust and waste of grain during processing. Dust as such cannot be let into air. Sometimes, cyclone separator is used to collect the light particles from air cleaner. It is also used in discharge of pneumatic conveyor to separate out air-borne materials. A schematic diagram of a cyclone separator is shown below.



4.2.4.1. OPERATION OF CYCLONE SEPARATOR

Air and materials both enter the cyclone tangentially at the top. Pressure drop occurs and air forms a vortex around the center. Whirling air being lighter gets collected at the center and comes out from the top of discharge. The heaviy particles accumulate at the bottom, which are later taken out by screw conveyor. Particles are subject to centrifugal as well as weight force as shown below.



The centrifugal and separation force are related to velocity, weight of materials and radius of rotation as follows:

$C_f = wv^2 / gR$

Where, C_f = centrifugal force; w = weight (kg); g = 9.81m/s^2; v = linear velocity; R = radius of rotation

Separation force, $F = w\sqrt{\frac{v^2}{g^2R^2}+1}$

Performance factor of cyclone = $S = C_f / w = v^2 / gR$

Separation becomes more effective as S increases.

4.2.5. ELEVATOR

Generally bucket elevators are used in the grain cleaning system. They are used to elevate a wide variety of granular (non-adhesive or light) materials. Very light, buoyant materials and those with poor flow characteristics cannot be used. Elevators are classified according to the method of discharge used, for example:

- Centrifugal discharge
- Positive discharge
- Direct discharge

An elevator that uses centrifugal discharge is shown in the following figure. Elevator capacity depends on many factors, e.g., speed, spacing of bucket, bucket size, etc. The speed for centrifugal discharge, C_f is given by:

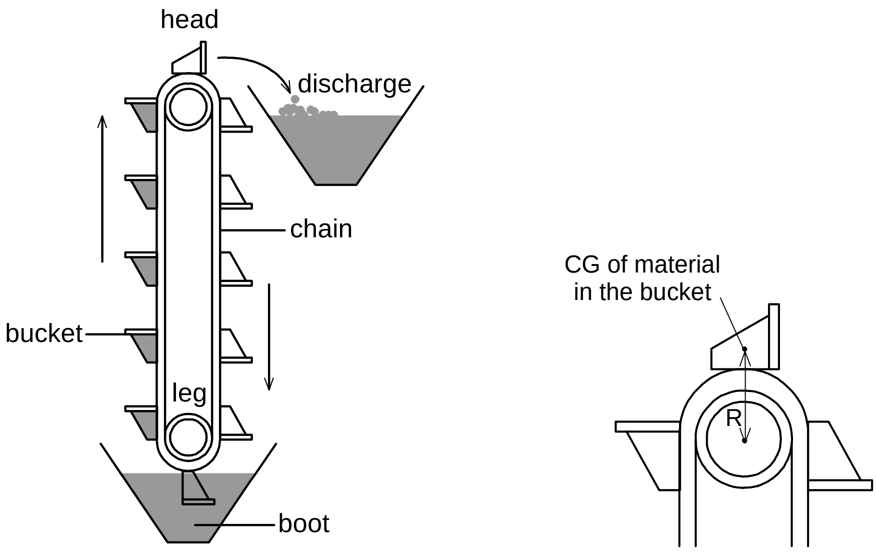
$$C_f = \frac{wv^2}{3600Rg}$$

Where, R = effective radius of center of rotation (radius of head wheel + distance to the C.G. of bucket); v = tangential velocity.

The elevator capacity Q is given by:

$$Q = \frac{\pi wDN}{S} \text{ lb/min}$$

Where, w = weight of material per bucket (lb); D = diameter of wheel drive; N = speed of drive wheel (rpm); S = bucket spacing.



5. DRYING

Drying and storage is a part of food production system. Post harvest losses can be reduced by proper threshing, cleaning, drying and storage of crops. A program to reduce drying and storage loss could probably result in 10-20% increase in food available in some developing countries.

The term ‘drying’ refers to removal of moisture to a safe moisture content and ‘dehydration’ refers to the removal of moisture until it is nearly bone dry.

"Grain drying" is the phase of the post-harvest system during which the product is rapidly dried until it reaches the safe-moisture level (~ 12-14%). The aim of this desiccation is to lower the moisture content in order to guarantee conditions favorable for storage or for further processing of the product.

Drying permits a reduction of losses during storage from causes such as:

- Premature and unseasonable germination of the grain;
- Development of molds;
- Proliferation of insects.

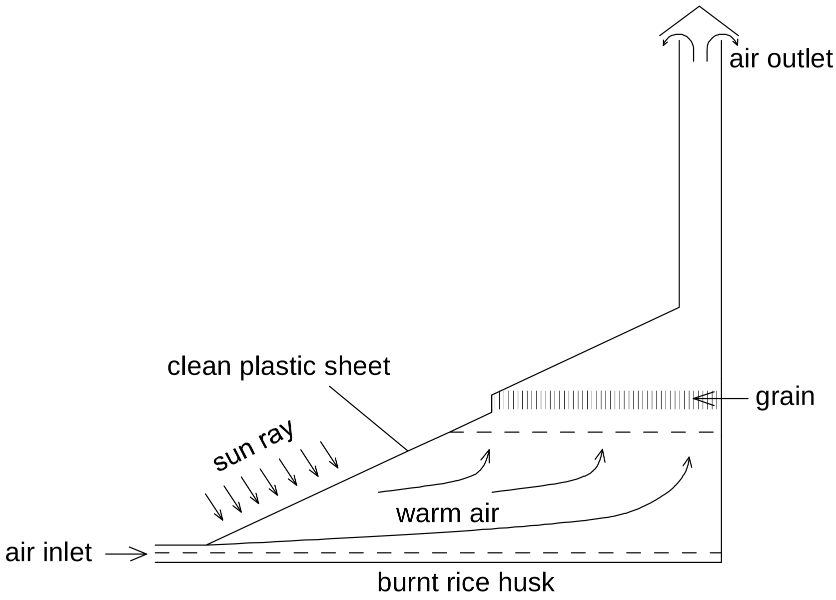
5.1. GRAIN DRYING METHODS

Grains can be dried by following methods:

1. Solar drying systems
2. Batch drying systems
3. Continuous drying systems

5.1.1. SOLAR DRYING SYSTEMS

This system is common in the tropical developing countries. The grains are usually spread on a flat surface directly in the sun. Solar energy drying is an elaboration of sun drying and is an efficient system of utilizing solar energy. Solar energy is collected by a flat plate collector for economical and efficient drying of grains. A typical solar grain drying system is shown below.



Solar dryers of tunnel design are also available. The temperature in such dryers can reach as high as 60℃. The burnt rice husk at the base acts both as an insulator and absorber. The air flow is either by natural convection or by electrical fans.

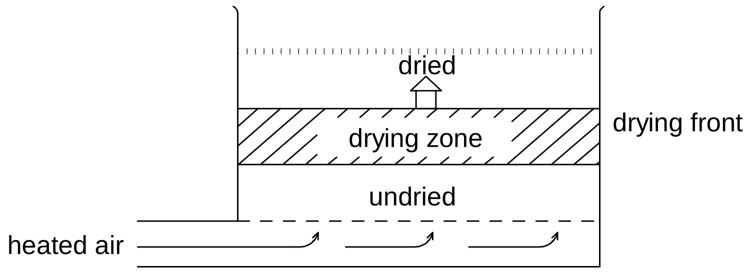
5.1.2. BATCH DRYING SYSTEMS

Common batch drying systems may be classified as:

1. Batch drying and storage system
2. Batch drying system

In batch drying and storage system the grains are dried in layers or in a full bin of grains and left in the same bin for storage. The drying periods are lengthy and may extend to several days or weeks. This system usually uses unheated air. Low temperature drying and low air flow rate are the special features of this type of drying. In batch drying system the batches of grains to be dried are introduced before starting of the drying cycle and none of its is discharged until the drying of the entire batch is complete.

All on-farm static dryers are designed on deep bed drying principles. In deep bed drying all the grains are not fully exposed to the same condition of the drying air. Grain and air conditions change with both time and position. The majority of the drying takes place in the volume called a drying zone which moves through the grain in the direction of the air flow and the volume of the drying zone varies with temperature and relative humidity of entering air. A typical schematic representation of a deep bed dryer is shown below.



Batch drying system

5.2.3. CONTINUOUS FLOW DRYING SYSTEMS

Continuous flow drying systems are characterized by the relative direction of grain and air movement through the drier. There are three basic types of continuous flow driers:

1. Cross flow dryer
2. Concurrent flow dryer, and
3. Counter flow dryer

5.2.3.1. CROSS FLOW DRYERS

In this type of dryer, air and grain travel at 90° to each other. The effect is that the layer adjacent to air inlet is soon dried and its temperature reaches quickly to that of the drying air. By contrast, the grain on the exhaust side of the dryer remains cool, never reaching the inlet temperature. As the grain is effectively over-dried on one side of the column and under-dried on the other, it must be mixed during discharge from the dryer to equalize moisture distribution throughout the sample. This type of dryer is inefficient in terms of energy consumption because at different stages of the drying process the grain is exposed to the inlet air temperature. Hence this temperature must be limited to that which does not damage its most sensitive moisture content. Furthermore, the discharge of warm air from some sections of the dryer causes inefficient use of energy.

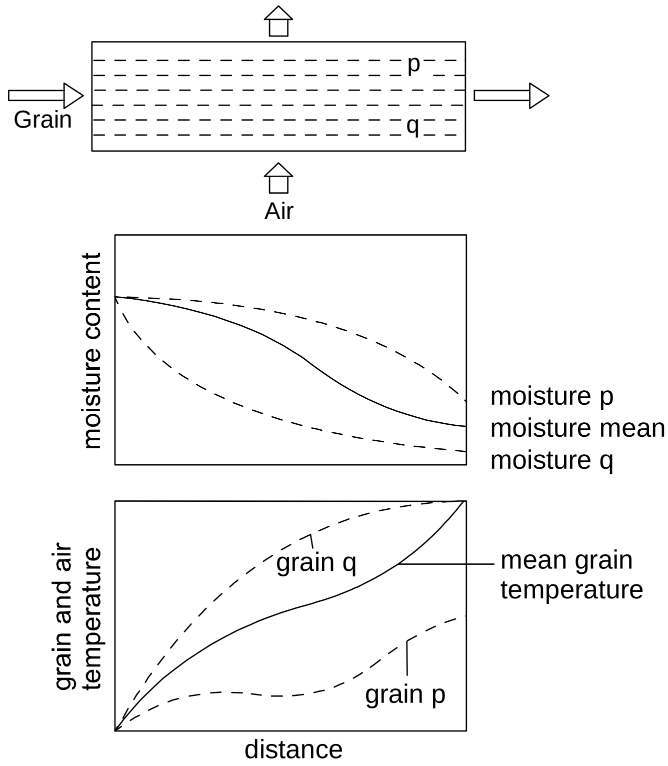


Fig. Moisture content and temperature changes in cross flow dryer

5.2.3.2. COUNTER FLOW DRYER

In this type of dryer the air travels in opposite direction to the grain. As a result the hottest air meets the driest grain at the inlet. As drying has virtually finished at this point, little latent heat is absorbed during evaporation of water as a result of which the temperature of the dry grain reaches the inlet air temperature. Thus, the inlet air temperature must not exceed the safe maximum grain temperature. As with concurrent flow type, all the grain seeds receive the same drying treatment during passage through the unit. Counter flow dryers can remove more moisture than either cross flow or concurrent flow dryers if the same depth and air flow rate are used.

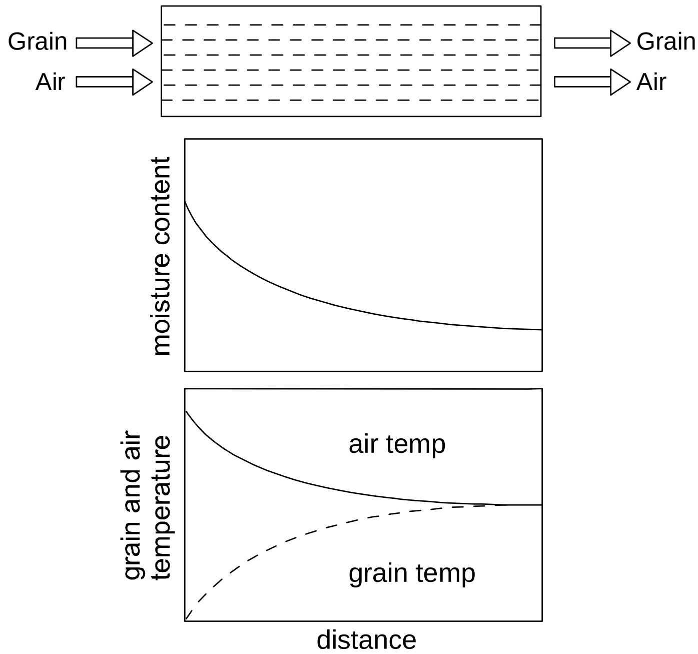


Fig. Moisture content and temperature changes in concurrent flow dryer

5.2. SAFE TEMPERATURE FOR GRAIN DRYING

High temperature dryer reduces the quantity of energy consumed, because the rate of moisture loss from grain increases with temperature and less air is required to maintain the same drying rate. However, excess drying rates or high temperature for drying may cause both physical and chemical damage to the product. The currently recommended maximum sage drying temperatures for various categories of grains are as follows:

Type of grain	Moisture content, %(w.b.)	Drying air temp (℃)
Malting barley	below 24	49
Seed grain	Above 24	43
Milling wheat	Below 25	66
Grain for stock	Above 25	60
Feed	Above 25	82-104

5.3. HYDRO-THERMAL STRESSES DURING DRYING

The change in moisture and temperature of grain continues simultaneously during drying and it results in reduction of moisture content and rise in temperature of the grain at the end of drying. The increase in temperature causes expansion resulting in tensile stresses in the grain and a decrease in moisture content causes shrinkage and develops compressive stresses in the grain. Thus, during drying grain seeds are subjected to complex hydrothermal stresses.

Cracks in grains develop by desorption (drying damage) and adsorption (wetting damage) of moisture on the surface. Desorption cracks are regular while adsorption cracks are straight. Adsorption cracks, also called fissures, are considered more serious than desorption cracks since visible damage from the latter sometimes disappears.

Fissures in grains are developed by (i) the grain surface re-adsorbing moisture from the environment, (ii) grain surface adsorbing moisture from the center of the kernel, and (ii) grain surface adsorbing moisture both fro the center of the kernel and the environment.

Grain seeds undergo simultaneous heat and mass transfer during drying. Because of differing thermal and physical properties, each part of the seed expands or shrinks differently. As a result of temperature and moisture gradients, stresses are induced within the seed. If the stresses exceed the kernel's strength, checks and cracks will develop.

---

6. GRAIN STORAGE SYSTEMS

Threshed grain is stored for following reasons:

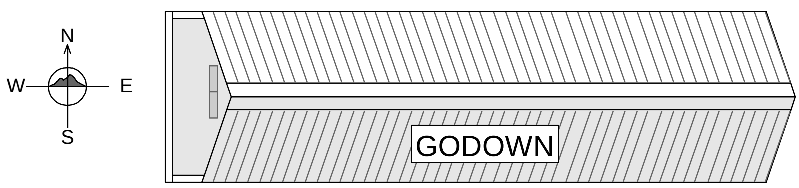
1. Maintain quality
2. Retain viability for planting
3. Maintain supply of grain (because of seasonal nature), buffer stock to advantage of higher price

Grains are stored by two methods, viz., (i) bag storage, and (ii) bulk storage

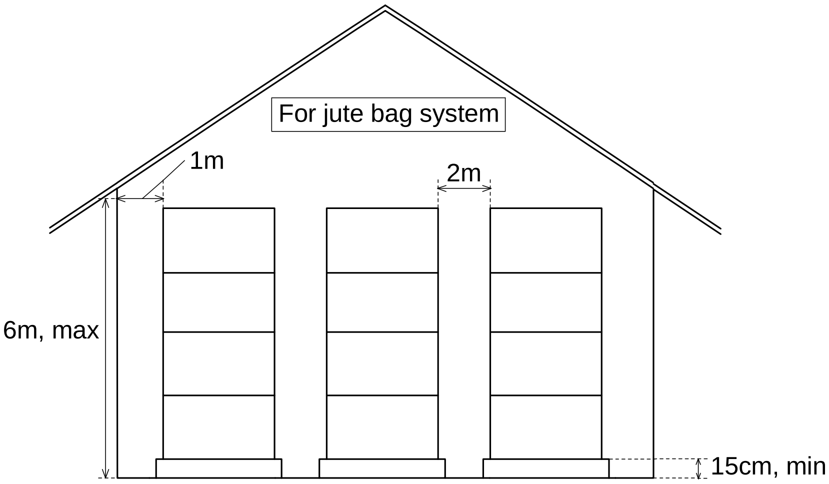
6.1. BAG STORAGE SYSTEM

Bag storage is a very primitive type of storage system. In Nepal most grains are stored in the rural areas (~ 70%) in bag storage. Bag storage system uses jute bags and polypropylene bags. The bags are cleaned, filled, sealed by stitching, and stacked over wooden pallets in godowns. The design of wooden pallet is shown below. Following points may be noted about bag storage:

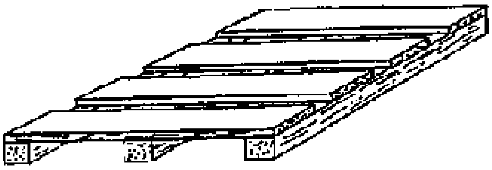
- The height of the wooden pallet should be 10-15cm. The space below the pallet is necessary for spontaneous aeration of the bags. The surface area of the supporting bars must not be less than 40% of the total surface of the pallet (otherwise the bottom bags will be damaged as a result of heavy pressure).
- Bags should be stacked in blocks, each of 6×9m dimensions. Each block is made of 6 bags lengthwise (or 10 bags breadthwise) amounting to a total of 256 bags. Each lot contains up to 6 blocks.
- The height of the block should not be greater than 6m in the case of robust gunny bags and 3m in the case of polypropylene bags. The weight per stack should not exceed 250 MT.
- The stacks should not touch the walls. A space of 2.5 to 3 ft is left between the wall and the stack. The space between the stacks is optimally 2m.
- The minimum space needed from the top of the roof is 1.5m. Any permanent ladder should not be used.
- There should be provision for rodent control, ventilation, etc.
- Trees should not be planted in the vicinity.
- Godowns for bag storage should be aligned along North-South axis so that the prolonged exposure to sun is received by the smallest area
- During storing, the stitched ends should point inwards the stacks
- The spacing between the bags at the bottom layer should be slightly more than the immediate upper layer so that the stack attains a stable, slightly conical structure
- Carry out 'first in first out' (FIFO)



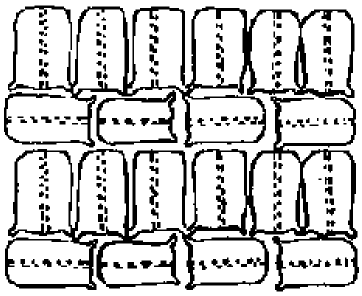
Godown layout (a)



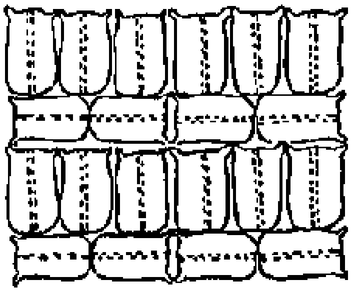
Godown layout (b)



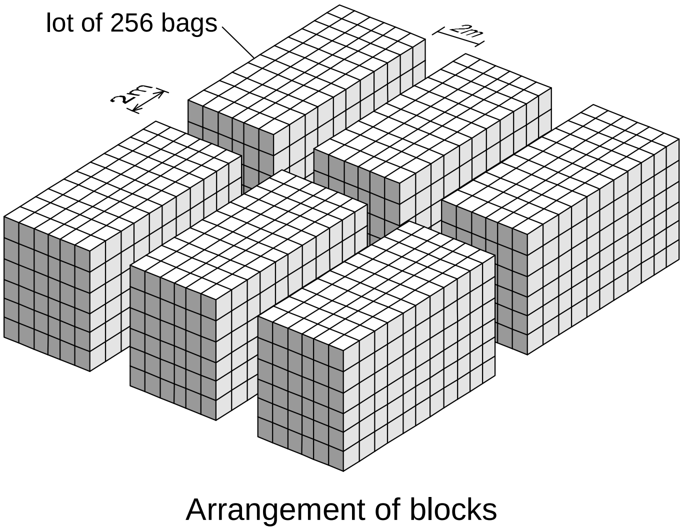
Wooden pallet



Right method



Wrong method



Arrangement of blocks

ADVANTAGES OF BAG STORAGE

- Flexible (can be transferred from one place to another)
- Low capital cost
- Suitable for small farm scale
- Suitable for transportation in bullock carts or by humans

LIMITATIONS

- Not fully mechanized
- Labor-intensive
- Excess spillage
- High rodent cost and operation cost
- High infestation and re-infestation problem
- Moisture absorption and migration

6.2. MODERN STORAGE SYSTEM

Modern storage system is classified on the basis of structure, operating principle, loading/unloading facilities, etc. Some of the systems based on operating principle are:

- Aerated storage system
- Damp grain storage with chemicals
- Low temperature storage system
- CA storage system

Modern bulk storage of grains is carried out in high capacity silos. They are complex structures intended for the commercial or industrial storage of large quantities (several thousand tones) of grains.

Specialized builders offer various types of silos; two, in particular:

- Vertical silos,
- Horizontal silos.

Vertical silos are made up of several sheet-metal or reinforced concrete storage bins stacked vertically. This category includes silos composed of: round bins made of flat or corrugated galvanized sheet metal; polygonal bins made of painted or galvanized metal panels; round bins made of reinforced concrete.

Horizontal silos are also made of sheet metal or concrete and are composed of juxtaposed square or rectangular bins laid horizontally.

The relatively common round metal bins require less investment and are easy to erect.

Polygonal bins are similar to round ones and their diameters are easily adjustable.

Round concrete bins guarantee good thermal insulation and permit much higher vertical stacking than can be obtained with metal bins.

Square or rectangular bins are generally flat-bottomed. They require a higher per quintal investment but make the best use of the available sites.

In order to avoid the disadvantages of a potential rise in temperature, and to guarantee good storage, storage bins are often equipped with ventilation systems backed up by temperature controls.

In terms of storage, these ventilation systems can have the following effects:

- To lower the temperature of the grain in order to slow down biochemical degradation processes (cooling ventilation);
- To keep the grain at a constant temperature, by systematically evacuating the heat produced by the grain mass itself (maintenance ventilation);

- To dry the grain slowly (drying ventilation).

In addition, again in order to guarantee good conservation of grain, special airtight silos store the products in the absence of oxygen, in a confined or controlled atmosphere.

In the first case, the oxygen inside the silo is consumed by the natural "breathing" of the grain, and the insects and micro-organisms, and is simultaneously replaced by the carbon dioxide produced by this breathing.

In the second case, once the airtight silo has been closed, the internal atmosphere is replaced by the injection of inert gasses (nitrogen, carbon dioxide).

Despite the obvious advantages of these storage systems, airtight silos still have limited distribution because of their technological complexity especially for the high-capacity bins.

6.2.1. VERTICAL STORAGE SYSTEM

The salient features are:

- Long time storage
- Quality maintained
- Large storage volume
- Low thermal conductivity
- Limited water condensation
- High initial cost

Steel bins are more popular than the concrete bins. The thickness of steel bin ~ 5-7cm and that of concrete bin ~ 15cm. Steel bins can accommodate 12% more than the concrete bins.

6.2.2. SILO SYSTEM

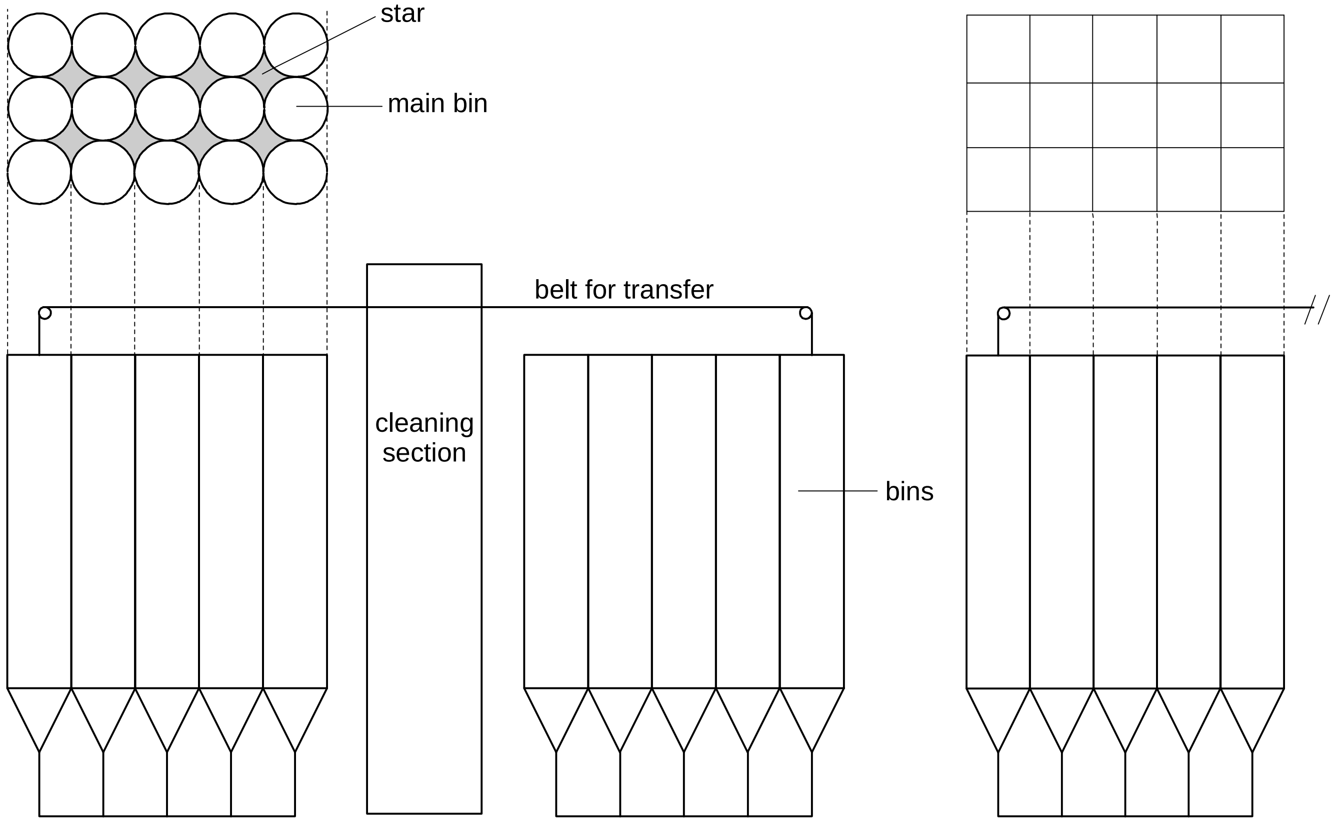
Silo storage is also called grain elevators. They are available in round type and square (star) type. The cleaning section is an integral part of silo system. Modern silo facilities include:

1. Silo tower workhouse section (cleaning section, etc.) and
2. Battery of bins (cylindrical or star bins)

Schematic diagrams of cylindrical and star bins are shown below. A small ‘star-like’ void space exists in the middle of every four adjacent cylindrical bins. This void space is also called ‘star bin’ and a small quantity of grain can be stored in this bin also. Typically, the height of a silo is about 30m and the diameter is 6m.

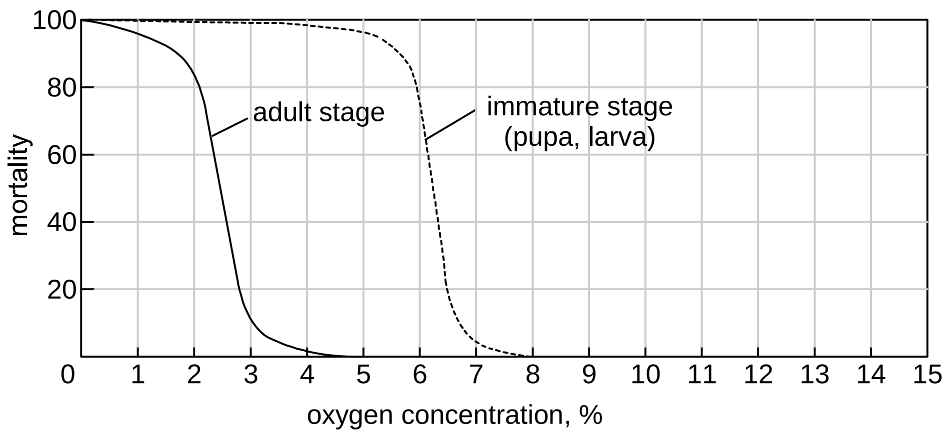
Modern bins are air-tight systems. However, completely air-tight storage is impossible in commercial scale. This is possible only on small scale. Normal level of O_2 is deflected (decreased) to control infestation by molds and insects. In this system, initially, aerobic respiration occurs due to porosity of grains (by microorganisms and grain itself). This results in the liberation of large amount of heat. The heat is used up by microorganisms again for growth and development. After some time, O_2 becomes deficient and the organisms utilize grains by anaerobic system (gives off alcoholic smell).

All the insects are killed at 2% O_2 level (by volume). Some fungi continue to grow under damp condition until O_2 level reaches 0.1%. Yeasts grow at up to 1% O_2 level.



Cylindrical bins   Star bins

For dry grains, the effect is less severe. The organisms show a different activity under this condition. Under sealed condition, most of O_2 is used by insect themselves and are killed subsequently. Removal of O_2 kills insects more than by accumulation of CO_2. At > 3% O_2 level, some adult weevil may exist but at < 2 % O_2 level, all insects are killed. Insects in immature stage are more susceptible to lack of O_2 (see the following graph).

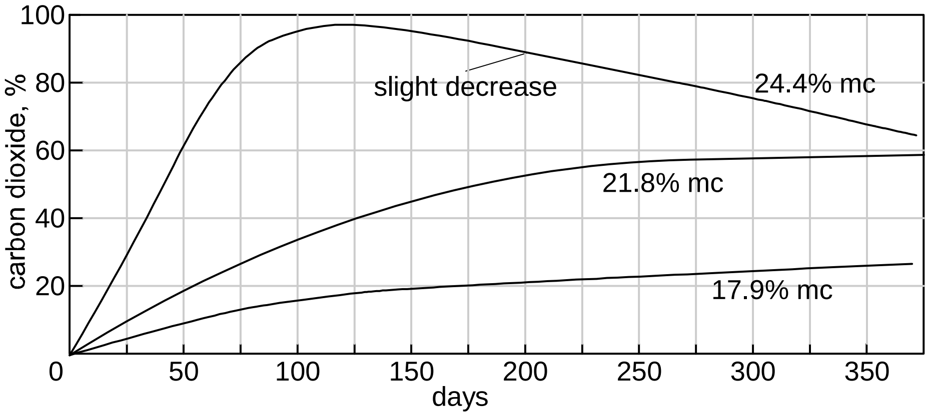


At 0.5% leak of O_2/hr, if the initial insect population is less (e.g., 27 insects per kg), not all insects are killed. Rather, they reach a 'suspended animation' stage. The activity resumes with the increase in O_2 level (due to leakage). But this activity again lowers the O_2 level and the insects return to suspended animation. The cycle repeats over and over without allowing insects to regenerate.

At heavy infestation, however, insects are eliminated at leakage rate of 0.5% O_2 per hour. For example, grain infested at the rate of 80 insects (*Sitophilus granarius*)/kg are eliminated after 10 days of air-tight storage. In tropical condition, infestation cannot be completely eliminated. Partial control is itself an achievement because it delays or prevents heavy infestation. It greatly reduces the damage to grain.

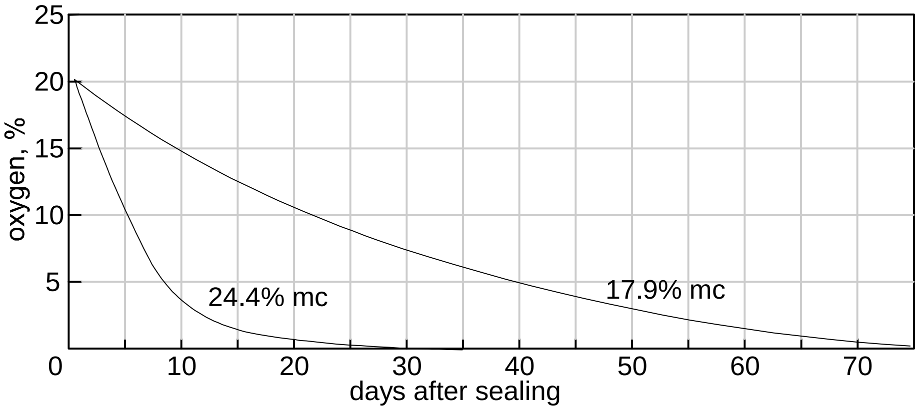
6.3. STORAGE OF FRESH (DAMP) GRAIN

The principle of damp grain storage is similar to that of dry grain storage. Microorganisms are mostly fungi that create the O_2-free condition. Molds use up O_2 for their own growth. Even in O_2-free condition, anaerobes (yeasts and bacteria) may grow. This results in fermentation. Alcohol and volatile substances are evolved. These substances impart sour-sweet or berry taint, which cannot be completely removed by drying or any other processes. Such grains are not suitable for human consumption. If moisture content is > 60%, O_2 is completely consumed by aerobes and anaerobes may take over. Anaerobes continue to grow even at 95% CO_2 level. The relationships of CO_2 content, moisture content and storage life of damp grains under sealed conditions are shown below.



Long term storage of damp grain (> 13% moisture content) under airtight condition is unsuitable for human consumption. It can only be used for feed purposes.

At moisture content > 22%, gluten in wheat is also affected. Germination capacity is affected and, sometimes, toxins are produced. Dry grain can be stored for a long time without attention in airtight storage. In warm regions, bins can be painted white so that less heat is absorbed.



Grain needs to be dried before storage. Sometimes, immediate drying is not possible. Drying is costlier than cooling or freezing in terms of electrical energy. Such damp grains can be stored by two major methods, viz., (i) storage by chemical treatment, and (ii) aerobic storage.

6.3.1. CHEMICAL TREATMENT OF DAMP GRAINS

This involves storage of damp grains after mixing with chemicals and /or natural compounds. These chemicals function as insecticides and fungicides. Some of the methods are described below:

6.3.1.1. STORAGE WITH ORGANIC ACIDS

Propionic acid, formic acid, acetic acid and other monocarboxylic organic acids have antimicrobial properties (rather than insecticidal). Propionic acid is most effective and widely used in damp grain storage system. It is used for barley, maize, oats, wheat, etc. Propionic acid has been found to affect rheological properties of dough. It affects the volume of loaf (loaf volume decreases). Propionic acid also affects gas retention power of gluten.

6.3.1.2. STORAGE WITH COMMON SALT

Addition of 1, 1.5, and 2% salt has been found to arrest growth of mold in damp grains for 70 days. There was no change in sensory quality of the product. Increased concentration of salt, however, gave a slightly salty taste (when salt > 2.5%).

6.3.1.3. STORAGE USING AMMONIA

NH_3 and NH_4 –salts are fungicidal and bactericidal. They are used in maize. Maize is sensitive to mycotoxin. The result, however, is controversial regarding the compatibility of NH_3 but it is known that microbial load is reduced.

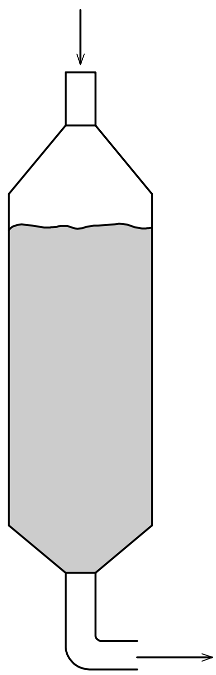
6.3.2. AERATED STORAGE OF DAMP GRAINS

Grain lots of different moisture contents sometimes need to be stored in aerated system. The air is moved through the stored grain for maintaining uniform moisture content and temperature. This aeration system limits the activity of fungi on any damper area and reduces the rate of auto deterioration of the grain.

The moisture content can be maintained at near-safe moisture content. The arrangement prevents moisture migration and accumulation from warm to cold layer. Aeration removes moisture and cools the grain. When air is drawn out from the grain surface, spontaneous cooling will occur. The aeration rate is typically 0.02 to 0.104m^3 / min / tone of grain. This can pass through grain depth of as much as 46m.

Energy consumption depends on quantity, depth, and type of grain for a given air flow. Air is removed from downward through the grain. This avoids the problem of condensation. Suction or exhaust system is used for drawing out air. Exhaust air which has been heated during the passage is exhausted thereby avoiding the possibility of condensation on cold surface of the grain.

Convection current caused by temperature changes are overcome by pulling the air downwards (see figure below).



6.4. CONTROLLED ATMOSPHERE STORAGE

This system is used in Australia. CO_2, N_2 or combination is used to control insects. The technique involves the alteration of normal atmospheric gases to give artificial environment. This storage system prevents growth of molds and insects. There are two types of controlled atmosphere storage system commonly used for storage of grains, viz., (i) externally by using CO_2, and (ii) Using nitrogen.

6.4.1. CA BY EXTERNALLY USING CO_2

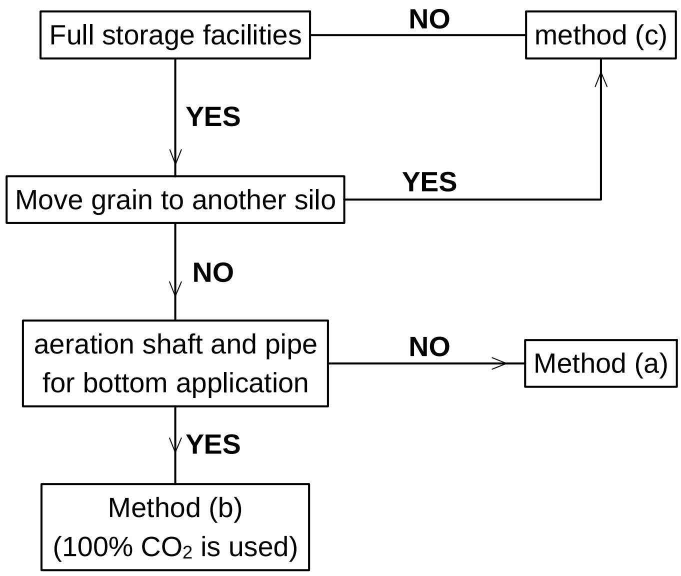
This is suitable for wheat, rough rice (paddy), maize, sorghum, etc. It is carried out in upright silos or steel bins. CO_2 is applied by 3 methods, viz., (a) purging of full silo from above, (b) lifting the gas out, and (c) mixing CO_2 in grain stream during transportation to silos.

(a) PURGING: CO_2 is introduced into the headspace above the surface of grain and forced down through the grain by positive pressure. CO_2 mixes with and displaces portion of existing atmosphere and creates a modified atmosphere lethal to any insect present.

(b) LIFTING THE GAS OUT (= PURGING FROM BOTTOM): The air from intergranular space is drawn and air and CO_2 is let in from the bottom.

(c) MIXING CO_2 DURING TRANSPORTATION: Semi-solid CO_2 (= CO_2 snow) is fed in the grain stream while it is transported to the silo.

The method to be applied depends on the storage facilities and this has been shown below schematically.



Decision tree for the choice of storage system

6.4.2. CA WITH NITROGEN GAS

This is applied in large scale in gas-tight bins, mainly for maize, barley and wheat. Long term preservation in N_2 is advantageous at all temperatures (30-31℃) and moisture levels (19-20%). Nitrogen is used in liquid stage delivered by tankers. Nitrogenous atmosphere prolongs storage periods (without fumigation, etc.). The effect of nitrogen on shelled grains, however, is slower compared to that of CO_2 (4 days compared to 8 days).

For example, if the initial and final targets of atmosphere are > 70% and > 35% CO_2 respectively, the grain requires 10 days exposure at 20℃. If the initial and final targets of atmosphere are > 99% and > 99% (same) nitrogen, the grain requires an exposure of 6 weeks exposure at 20℃ for the same effect as CO_2.

Both nitrogen and CO_2 have merit in residue-free insect control program.

The basic considerations for nitrogen storage are (i) tightness of storage structure, and (ii) availability of gas and cost.

6.5. REFRIGERATED STORAGE OF GRAINS

Aeration with refrigerated air achieves much lower temperatures when ambient conditions are warm. It is an expensive method of disinfestation compared to fumigation, but can be justified for storage of grains such as malting barley and seed grains in hot conditions, where maintenance of germination viability is important. Technically, the requirements are the same as for ambient aeration, except that no fan control is required since the system will operate 100% of the time until the temperature front has passed through the grain mass.

An evaporative cooling system is also used to reduce air temperature and to remove moisture. It is useful to place the fan between the cooling unit and the store, so that heat from the fan can be used to raise the air temperature by a few degrees, thus reducing its relative humidity and minimizing risk of grain wetting.

By recirculating the cooling air, it is possible to maintain a sealed storage system. In this way the grain may first be fumigated to render it insect-free, and then cooled to preserve quality, with the fumigant still present.

6.6. USE OF NATURAL INSECTICIDES

There are several plants or plant parts that are traditionally or semi-commercially used against storage insects and microorganisms. *Neem*, *bojho*, *titepati*, *timur* (all vernacular names) are some of the plants used by rural people for the protection of grain during storage.

Neem seed powder is used at the rate of 1g/100g paddy, wheat and pulses to protect grain from store pests for 6-10 months. *Bojho* and other wood ashes are used at the rate of 2g/kg grain. *Timur* powder can be used at the rate of 1-5g/kg grain. *Titepati* can be used against insect pests.

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7. INTEGRATED PEST MANAGEMENT

Current global losses in crop production due to pests are of the order of US$ 300 billion annually. The estimated annual cost of pesticides used in agriculture is US$ 20 billion. The costs of pesticides to developing countries are a major drain on foreign exchange at the national level, as well as requiring a significant outlay by farmers at the village level. The estimated expenditure by international development agencies on pest control projects in 1988 was at least US$ 150 million.

Integrated pest management (IPM) is the strategy widely recommended, although less widely used, for the reduction of pest damage through the careful integration of a number of available pest control techniques.

IPM is not a new concept, but has its root in the 1950's. FAO defines IPM as "a pest management system that, in the context of associated environment and the population of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains pest populations at levels below those causing economic injury. It is not simply the juxtaposition or superimposition of two control techniques but the integration of all suitable management techniques with the natural regulating and limiting elements of the environment".

IPM implies the improved use of chemical inputs, natural environment controls and cultivation practices, including traditional controls which farmers have developed through trial and error, often over centuries. IPM is based on the principle that each control method used will influence the potential role of other methods, with pesticides and other chemicals envisaged as last-resort tactics. This integrated approach, giving priority to natural mechanisms while adopting chemical pesticides for strategic interventions, has been the subject of world-wide scientific research and field testing for more than 20 years.

The driving forces behind the development of IPM can be summarized as:

- Population increase
- Low production of food
- Problem of pesticide residues
- Food security problem
- Environmental and ecological degradation by chemical pesticides
- Resistance of pests to pesticides

Integrated pest management is found mostly to refer to preharvest phase at the farm level. In terms of post harvest phase, particularly the storage, IPM may be defined as the acceptable use of practicable measures to minimize, cost-effectively the losses caused by pests in a particular management system. In this context, cost-effectiveness requires that all costs and benefits, including sociological and environmental effects, should have been taken into account.

7.1. PHASES OF IPM

IPM has been divided into 5 phases, viz., (i) subsistence phase, (ii) exploitation phase, (iii) crisis phase, (iv) disaster phase, and (vi) integrated control phase.

(1) SUBSISTENCE PHASE

This refers to cultivation of crop as a normal practice, without use of protection inputs like chemical pesticides. The produce is locally consumed. The yield depends solely on the natural protection of crop from pest enemies. The pests are naturally controlled to the tolerable level.

(2) EXPLOITATION PHASE

This refers to development of protection programs due to increased demand of crops. New plants, new protection methods, etc., are used. Growers adopt synthetic pesticides and intensive practices to protect the crop and maximize yield.

(3) CRISIS PHASE

This is due to increased population, increased immune power of insects and loss of land fertility. The increased yield is not sufficient to keep up with the demand and this leads to increased cost of production and protection.

(4) DISASTER PHASE

The crisis is climaxed. Cost of production increases (including cost of protection). Input in agriculture does not get return. This is the collapse of present pest control program.

(5) INTEGRATED CONTROL PHASE

This refers to integration of different pest control programs. Optimal control (not maximal) is exercised. This phase has to be carried out before entering the latter two phases, viz., crisis phase and disaster phase.

7.2. BIOLOGICAL ECOSYSTEM CONCEPT

Scientific approaches to grain storage pest management, having regard to grain storage as a part of the food production and distribution management system, have sometimes referred to the *biological ecosystem concept* as a means of comprehending grain storage processes and problems.

In grain storage, as with other durable agricultural products, it is good commodity management and good store management which are the major prerequisites. The various options for more intensive insect pest control, listed in the tables that follow, include several which are themselves based upon traditional concepts of pest management. Thermal disinfestation, cooling and hermetic storage are examples. These latter two methods are also examples of the opportunities, provided by the process of storage, to manage the generally enclosed storage environment in such a way that insect pests are prevented from multiplying or, as in efficient hermetic storage, effectively eliminated. Preharvest problems of insect pest control are rarely, if ever, so easily managed!

Control of the storage environment is thus an essential element in grain storage pest management. It involves, primarily, the controls on in-store climate and infestation-pressure which can be achieved by technically sound store design and construction. Equally important, however, is the climatic control attainable by scientific management of the commodity to ensure that the stored grain is itself both dry and cool when loaded or, in ventilated stores and bins with aeration equipment, that the storage procedure achieves drying and cooling sufficiently rapidly. In a fully loaded store it is the stored grain itself which largely determines and stabilizes the temperature and humidity conditions in the store.

Commodity management can also control, to a considerable extent, the initial insect infestation level in the stored grain. However, in tropical countries, where preharvest infestation by storage insects is hardly ever completely preventable, the ideal of loading insect-free grain into the store is not often attainable. Special facilities to completely disinfest the grain before loading may not prove cost-effective. The common alternatives, if early disinfestation is required, are to treat the grain, at intake, with a suitable admixed insecticide or to disinfest the loaded grain by in-store fumigation.

The prerequisites and options for both on-farm and main-depot storage pest management involves use of basic IPM and additional measures.

The basic IPM (essential) consists of:

(i) Site and store management (protection from birds, rodents and weather plus basic hygiene), and
(ii) Commodity management (cleaning, drying, etc.)

The additional measures consist of:

(i) Maintenance of conditions for natural control, and
(ii) Disinfestation

The need for an interdisciplinary approach in the integrated pest management of stored products is generally well-known. Entomology, mycology, chemistry, engineering and food science are commonly involved, but effective integration of technical solutions is often lacking; possibly because some of the more pragmatic disciplines, notably economics, sociology and business management, are not always sufficiently involved. It is the interface between the research team and the storage managers, whether these be individual farmers or a large storage organization, which may sometimes be the most crucial barrier to progress.

7.3. MODERN BIOLOGICAL METHODS

Conventional biological control techniques for possible application in stored-grain pest control include control by the use of predators, parasites, insect diseases and sterile males, the use of pheromones for pest monitoring, mating disruption or enhanced mass trapping, and the use of resistant crop varieties. There are published reports of the successful practical application of a number of these techniques, notably in the USA, but the area of most interest for application in tropical countries is the use of crop varieties with resistance to storage insects as well as preharvest pests. It should be noted that control by the use of a resistant variety will generally retard the increase of infestation and grain damage, thereby prolonging the period in which damage remains relatively low, while control by predators or parasites can be expected to suppress the pest population and the consequent grain damage but is unlikely to restrict insect numbers or grain damage to a low level.

7.4. ECONOMIC CONTROL THRESHOLDS (ECT)

Modern theories of pest management have also generated the concept of economic control thresholds (ECTs). An ECT is most simply defined as the level of pest damage which justifies, in cost/benefit terms, the expenditure of resources upon control actions (Hebblethwaite, 1985). It is always a variable threshold because the costs and benefits of any action will depend upon the situation and its circumstances. An ECT is situationspecific. For insect control in grain storage the ECT is likely to be at or very close to zero if the demand for infestation-free grains is very high. The ECT may be well above zero if the grain is stored for domestic use or for eventual sale in an uncritical market (because the true economic significance of a low % of insect damage may be virtually nil and the actual loss in real food value may be negligible).

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8. SAMPLING OF GRAINS DELIVERED IN BAGS

For a given batch of grains, the number of bags from which samples must be taken depends on the total number of bags, as shown in the following table:

Composition of batch	Bags sampled
1 to 10 bags	All bags
10 to 100 bags	10 bags chosen at random
More than 100 bags	The square root of the total number of bags

After the bags are selected, there are two ways of making up the global sample: by probing or by emptying the bags.

8.1. SAMPLING BY PROBING

The primary samples are taken directly by introducing hollow probes into the selected bags (bag probes, probing rods, etc.). The samples should be of about 50 g per 100-kg bag and, in any case, sufficient for composition of a global sample of at least 500 g; after they are taken, the samples must be carefully mixed together.

8.2. SAMPLING BY EMPTYING THE BAGS

The contents of each bag are stirred and spread in a layer 10 cm thick on a clean surface; a primary sample of about 1 kg is taken from each layer of grain; the various primary samples are then carefully mixed together to obtain the global sample.

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9. CHEMICAL CONTROL TECHNIQUES

9.1. GENERAL CONSIDERATIONS

The chemical compounds, including both fumigants and contact insecticides, which are approved by FAD/WHO for use on food grains to control storage insects, are regularly reviewed. In general, the contact insecticides that are approved for use are compounds of relatively low mammalian toxicity, which are considered to be non-hazardous when applied at prescribed dilution rates for the purposes indicated. They are also relatively safer to handle than many of the pesticides quite commonly approved and widely used for preharvest pest control.

It should be noted, there is no acceptable residue for the insecticide DDT, which remains available in many developing countries but is no longer recommended for use in stored-grain pest control. Lindane, which is still of some use, is given a very low residue limit (0.5 ppm). This serves to preclude or discourage application to grains for export to countries which object to its use. It should also be noted that the limits for fumigant residues broadly represent the maximum levels that should be expected if fumigation treatments are properly done. This applies also to residues of inorganic bromide and these have recently been declared of no toxicological concern by the U.S.A's Environmental Protection Agency and by the British Government.

Current usages for stored-grains pesticides, including fumigants and contact insecticides, constraints on their use and the ways in which chemical pest control may be integrated into storage systems are subjects which have received much attention.

9.2. TREATMENT OF GRAIN BY FUMIGATION

Fumigation is a treatment that rids stored grain of insects by means of a poisonous gas called a fumigant. This substance, produced and concentrated as a gas, is lethal for specific living species.

Fumigants are toxic gases used to disinfest a commodity in an enclosure which, ideally, is completely gaslight. Fumigation enclosures should certainly be sufficiently gastight for the gas to penetrate and remain in the commodity for long enough to kill all stages of the insects present in or amongst the grains. Unlike contact powders, the fumigant penetrates to the interior of the grain mass and reaches the largely invisible incipient forms (eggs, larvae) developing there.

The purpose of a fumigation is thus to obtain a more-or-less immediate disinfestation of the commodity and the space enclosing it. Its main disadvantages are that the treatment confers no residual protection against reinfestation, once the commodity is again exposed, and the fact that the most effective fumigants are all highly toxic to humans and other non-target organisms. The precautions required to ensure the safe use of fumigants are, necessarily, much more stringent than those required to ensure the safe use of most other insecticides.

Phosphine and methyl bromide are the most widely used approved fumigants. Fumigants such carbon tetrachloride and ethylene dibromide are no longer approved for use on stored grain due to restrictions placed upon their use in some countries (recently identified chronic user hazards).

It should be noted that both phosphine and methyl bromide are currently regarded as gases with potential negative impact on the atmospheric environment. Constraints on their use are likely to increase and requirements for careful, responsible use, with more regular monitoring of application rates, are likely to be more strictly enforced. A comparison of phosphine and methyl bromide is shown in the table (next page).

The desirable properties of a grain fumigant, notably efficient penetration of the commodity, toxicity to target insects and lack of harmful residues, make it unlikely that new chemical compounds will become available as fumigants. Carbon dioxide can be used as a conventional fumigant but low toxicity to insects and the consequent high degree of gas-tightness necessary for effective insect control makes it unlikely that this gas will find widespread use except in controlled atmosphere (CA) storage systems.

Phosphine, because of its availability in solid formulations of metal phosphides which are relatively easy to apply, compared with the pressurized gas fumigant methyl bromide, has become the most popular and widely used fumigant in most tropical countries. Methyl bromide, which is in some ways more versatile, retains its place as the fumigant of choice wherever circumstances do not easily accommodate the protracted fumigation period, of several days duration, that is required for the effective use of phosphine.

Table: Phosphine and methyl bromide as fumigants: advantages (highlighted) and disadvantages.

Phosphine	Methyl bromide
Easy to transport	Refillable cylinders are expensive to transport
Easy to apply	Difficult to apply, requiring special equipment and skill
Good penetration and distribution	Distribution rather poor
Taint, residues and loss of viability in treated seeds are generally negligible	Sorption occurs and may cause taint, bromide residues and loss of viability in treated seeds
Slow acting, particularly at low temperatures and humidities	Rapidly toxic and widely effective even at lower temperatures
Flammable: spontaneously explosive ignition can occur in some circumstances	Non-flammable
High acute mammalian toxicity but low chronic toxicity	Dangerous acute and chronic poison with delayed symptoms
Fairly easy to detect	Very easy to detect
Rapidly lost by leakage unless fumigation space is well sealed and gas tight soon after application	Needs very good seeing before application

For grain stored in bags, the usual method is to cover the bags with a tarpaulin whose edges are sealed to the ground or the walls. The effectiveness of fumigation depends, on the one hand, on the actual concentration of the gas and, on the other, on the length of time during which the grain is fumigated.

Depending on whether methyl bromide or phosphine is used, the duration of fumigation should be 24 to 48 hours for methyl bromide, or a minimum of five days for phosphine. The latter product is more commonly used, since its application, in the form of pellets spread throughout the grain mass, is the simpler.

It is essential to recognize, however, that fumigants are very poisonous to people and therefore the staff that is to use them must be carefully trained in their application. For all these treatments, it is important to scrupulously observe the recommended protective and safety measures (masks, gloves, hand-washing, hermetic sealing of phosphine containers, etc.).

Furthermore, remember that these treatments are curative, and have no persistence over time: therefore, a combination of the techniques of contact insecticide and fumigation is recommended.

9.3. THE USE OF CONTACT INSECTICIDES

Some of the currently acceptable compounds, and recommended rates for their application as dust formulations admixed with cereals or as liquid surface treatments, are given in Table below.

Table: Recommended insecticide application rates.

Insecticide	Dust admixture with cereals (ppm)	Surface treatments (g/m²)	
		Walls	Bags
Malathion	8-12	1-2	1-2
Pirimiphos methyl	4-10	0.5	0.5
Fenitrothion	4-12	0.5	0.5-1
Dichlorvos	2-20	0.5	
Methacrifos	5-15	0.2	0.4*
Lindane	0.5		
Phenothrin	5		
Permethrin	0.05-0.1	0.05-0.1	
Carbaryl	5-10	1-2	

9.3.1. GRAIN ADMIXTURE TREATMENTS

Admixture treatments depend upon reasonably uniform application of a suitable contact insecticide at an acceptable dosage level. These insecticides are commonly applied as dusts (dusting powders) on grain. Such formulations are generally recommended for small-scale treatments. Liquid formulations can also be used, if suitable application equipment is available, and these are generally preferred for large-scale treatments.

The advantages of insecticide admixture treatments are that they are generally inexpensive and a single application of an effective insecticide, correctly formulated, will give control of existing insect infestation (including, eventually, any insect stages within the kernels) and will protect the grain against reinfestation for a substantial period. The duration of protection varies considerably between different insecticides and, more importantly, between different climatic conditions.

Disadvantages of admixture treatments include the effect of admixed powders upon the bulk density of the grain and the risk of over-wetting (by spray rigs).

9.3.2. INSECTICIDE DEPOSITS ON BULK GRAIN SURFACES AND BAGSTACKS

Spraying the surface of a bulk of uninfested grain, in a bin or in flat bulk storage, can give quite good protection against reinfestation for a limited period, depending on the persistence of the insecticide used. The decay of insecticidal effectiveness on exposed surfaces is generally faster than in a bulk treated by admixture and re-spraying at intervals of more than 1-2 weeks is likely to allow a limited build-up of infestation which, once established in grain below the surface, will be largely unaffected by retreatment. In practice, control of warehouse moths is often quite well achieved but control of beetle pests is generally less effective.

An alternative treatment, for the same purposes, would be the use of a dusting powder applied to the surface and raked-in to a depth of 10-20cm. Insecticidal sprays and dusting powders applied as surface treatments to protect fumigated bagstacks against reinfestation are also of limited effectiveness.

9.3.3. INSECTICIDE DEPOSITS ON THE FABRIC OF GRAIN STORES

The notional contribution made by fabric treatments to the sustained control of insect infestation in warehouses has rarely, if ever, been confirmed in practice. On the other hand, it is considered likely that they do contribute substantially to the build-up of insect resistance to pesticides.

Recent trials in grain storage warehouses in Java (Hodges et al., 1992) found no substantially significant differences in the resurgence of pest populations, following the fumigation of all bagstacks and an initial spray treatment of the warehouse fabric using fenitrothion at $1g/m^2$, between warehouses with routine, monthly respraying of walls, or walls and floors, and those with no respraying treatment.

The practical value of these treatments may be considerable when they are used as a supplement to physical cleaning, in an unloaded store, to kill insects which may remain on the fabric of the store even after reasonably thorough sweeping. Repetitive use, as an alternative to more effective measures to control infestation in the stored grain, are of little value and may, conversely, have negative effects in the long term by accelerating the development of resistance to the insecticides used.

9.3.4. SPACE TREATMENTS

This term is used to describe insecticidal treatments, by aerosols or vapors, intended to kill insects exposed to the treatment in the free space of a store or other enclosure to which the treatment is applied. They are thus quite distinct from true fumigations and cannot be expected to disinfest commodities within the enclosure.

Space treatments, to be effective, require reasonably good sealing of the enclosure which should certainly be made wind-tight. Complete gas-tightness is not essential.

Most of the insecticidal formulations that have been employed for space treatments leave a small residual deposit upon exposed surfaces and may have a slight persistent insecticidal effect. However, this is generally negligible unless the treatments are applied repetitively and frequently. Space treatments achieve most effect through their direct impact on insects in flight or trapped on exposed surfaces during the treatment. In general, and probably for this reason, they appear to be most effective against warehouse moths and some other insects (such as the beetle *L. serricorne*) that spend little or no time concealed within a commodity bulk or bagstack. For maximum effect, even against these more susceptible species, space treatments should be applied regularly and frequently: preferably daily at dusk when insects are generally most active in flight.

Aerosols containing pyrethrins, with or without a synergist, applied as thermal 'fogs' or mist-sprays ('cold fogs') were previously the treatment of choice in stored-grain pest control but cheaper alternatives are now more often used. Various synthetic contact insecticides can be used in aerosol formulations and one compound, dichlorvos, can be used effectively as a vapor treatment (McFarlane, 1970; Ashman et a/., 1974) in those countries where its use is approved.

10. INFESTATION DETECTION AND MONITORING

The inspection of stored grain and storage facilities becomes necessary for the following reasons:

1. To detect the presence or absence of insects and to determine suitability of grain for export purposes, milling, etc.
2. To detect insects as they may affect grade and price.
3. To determine the suitability of grain for further storage.
4. Whether control measures will have to be implemented to secure its end usefulness for human consumption.
5. If control measures have been applied previously, whether their implementation was successful or whether further controls are required.

A number of methods are available for the detection of infestation. The easiest method relies on the visual examination. This is a subjective method and applies to storage facilities as well as the grains. When the infestation is heavy the job can be easy. For light infestation, several visual techniques have been developed:

Following methods are rewarding:

10.1. QUALITATIVE INSPECTION

(I) AGITATION OF BAGS

This is effective for low population densities of *Sitophilus granaries*, *S. oryzae* and *S. zeamais* which will often walk out of sacks after they have been sufficiently disturbed. A long stick maybe drawn over surfaces of vertical stacks or they can be hit to activate small numbers of adult moths which are therefore more readily observed.

(II) THE FEEL OF GRAIN IN BULK

Walking across the surface of bulk grain with bare feet may prove an excellent guide to its general condition. If it feels cool and free flowing chances are there is no cause for immediate concern. However, if a hotspot exists, this can be exemplified by solid caked patches indicative of high dust content and moisture migration with subsequent rises in temperature.

(II) TRAPS

Various traps have been designed to exploit the activities of many species of insects. Tube traps, consisting of a smooth inner surface and rough external surface (approximately 7.5 cm long x 2.5 cm diameter) can be inserted into bags to catch species such as *Tribolium castaneum* which are unable to escape by climbing the smooth inner surfaces. It is a useful cumulative trap, but is not effective in trapping *Sitophilus* sp. or *Oryzaephilus surinamensis* (plus others) and may become ineffective where the webbing activity of moth larvae is apparent.

Various forms of home-made, fly paper-type, sticky traps are commonly used to give an indication of the presence of flying insect pests at an early stage of infestation. Attractant traps, such as light traps (incandescent, fluorescent or black light) as well as suction traps, can be helpful in large warehouses where suitable power is available to give reliable early indications of the presence of moths and beetles that fly readily. Traps that employ a sex attractant or pheromone as a lure offer a potential approach, not only for estimating the degree of infestation but also as a control measure.

(IV) ARTIFICIAL CREVICES

Sections of corrugated cardboard (4 cm wide x 20 cm long) can be placed between bags to attract pupating moth larvae. It can be examined after 24 hours for insects, but it is more applicable if the bulk is only lightly infested in which case examination may be done after 4 to 5 weeks.

Plank traps, consisting of two strips of wood 15 cm wide and 60 cm long, hinged together but held 3 to 4 mm apart, is useful for *Trogoderma granarium* larvae and *Tribolium castaneum* adults. These are inserted in bags and left for several days before withdrawal and examination.

(V) DEAD INSECTS

When residual protectants have been applied as a surface treatment and dead insects continue to accumulate, the conclusion might be reached that the treatment has been fully effective. Usually it indicates a source of live insects in the area, or from infested bags, some of which may be obscured within the stack. If these insects are removed and the location marked for future reference, any further accumulation of dead insects indicates the need for further action.

(VI) REPELLENTS

Insecticidal formulations that possess a strong repellency action such as pyrethrin or synergized pyrethroids, can be particularly useful in exposing hidden insects in cracks and crevices. A light application will often stimulate insects to crawl onto exposed surfaces before they finally succumb to the insecticide.

(VII) GRAIN TEMPERATURE AND MOISTURE CONTENT:

As mentioned earlier, it is often more rewarding to investigate for the signs of insect presence rather than looking for live insects. Localized rise in grain temperature or moisture within a bagged stack or grain bulk are most important indicators of insect activity.

Knowledge of insect pests and the physical behavior and properties of stored grain should be used to help the inspector. Most storage insects are inconspicuous and secretive, and as a consequence are difficult to find. Nearly all storage insects are more easily found in dark premises because they are more active in the dark than in the light. They also lay eggs more readily in the dark.

The proportion of insects at or near the surface of produce varies with the insect species and the produce concerned. This is related to the size of the insect and its developmental instars and to the grain size of the product. Packing of stacks, diurnal rhythms, a tendency to stay near boundaries when brought to them by random movement, upward movement stimulated by disturbance, and outward movement stimulated by heating-all tend to bring insects near the surface of bagged stacks where the inspector has some chance of finding them.

Some of the reactions of insects to stimuli also help the inspector. Most prefer the dark; some are thigmotactic and collect in cracks between bags or under rubbish; most seek out wetter spots and many drink; yet others react to temperature gradients. Therefore, the inspector should examine dark places, the conical tufts of sprouting grain under leaks in the roof, the wet surfaces of bags and areas of produce known or thought to be wetter than the rest, and the tops of stacks especially those under metals roofs if *Trogoderma* is likely to be present."

10.2. QUANTITATIVE SAMPLING INSPECTIONS

The aim of drawing random samples of the commodity is to determine the mean value and the variability of the level of infestation or contamination (% discolored kernels) in any given situation. Some sampling methods are given below:

(I) SEQUEL SAMPLING

Involves collecting a number of spear samples from several bags (dependent on the total number of bags in the consignment, the number of which should not be less than the square root of the total number) until a 1 kg sample is obtained, and examined for insects by sieving. Resampling occurs if low numbers are found and may involve a further three consecutive sampling occasions consisting of 3, 9 or 22 kilograms.

(II) SPEAR SAMPLING

There are many inherent problems with such a classification and could therefore be open to a variety of interpretations.

- Different insects preferentially attack different commodities and consequently inflict greater damage (i.e., pest status is variable)
- When insects are present in low numbers and are unevenly distributed, sampling spears are likely to give an inadequate assessment of the infestation, either grossly over or underestimated.
- The sampling size required to give an accurate assessment of the infestation using sampling spears is often laborious or time-consuming if the consignment is 10 bags then not less than 10 bags should be sampled at random: (1000 bags require 32 bags to be sampled).
- The sample taken is rarely a random sample, due to the difficulty of sampling from the central portion of the stack.
- Samples taken from individual bags are rarely a random sample or truly representative of the condition within the bag. At least six more samples should be removed from each bag to make up the primary sample, a practice that is rarely adhered to (approximately 1 kg sample).
- Sampling spears damage sacking and consequently create potential for more spillage.

Insects do not distribute themselves randomly or uniformly in any container of grain. They are most often found in pockets associated with dust, broken grain, and foreign materials towards the bottom or in areas of localized heating or wetting. It is very difficult to sample with a grain trieur or spear close to the peripheral margins of the bags, especially at the top and bottom. Therefore, a large population crawling on the bottom could be completely missed. Alternatively, small pockets of insects within the bulk maybe, by chance, included in a spear sample. For example, 6 *Sitophilus oryzae* in a 500 g sample is not equivalent to 1200 individuals in a 100 kg. bag because of non-uniform distribution, and in fact the bag may contain less than 10 individuals altogether.

(III) BAG SNAKING:

A number of bags maybe emptied by pulling the open bag backwards over the floor surface, allowing a small stream of grain to flow out gradually. Most visible insects will be concentrated in the latter portion and will be readily observed at the sides of the band.

(IV) CONING AND QUARTERING

It is a simple and cheap method of obtaining highly representative samples (approximately only 10% sampling error and therefore more accurate than spear samples) but suffers from time and capacity constraints. The procedure involves tipping bags into the floor forming a cone, constantly mixing materials from the periphery to the apex of the cone, then spreading it evenly and dividing into 1/4, 1/8, 1/16, etc. subsamples depending on the volume required.

(VI) SIEVING

"Hand held sieves" are particularly useful in assessing the dust content and live insects from small samples. Different-sized mesh openings can be used for different particle size, or a combination of appropriate sizes can be used for mixed commodities varying in particle size.

"Sack sieves" have also been developed to sample an entire sack; the time taken can be between 5-15 minutes. The recovery of insects is dependent on insect species, time of sieving, slope of the oscillating sieve mesh and mesh size, but tests have shown better than 90% recovery of insects and is independent of population density.

For greater accuracy and representation, it is advantageous to take larger primary samples and then take subsamples to form a suitable working sample. Various methods (such as coning and quartering mentioned earlier) can be employed, or by using specific apparatus designed for the purpose. These consist of the gravity mechanical types such as the Boerner conical divider, a simplified alternate channel box divider or the motorized centrifugal types such as the Gamet divider. Simplified dividing trays are also available.

10.3. DETECTING HIDDEN INFESTATIONS

Most of the damage and weight loss caused by insects on grain are inflicted by the primary grain feeders. They are capable of penetrating sound whole kernels of grain and their life cycle is completed entirely within the kernel in which the egg is laid or entered by the first instar larva.

The absence of any live adults of storage insects in grain samples separated by the previous methods, does not necessarily mean the absence of an infestation and consequently many methods have been devised to identify individual kernels that have become the home of the immature stages of the major insect pests.

Concentration of infested grains in a sample in any detection method is greatly enhanced if the infested material can be adequately separated from sound grain and hence reduce the number of grains and the amount of dust and broken kernels that have to be examined. It becomes desirable to concentrate the insect-damaged kernels as a preliminary step. For this purpose, flotation in an air stream or liquid maybe employed.

10.3.1. CONCENTRATION TECHNIQUES

(I) FLOTATION SEPARATION IN LIQUIDS

The feeding activity of insect larvae progressively reduces the density of the grain, and by immersing the grain sample in a liquid of suitable specific gravity, the infested grains should float and the sound ones sink. At specific gravities between 1.050 and 1.190, the floating layer contains only infested kernels and approximately 50 to 70% of all infested kernels were separated (White, 1956). Absolute separation is therefore unlikely, but the presence of hidden infestations can be estimated quite accurately; while a general indication of the severity of infestation (the degree) will also be obtained.

(II) FLOTATION SEPARATION IN THE AIR

A vertical column with a fan which produced a stream of air sufficient to float the grain sample was used by Milner (1953). By progressively increasing the intensity of blowing, it was noted that virtually all insect-damaged kernels were removed in the first two fractions, from which no emergence had occurred. The detection of insect-damaged grain (i.e. those containing exit holes) can then be a relatively quick and efficient operation, and may speed up the exit-hole inspection procedure in commercial samples by a factor of ten or better.

(III) PROJECTION SEPARATION IN AIR

By projecting the grains of a sample through the air at an initially constant velocity, they should separate according to their relative density (Bailey, 1975). Air drag and gravity then further separate the grain according to kernel size, shape and the surface texture which also determine the bulk density or test weight of any particular grain example. Infested kernels tend to fall short of sound kernels of the same size and shape.

This separation has enormous practical implication. Wheat that has been designated as heavily infested can be separated into different bins reclaiming as much as 50% of the grain for food purposes rather than condemning the entire consignment for feed purposes.

10.4. METHODS AVAILABLE FOR DETECTION OF HIDDEN INFESTATION

10.4.1. PHYSICAL METHODS

(I) ACOUSTIC DETECTION

This method provides an immediate answer if active immature forms are present, and has an advantage of not destroying the sample. A microphone, low-noise amplifier, and loud speaker or a cathode ray oscilloscope display tube are required, and to limit extraneous laboratory background interference, the sample and microphone needs to be insulated or alternatively, the grain can be directly linked to a piezo-electric crystal.

Vibrations are noted at several characteristic frequencies, e.g., 200 cycles/s are associated with movement and dispersal, while frequencies round 1200-1500 cycles/s are associated with feeding.

This method is potentially valuable for detection of insect activity within silos and other storage facilities, and possibly transport vehicles, provided extraneous noises can be successfully eliminated. The system can be modified for adequate sensitivity under field conditions.

Other limitations of acoustic detection are that quiescent stages (pupae) and eggs cannot be identified.

(II) GRAIN RADIOGRAPHY

This method is appropriate for detecting hidden insects at most stages of development and has been developed and used extensively under commercial applications in the United States.

An automated X-ray system inspects grain on kernel-to-kernel basis. The procedure uses fine-grain "mammography" film that gives a contrast of about 75%, after only 2.5 minutes exposure. The film is examined by low-power binocular microscope (6x to 30x) with transmitted light. It has an efficiency of close to 100% with fully grown larvae and pupae and 80 to 90% with early instar and eggs.

The disadvantage of X-ray method is that it does not distinguish between live and dead insects. Another disadvantage is that it is very expensive.

(III) NUCLEAR MAGNETIC RESONANCE

The application is similar to the X-ray technique but suffers from the same limitations of time constraints, sampling efficiency and relative cost.

(IV) CARBON DIOXIDE EVOLUTION

This method gives an accurate measurement of the total metabolic rate of the grain, and therefore cannot be specifically applied to insects. The method requires enclosing a quantity of grain in a gas tight bottle at 35℃ for 24 hours, then drawing a s ample of intergranular air and analyzing it for percent CO_2 evolved. Dry uninfested grain normally shows < 0.25% CO_2. CO_2 levels between 0.3 and 0.5% suggest a light insect infestation (or a moisture content > 15%), and if the CO_2 evolution is > 0.5% in 24 hours, the grain is definitely unsuitable for storage without any further treatment.

A further development requires the detection of respired CO_2 by infrared absorption spectroscopy which is extremely sensitive, and is applicable to all stages except possibly the egg. The procedure requires a chamber containing the grain sample to be purged with a carrier gas, and then sealed during which time the CO_2 evolved by insect activity reaches a concentration sufficient for detection. This takes approximately one minute and is followed by flushing with a carrier gas for 2 minutes, and moves into the infrared detector by a pusle-flow movement. It is capable of picking up slight increases in CO_2 above the natural atmospheric background concentration of 300 ppm.

Other sophisticated detection systems that may find future application in the grains industry involve infrared radiation detection such as Far infrared (FIR) imaging, photoacoustic spectroscopy and thermal imaging with a pyroelectric vidicon.

All these detection systems are based on the principle that all physical bodies with a temperature greater than absolute zero have an infrared radiation spectrum which is a function of the body's absolute temperature and that living metabolizing tissues (such as insects) generally have a higher temperature than its surrounding environment, thus giving off different radiation characteristics.

(V) BREEDING OUT

Grain suspected of being infested maybe incubated thus allowing insects to complete their life cycle. The biggest disadvantage is the time factor since even under the optimum conditions of temperature and moisture content (26-30℃; 14-16% m oisture content.), at least 4-6 weeks will be required to breed out the full population of grain weevils and even longer incubation periods will be required for many other storage species.

(VI) VISUAL EXAMINATION OF EXIT HOLES IS

It has been standardized by the FDA of the United States that > 3 holes per 100 grains was cause for rejection. An experienced observer can also detect the presence of mature, late instar larvae and pupae of weevils in grain by changes in color transmitted through the seed coat. This only indicates the presence of an advanced infestation, but neither the degree nor the severity of the infestation.

(VII) GRAIN DISSECTION

This will reveal any internal infestation, and gives a valuable indication of the stage of development of an infestation relevant for any impending control method. It is best done under a binocular microscope, and dissected with a sharp scalpel after the grains have been pre-softened by soaking for 2 hours.

(VIII) CRACKING FLOTATION

This technique has long been employed to determine the internal insect content of grains. Insect fragments are released after coarse grinding of the sample. Concentration of insect material is achieved from an alcoholic solution by flotation-separation with the addition of mineral solvents. This enables microscopic examination and identification, and provides objective data on the number of insects present as well as an indication about the stages of development within the test sample.

The technique is complicated and laborious, requires the facilities of a grain test laboratory and sufficient skill and experience on the part of the technicians.

(IX) ELECTRICAL CAPACITANCE AND RESISTANCE METHODS

These methods have been investigated by Wirtz and Shellenberger (1962) where changes in both these properties occur when insects are present within the grain.

Additionally, temperature testing as mentioned earlier is of extreme value in detecting the presence of insects, as well as the effectiveness of applied control measures (i.e. fumigation) as indicated by a gradual decline in grain temperature compared to the ambient.

10.4.2. CHEMICAL METHODS

(I) ALKALI TREATMENT

This method is often referred to as the sodium hydroxide gelatinization procedure which depends on rendering the seed coat and endosperm translucent so that the more advanced stages of immature insects become visible. Tests by Keppel and Harris (1953) have shown that it has too many constraints to be adaptable as a quick and efficient method, although its reliability is unquestionable.

(II) EGG PLUG STAINING

A soluble fluorescent dye (berberine sulphate) is used to stain the gelatinous plug secreted by female *Sitophilus* spp. to cover the egg cavity in the grain. Grains are soaked in a dilute solution of 20 ppm followed by rinsing and examining the kernels under ultra-violet light for the greenish-yellow plugs. The degree of internal infestation can be then estimated by the number of egg plugs observed. This method is not particularly accurate; it is time-consuming, gives no indication on the stage of insect development and is only useful for weevil infestation.

(III) URIC ACID TEST

Measurement of the uric acid content of infested grain will give an indication of the past insect infestations which may have been concealed during processing. The method was found too insensitive to detect present infestations, and was only useful when population densities were high, in which case they were visibly obvious anyway.

(IV) INSECT PHENOLS

A test based on spectrophotometric analysis for the concentration of a hydroxyphenol occuring in insect cuticle, which produces phenolidophenol dyes when chemically treated with 2, 6-dichloroquinone chlorimide was proposed. Bailey (1975) stated that the method showed particular merit based on Food and Drug Administration evaluations, but at that stage required more work to perfect the method.

(V) ULTRA-VIOLET LIGHT ILLUMINATION

Ashman (1986) stated that insects or insect fragments when present in finely ground commodities will appear red when stained in crystal violet and illuminated with ultra-violet light. Similar to the uric acid test, it provides useful information of any previous insect infestations in the grain before processing.

(VI) NINHYDRIN SYSTEM

In practice, the grain and any internal insects are crushed between filter paper which has been impregnated with a 0.7% solution of ninhydrin in acetone. If the grains are infested, the amino acids contained in the body fluids of live insects are absorbed by the paper and chemically react with ninhydrin to produce a strong purple coloration. Machines are available with a sample flow rate of 300 kernels per minute. Spot paper is previously heated to approximately 120℃. The test paper can be kept as a visual record and retained for more than two years. Unreacted treated paper loses some of its sensitivity with aging, resulting in a slight color intensity reduction if the paper is used several months after treatment.

Moisture content above 16% moisture content will give a faint general reaction, especially if contaminated by storage molds. Other forms of interference listed were 1) kernels damaged by cracking or checking; 2) kernels damaged externally by insect feeding or mechanical injury; 3) previously infested kernels where adult emergence has been completed; 4) kernels containing dead insects; 5) sooty or heat-damaged kernels; 6) kernels with a high free fatty acidity (FFA) value. These interfering reactions tend to produce distinct, sharply outlined spots.

10.5. RECORDING OF RESULTS

Accurate and complete records give essential background information especially when compiled over a period of time. A standardized inspection record sheet should be used so that information is recorded in a systematic and comprehensive manner for convenient analyses. (Appendix lll).

Some of the points that need to be considered in compiling a report are:

- Weather conditions have an important influence on the development of a pest infestation and are less variable in tropical climates where temperature and relative humidity (which are functions of the EMC) approach the optimum requirement of many major insect pests.
- The structures used for storage of produce have an important effect on produce quality and subsequent build-up of populations. Accurate information of these structures, their condition, and potential sources for cross-infestation should be noted.
- The type of produce, its variety and grade, and observations on insect damage will often prove valuable.
- Origin, destination and length in storage of commodities inspected have an important effect on future implementation of control and,

- Previous applied control measures should foe documented as an assessment to their efficiency.
- A plan of the storage layout (bagged stacks and their dimensions) will also prove useful.

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11. ADVANCED CONTROL TECHNIQUES

The conventional insect control techniques involve physical methods (cleaning, drying, grading, good warehousing, etc) and chemical methods (e.g., fumigation, etc.).

New techniques have now evolved, some of which are still under study. Some of the noted new techniques are (i) sterility technique (genetic control), (ii) attractants, and (iii) repellents.

11.1. STERILITY TECHNIQUES

There are two sterility control techniques, viz., (i) addition of sterile insect into storage, and (ii) sterilization of insects inside the storage

11.1.1. ADDITION OF STERILE INSECT

This theory asserts that introduction of fully sterile competitive organism into a natural population in proportion to fertile insects in general show exponential growth under the stable condition of environment. Release of sterile male in the ratio 9:1 of the wild population ultimately brings the population down to nil in the 4th generation.

11.1.2. STERILIZATION OF INSECTS IN THE STORAGE

There are several techniques of achieving sterility in insects, the important groups of which are (a) radiation, and (b) chemical sterilization.

11.1.2.1. STERILIZATION BY RADIATION

Sterilization by radiation affects oogonia of female insects and they fail to produce egg. The inability of male to mate generates unfertile eggs. It is debatable whether the effect is due to female or male. Radiation may cause sperm inactivation. Dose of radiation is determined carefully, especially for polygamous species because mating with male with inactive sperm will be negated if it mates again with a fertile male.

11.1.2.1.1. PRESENT STATUS OF IRRADIATION (RADIATION STERILITY)

γ-rays, X-rays (less used), α-rays and neutron particles can be used for bringing about sterilization of insects. These can produce lethal mutation to the gametes but does not affect the maturity of germ cell or their participation in the fertilization to form zygote. However, they prevent zygote from developing into matured organisms.

γ-rays help in disinfection as well as mutation in reproduction. Body fluid is ionized by 3-5kGy (kilo gray) of γ-ray and will kill the insect. The source of γ-rays is usually cobalt-60. For reproduction sterility, 0.12-0.2 kGy is used for Lepidopterans and Coleopterans. Some mites are also killed at this does. Dose up to 0.3kGy does not affect the grain germ and can be used for human consumption. The time of radiation is very short of the order of 0.06s or less.

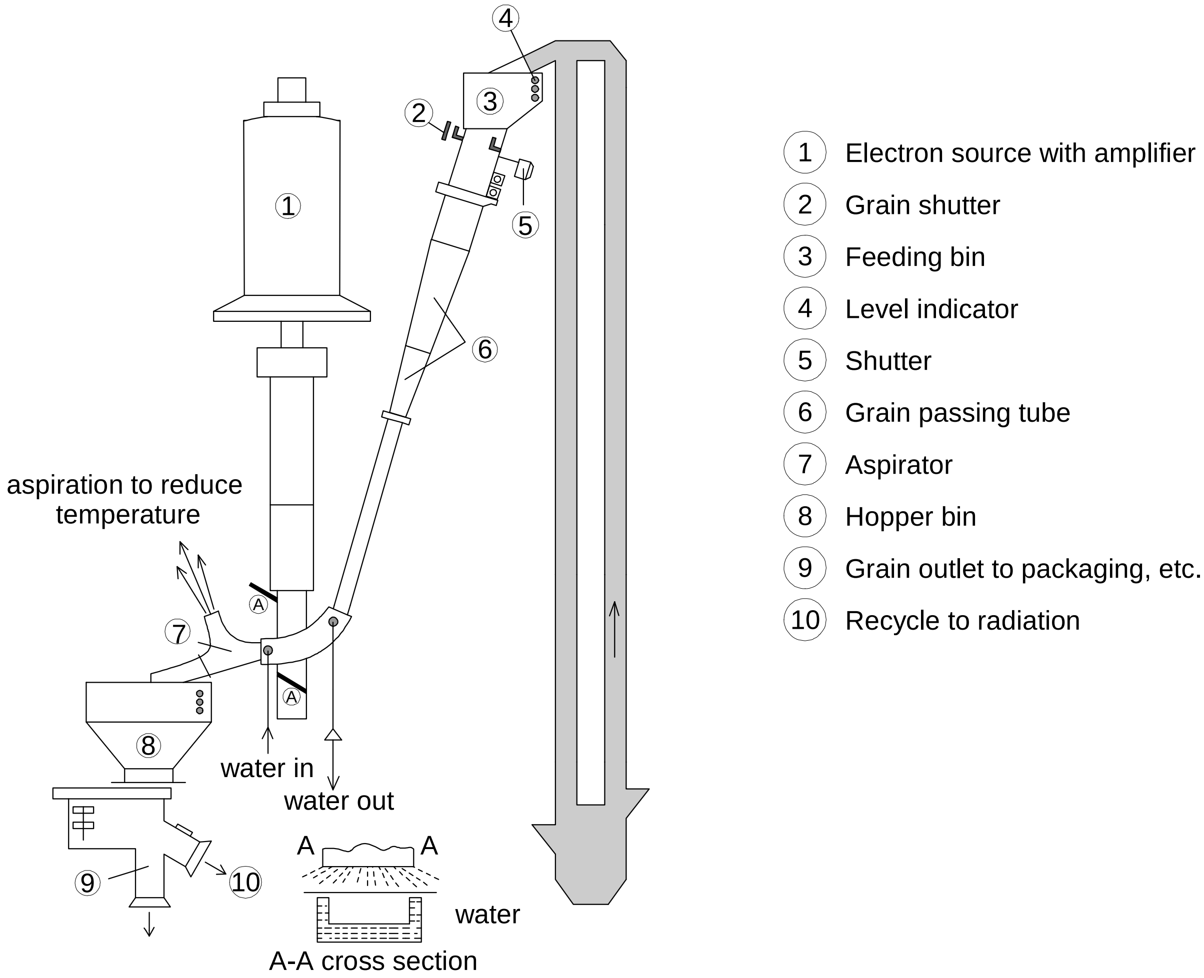


Fig:Typical grain radiation facility

11.1.2.2. STERILIZATION BY CHEMICALS (CHEMOSTERILIZATION)

Chemosterilants are chemicals that deprive insect species of their ability to reproduce. They can disrupt the first generation itself. For instance, the insect may not deposit egg, eggs may not hatch, larva may not pupate and pupa may not develop well.

There are several chemical agents that can work as chemical sterilants, e.g., alkylating agents, antimetabolites, miscellaneous chemicals.

11.1.2.2.1. ALKYLATING AGENTS

All of the alkylating agents form strong electrophiles through the formation of carbonium ion intermediates. This results in the formation of covalent linkages by alykylation of various nucleophile moieties. The chemotherapeutic and cytotoxic effects are directly related to the alkylation of DNA mainly through the 7 nitrogen atom of guanine although other moieties are also alkylated. The formation of one covalent bond with nucleophiles can result in mutagenesis or teratogenesis but the formation of two of these bonds through cross linking can produce cytotoxicity. Bifunctional alkylating agents (those containing two reactive chloroethyl side chains) such as nitrogen mustard react with another nucleophilic moiety resulting in the cross-linking of two nucleic acid chains or the linking of a nucleic acid to a protein. This type of alteration could cause a major disruption in nucleic acid function. Cytotoxicity of bifunctional alkylators correlates very closely with interstrand cross- linkage of DNA. The ultimate cause of cell death related to DNA damage in not known. Some of the cellular responses produced include cell-cycle arrest, DNA repair and apoptosis or programmed cell death. The nucleophilic groups of proteins, RNA and many other molecules can also be subject to attack by the alkylating agents, although the exact result of these interactions is not known.

Some of the alkylating agents are nitrogen mustard, cyclophophamide, apohalate, nitrosoureas, etc.

11.1.2.2.2. ANTIMETABOLITES

They are structurally related to biologically active substances, e.g., 5-fluoro uracil, which is able to replace a large percentage of uracil in RNA in organisms. Amethopterin is an analog of folic acid and may interfere with the formation of vitamin B.

11.1.2.2.3. MISCELLANEOUS

This group includes unclassified compounds like dimethylamine analogs and other triphenyl tin derivatives. Their increased dose causes complete inability to form eggs because the ovary becomes irreversibly damaged.

11.2. ATTRACTANTS

These are chemicals whose vapors attract the insects. They can be classified into (i) food attractants, (ii) substance that lures insects to the place of oviposition, and (iii) sexual attractants.

11.2.1. FOOD ATTRACTANTS

These compounds are decomposition of organic matter, e.g., proteins, acids, enzymatic hydrolysates, molasses and various syrups. They do not persist long (only 4-7 days). Mediterranean moth, apple worms are common insects. Baits are also used. Dioctylphthalates, trimethylamine, piperidine, mercaplin and various fatty acid, indole, etc., are some of the useful baits.

11.2.2. ATTRACTING TO THE OVIPOSITION

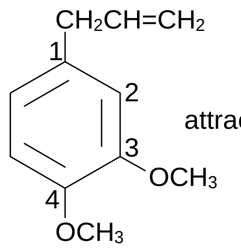
Host plants secrete the attractant that can be used to control insects. Boll weevils are separated from cotton plant and alfalfa weevil from alfalfa plant can be separated by this technique.

11.2.3. SEXUAL ATTRACTANTS

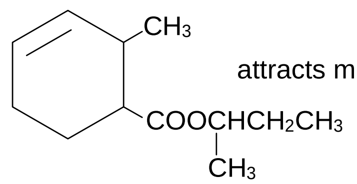
They are stimulators and regulators of reproduction process of some species and capable in negligible doses to attract opposite sex over a considerable distance. For example, a female gypsy moth attracts male from 400m by 10-12mg substance it liberates. The male can be attracted away from the female if this substance can be placed away from the female.

Similarly, the amount of attractant emitted by one female of pine sawfly is sufficient to attract 11000 males from a distance of 17.5km in 5 days.

Attractants are generally used in fruits to protect the parental plant. Some of the attractants are shown below.



attracts mediterranean grain moth



attracts melon fly

11.3. REPELLENTS

These chemicals can be used against grain, plants, fruits and vegetables, rodents; birds; insects; and mites. Repellents can also be used to protect humans from parasitic arthropods. In plants, this technique is used for protecting parental plants. Amines, pyridine and its derivatives, cyclic amides and rosins are the most commonly used repellents.

Formulation:

EXAMPLE 1

Dissolve rosin in denatured alcohol (1:1). Disslove 50g of naphthalene in 60g of terpentine, make 1 liter and add to rosin solution.

EXAMPLE 2

Naphthalene emulsion

Take 0.35g laundry soap, 20-40g naphthalene, 25-50g turpentine, 10g blue vitriol and 0.2 liter vegetable oil. Mix with 1 liter of water.

Dimethylphthalate and dibutylphthalate (DEET) protects humans and animals from insects and mites. They are used in the form of ointment, paste, solution, emulsion and aerosol.

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12. ORGANIC FARMING AND ORGANIC FOOD

Traditional farming practices used prior to the 20th century are generally regarded as ‘organic.’ Introduction of chemically synthesized farm inputs such as urea and DDT were criticized by scientists, philosophers, and practitioners who questioned whether the widespread adoption of such practices was sustainable. Farmers continued to practice traditional methods rather than adopt ‘progressive’ methods of chemical farming. Despite some economic disadvantages, a number of these traditional farmers remained competitive.

Organic food became established in the public’s mind as a separate identity during the 1960s and 1970s.

Organic farming management relies on developing biological diversity in the field to disrupt habitat for pest organisms, and the purposeful maintenance and replenishment of soil fertility. Organic farmers are not allowed to use synthetic pesticides or fertilizers. Some of the essential characteristics of organic systems include: (i) design and implementation of an "organic system plan" that describes the practices used in producing crops and livestock products; (ii) a detailed recordkeeping system that tracks all products from the field to point of sale; and (iii) maintenance of buffer zones to prevent inadvertent contamination from adjacent conventional fields.

12.1. METHOD OF ORGANIC FARMING

Farmers following “organic” farming practices replace chemical fertilizers, pesticides, and other agrochemicals with organic materials such as composted vegetation and manure from farm animals.

Organic farmers build healthy soils by nourishing the microbial inhabitants that release, transform, and transfer nutrients. Soil organic matter contributes to good soil structure and water-holding capacity. Organic farmers feed soil biota and build soil organic matter with cover crops, compost, and biologically based soil amendments. These produce healthy plants that are better able to resist disease and insect predation. Organic farmers' primary strategy in controlling pests and diseases is prevention through good plant nutrition and management. They use cover crops and sophisticated crop rotations to change the field ecology, effectively disrupting habitat for weeds, insects, and disease organisms. Weeds are controlled through crop rotation, mechanical tillage, and hand-weeding, as well as through cover crops, mulches, flame weeding, and other management methods. Organic farmers rely on a diverse population of soil organisms, beneficial insects, and birds to keep pests in check. When pest populations get out of balance, growers implement a variety of strategies such as the use of insect predators, mating disruption, traps and barriers. Under the National Organic Rule, growers are required to use sanitation and cultural practices first before they can resort to applying a material to control a weed, pest or disease problem. Use of these materials in organic production is regulated, strictly monitored, and documented. As a last resort, certain botanical or other non-synthetic pesticides may be applied.

Chemical fertilizers, insecticides and hybrid or genetically modified seeds should not be used. Before starting organic farming, one has to wait at least for three years so that the land becomes free from residues of synthetic fertilizers and pesticides.

By analogy, organic foods refer to foods obtained from organic farming. The processed food should not have any synthetic compounds. Irradiation is not allowed. To protect food from infestation, natural preventive measures are taken.

12.2. RAISING ORGANIC LIVESTOCK AND POULTRY

Organic meat, dairy products, and eggs are produced from animals that are fed organic feed and allowed access to the outdoors. They must be kept in living conditions that accommodate the natural behavior of the animals. Ruminants must have access to pasture. Organic livestock and poultry may not be given antibiotics, hormones, or medications in the absence of illness; however, they may be vaccinated against disease. Parasiticide use is strictly regulated. Livestock diseases and parasites are controlled primarily through preventative measures such as rotational grazing, balanced diet, sanitary housing, and stress reduction.

12.3. DEBATE OVER ORGANIC AND MODERN FARMING

Some people in the first-world countries now believe that modern farming practices have become destructive of the environment and of the health and welfare of the populace. It is argued that agrochemicals have polluted the environment and damaged the local ecology: this is highly debatable because far less land is needed for staple food production under modern intensive systems than organic systems, which are labor intensive and give low yields. It is also argued that the crops produced by modern farming methods are “inferior” to those harvested by our forefathers. It is claimed that they taste inferior, have different textures, and poorer nutritional value. Crops from farms using agrochemicals can also contain residual amounts of pesticides and alternative “organic farming practices” are being encouraged or at least experimented within regions where food is in surplus.

Organic farming is more labor intensive and therefore the products are more expensive; however, the defenders of organic practices argue that as less non-sustainable fossil fuel is needed and other “hidden” advantages such as better soil structure, less soil erosion, and more diverse ecology are achieved, the price is worth paying. However, for the foreseeable future only a rich population can afford to pay for the luxury of organic staple foods should they wish to.

Even on the best-managed farm the crops can fail. The farmer cannot control the weather or other factors (such as wars or major infestation). These uncontrollable factors may have devastating consequences on crops. Storing food from one year to the next (or some parts of the world until the second crop of the year) is one way in which a community can survive a failed harvest.

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13. FOOD SECURITY

Food security is a term used in development and humanitarian aid. It does not have one agreed definition; but is often used broadly to mean a situation in which people have continuity of food supply, or the methods by which this aim is achieved. The term — in the development context — grew out of a reaction to the problems associated with food aid. Food aid is one development paradigm, in which the solution to hunger is seen as being the donation of surplus food commodities, usually by rich developed nations. The focus of food security interventions is usually contrasting: *the development of indigenous mechanisms to fight hunger and malnutrition*. The stages of food insecurity range from food secure situations to full-scale famine.

A commonly-used definition is that a community enjoys food security, when all people, at all times, have access to enough (quantity), nutritious (quality), safe, personally acceptable and culturally appropriate foods, produced in ways that are environmentally sound and socially just, or in other words by sustainable development.

The definition provided by the FAO during the World Food Summit is the most acceptable one. FAO defines food security as a situation "when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life.

Gulati (2000) has gone a step further to track down the various constituents of this definition, by maintaining that food security means at least five things:

1. That food security is as much a matter of physical access to food as it is of economic access or entitlement to food
2. That food security is related to all the people, irrespective of their income levels, age, education and gender
3. That food should be available to them at all times, be it a period of war, civil strife, or any natural calamity
4. That food has to be available in sufficient quantities, preferably in line with the consumption preferences of the people, and finally
5. That food has to be safe and nutritious, which leads to a healthy and active life

13.1. WORLD FOOD PRODUCTION

Today 370 kg of cereals (carbohydrate sources) per person are harvested versus 275 kg in the mid-20th century, which is a per capita gain of more than a 33%. Other crops (protein and vitamin sources) gained 20% since the early 1960s. Globally there is enough food (in the form of cereals) to take up 3500 kcal/day/per person. In spite of this fact, around 828 million men, women and children are chronically hungry while 2 billion people lack food security because of poverty (FAO, 1998).

A famous quote in this respect is therefore: "The true source of world hunger is not scarcity but policy; not inevitability but politics." (Peter Rosset, Executive Director of *Food First*).

The four most important reasons of food scarcity are stated as (Singer, 1997):

1. National deficit, political and social instability resulting in deteriorating terms of trade
2. More cash crops are harvested than food crops due to agricultural globalization. In this case, cash crops are crops planted in the (sub)tropics for sale in the North. Cash crops require more surface, and thus more fertilizer and pesticides, and the general effect of this is that smaller farmers have to fight for every square kilometer.
3. Population increase. Farmer families tend to have more children to work on the field. Children are an investment (sexual contraception methods are not even considered). The problem arises when those children move to the cities to leave their poor lives behind. In general, they meet even more poverty.
4. Subsidies and food donations (giving away excess food) generally undermine local economy. Prices of the same or comparable local crops will drop, giving local farmers less money.

13.2. WORLD FOOD SUMMIT

The World Food Summit was held in Rome in 1996, with the aim of renewing global commitment to the fight against hunger. The Food and Agriculture Organization of the United Nations (FAO) called the summit in response to widespread under-nutrition and growing concern about the capacity of agriculture to meet future food needs. The conference produced two key documents, the Rome Declaration on World Food Security and the World Food Summit Plan of Action.

The Rome Declaration calls for the members of the United Nations to work to halve the number of chronically undernourished people on the Earth by the year 2015. The Plan of Action sets a number of targets for government and non-governmental organizations for achieving food security, at the individual, household, national, regional and global levels.

13.3. ACHIEVING FOOD SECURITY

In general the countries that succeeded in reducing hunger were characterized by more rapid economic growth and specifically more rapid growth in their agricultural sectors. They also exhibited slower population growth, lower levels of HIV and higher ranking in the Human Development Index.

USAID proposes several key steps to increasing agricultural productivity which is in turn key to increasing rural income and reducing food insecurity. They include:

1. Boosting agricultural science and technology. Current agricultural yields are insufficient to feed the growing populations. Eventually, the rising agricultural productivity drives economic growth.
2. Securing property rights and access to finance.
3. Enhancing human capital through education and improved health.
4. Conflict prevention and resolution mechanisms and democracy and governance based on principles of accountability and transparency in public institutions and the rule of law are basic to reducing vulnerable members of society.

13.4. A CHECKLIST OF FOOD SECURITY PLANNING

More than a decade ago, when drought crippled more than half a dozen countries bordering the Sahara, the subsequent famine caught the world unawares. As the severity of the crisis became known, shiploads of cereals poured into the stricken countries. Global conferences were convened to find out why preparation was so inadequate and how to prevent a repetition.

The exercise of providing for food emergencies was partially successful. The most debilitating effects of the drought were blunted, and the machinery to handle future acute shortages was overhauled. Even so, each of the Saharan countries has since depended on ever-rising volumes of food aid. Food aid shipments into Africa have tripled. Several countries worldwide, including low-income developing countries, are still relying on such assistance to supplement inadequate domestic food production.

The lesson is clear. Unloading millions of tons of food aid on the wharves of food-deficient countries each year is not the solution. Emergency aid is by its nature a temporary solution. Permanent food security will come only through strengthening food production in the vulnerable countries themselves. Deep-rooted structural deficiencies that inhibit production and distribution of foodstuffs are the obvious targets for reform.

As countries try to improve their own food output, a tangle of issues arises. For example, if indigenous food production is to increase sharply, costly inputs will be necessary. A trade-off between expansion of food crops for local consumption and stimulation of cash crops for export may be inevitable where countries lack foreign currency to pay for the inputs. A similar delicate process of reconciliation will be necessary to overcome problems caused by the rapid transition of underdeveloped food economies: pressure on fragile ecosystems, huge investment in the physical requirements to produce, store and preserve food, and the social distortions of development. The risks are obvious.

According to B.S. Raghavan (former Chairman of the Committee on World Food Security) there is a need for close attention to five central concepts if food security is to be strengthened:

1. *Input security:* agricultural inputs (seed, fertilizer, water, energy)
2. *Ecological security:* management of land, water, forest, energy resources, rivers, biodiversity, local environment, etc
3. *Technological security:* study and implementation of appropriate technology, adaptation by farmers of new technology, equipment, etc.
4. *Physical security:* prevention of loss, appropriate storage, preservation, processing, value addition (by-product utilization)
5. *Social security:* democratic and equitable distribution of resources such as land, credit, information, and incentives

To pursue Raghavan's concept toward a detailed analysis is one way of beginning to unmask the deceptively simple terms in which food security is often discussed. For those who are planning or promoting concepts of food security his approach provides a useful benchmark against which to assess national programs.

13.5. FOOD SECURITY IN NEPAL

According to Manish Gautam (reporter)

According to Food and Agriculture Organization on its report "The state of food insecurity in the world 2000" in Nepal the kilocalorie per person per day is 260 and in Germany it is only 130. And the depth of hunger is measured by the average dietary energy deficit of undernourished people, not of the population as a whole, expressed in kilocalorie per person per day. The higher the number, the deeper is the hunger.

Where the average kilocalorie deficit is very high many people's diets are deficient in everything. The state of food insecurity in the world regularly reports on the latest estimates of the number and prevalence of chronically hungry people and the number of hungry people living in developing countries like Nepal. This clearly shows the difference between 'have' and 'have not'. When governments talk about security, it means defense against an external force. But the food deficient or its security has other meaning that has not been in the priority list of the governments of developing countries. Food security is an ability of a household to get access of enough food, either by producing or by earning enough to buy it. In the case of Nepal, sadly both are not happening.

Lack of cash income is one of the most important factors hindering both urban and rural people from obtaining the diverse foods needed for an adequate diet. Food insecurity, poor nutritional status and absolute poverty are closely associated in Nepal, but they are not identical. During the last ten years Nepal has changed from a net exporter to net importer of food. The FAO food balance sheet for Nepal reveals that since 1991/92, there has been deficit and it is increasing every year.

In 2000, 33 of Nepal's 75 districts had food deficit while only seven achieved food surplus. Food insecurity was a serious problem when there were unfavorable climatic conditions in 1972 and again during the drought of 1980. Food had to be imported on a large scale to meet the deficit. Although agriculture sector has received the highest priority in most of the development plans, its performance has been dismal. The first national plan (1956-61) had allocated 27% of the budget to agricultural and rural development. The aim of the investment was to increase agriculture output and productivity.

Since the beginning of the 1990s the proportion of population experiencing the food deficit is especially critical in the hills of the Nepal where 47% of the population are under supplied. The respective figures for the Lowlands and for the Mountains are 23% and 31%. The main reasons for the adverse food availability situation in the hills are the high population density and degradation of land and forest resources. Land productivity in Nepal has stagnated in spite of the increasing use of fertilizers, indicating land degradation and excessive utilization of natural resources.

It is argued that poverty has been a problem in Nepal Since about the 18th century because of slavery and a feudal system of land ownership and labor arrangements. But the problem of food insecurity has grown tremendously only in recent years. In the past, traditional safety-net mechanisms had helped poor people to secure a food supply to a certain extent. But now, this system has eroded. Landlords who used to employ laborers on the basis of patron-client relationships now prefer to pay wages and do not want to carry any other obligation. Moreover, the abundant availability of other resources such as the forest and wasteland meant that landless and marginal people could afford to keep animals and derive forest products for their livelihoods. Access to land has been declining for a large proportion of households because of increasing population pressure and skewed distribution of land.

The top 5% of the population controlled 40% of the cultivated land while the bottom 60% controlled only about 20%. On the other hand, population growth rate in the last three decades has remained well above 2.0%. All these figures lead to conditions that make vulnerability to food shortage. The decline in food security in Nepal is also evident from the decreasing per capita food production. The per capita food grain production decreased from 376kg in 1974/75 to 277 kg in 1991/92. A USAID report published in 1979 revealed 85% of hill households and 50% of terrestrial households had been unable to produce sufficient food. Another sign of lack of food security is malnutrition, a result of inadequate consumption. It is reported that 65% of the children from six month to six years of age are malnourished. Poverty and malnutrition remain endemic in Nepal, an overwhelmingly agrarian country where most rural households do not own land and few other opportunities to earn an income exist.

13.6. NUTRITION AND FOOD SECURITY ISSUES IN THE SOUTH ASIAN CONTEXT

Malnutrition is a problem of staggering dimension in South Asia. More than half of all the world's malnourished pre-school children live in this region. The rate of women and child malnutrition here is much higher than anywhere else in the world. Over 50% of the children are underweight, 17% experience wasting, and half of the world's malnourished children are to be found in just three countries – Bangladesh, India and Pakistan. Other disorders like low birth weight, stunting and micronutrient deficiencies are also rather high.

Malnutrition is a part of the complex and widespread problem of poverty and deprivation that affects millions of Asians.

13.7. NATIONAL COMMITMENTS FOR NUTRITIONAL AND FOOD SECURITY

In keeping with the commitments at two World Conferences, the International Conference on Nutrition (ICN) in 1992 and the more recent World Food Summit (WFS) in 1996, Asian countries have prepared a National Plan of Action for Nutrition (NPAN) which has household food security and food safety as prime themes. Nepal has incorporated NPAN into its present Ninth Plan.

Food and nutrition security poses a multifaceted problem. The responsibility of the governments to solve this extends to the following broader and concerted efforts and actions:

- To ensure the best political, social and economic conditions for poverty alleviation with full and equal participatory role of men and women, in order to achieve sustainable food security for all
- To implement policies for eradication of poverty and inequality, and for improving physical and economic access by all, at all times, to sufficient, nutritionally adequate and safe food and its utilization

- To pursue participatory and sustainable food, agriculture and rural development policies and practices which are essential for adequate and reliable food supplies at various levels
- To strive to ensure that food, agriculture, trade and overall trade policies are conducive to fostering food security for all through a fair and market-oriented system
- To be prepared to meet the transitory and emergency food requirements
- To promote optimal allocation and use of private and public investments to foster human resources and sustainable food and agriculture, and
- To implement, monitor and follow efforts to implement these actions at all levels in cooperation with the international community

So far, more words than resources have been allocated to implementing government plans of action and follow up. The ICN appears to have advanced in the countries concerned. Yet the gap between the declarations and actions remains.

Two major trends of food security and nutrition are simultaneously underway in Asia – urbanization and globalization. Urbanization has brought along with it changes in food habits and the concomitant diet-related non-communicable diseases. Globalization and liberalization have also increased the risk from cross-border transmission of infections and contamination.

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14. INFLUENCE OF PESTICIDES ON ENVIRONMENT

The continuing intensive chemization of the world's agriculture leads to a large amount of various chemicals, including pesticides, being introduced every year into the planet's biosphere – the habitat of all living beings including man. Pesticide contaminants differ from other chemicals in that they are health hazardous, persist in natural conditions, are transferred along the food chains, and get biomagnified to the detriment of the organism and the environment. Thus, prolonged and indiscriminate use of pesticides may lead to:

- Degradation of environment,
- Death of beneficial organisms,
- Adverse physiological effect on man and animals (non-vitality of bird's eggs, extermination of man, birds, fish), and
- Development of resistant pest forms

The circulation of pesticides may occur according to the following schemes:

Air → Plants → Soil → Plants → Herbivorous animals → Man;

Soil → Water → Zoo- and Phytoplankton → Fish → Man

Since the path of pesticide residues leading to man is through food, a safe barrier must be created between man and his food, which is given by *tolerance levels* of pesticides. The tolerance levels of pesticides in food are officially allowed harmless amount of them in food in mg/kg of relevant product.

14.1. BEHAVIOR OF PESTICIDES IN AIR, WATER AND SOIL

During aerial treatment of plants with pesticides as much as 50% of the fine droplets gets airborne, which later on settle down on vegetation and soil at a considerable distance from the place of treatment. Some airborne pesticides are brought down by precipitation and eventually to soil and water bodies.

Water is the main means of transporting pesticides in the environment. The pesticides from surface and aerial treatments eventually find their way into water bodies, where the effect can be anything from change in organoleptic property of water to incapacitation of water flora and fauna, and even those organisms that consume the polluted water. Organochlorine and toxaphene pesticides in particular are very dangerous.

Pesticides are introduced into the soil for destroying soil-dwelling pests, nematodes, and the pathogens of bacterial and fungal diseases. They are washed during atmospheric precipitation and are also carried off by the wind.

Whether it be in air, soil, or water, some degree of decomposition of pesticides take place via various physicochemical and biological means, the extent being dependent on the type of pesticide used. Some get easily degraded while some are very persistent, thereby posing great risk.

14.2. INTEGRATED SYSTEM OF PLANT PROTECTION

An important role in eliminating the harmful action of chemical means of plant protection on the environment is assigned to the rational application of pesticides in integrated plant protecting systems. The latters are based on the integrated and greatest possible use of environmental factors to limit the number of harmful insects at a level when they do not cause perceptible harm. Chemical pesticides must be used only when absolutely necessary and this should be preceded by very careful planning. Only the most selective and least hazardous pesticide must be used.

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15. MYCOTOXINS

Mycotoxins are secondary metabolites of molds which may contaminate foods, animal feeds, or the raw materials for their manufacture, and that happen to be toxic to man or his domestic animals. Animal and human health problem related to contamination by toxic metabolites from fungi have long been known. FAO estimates that 25% of world food crops are affected by mycotoxin. They are pathologically classified as hepatotoxins, nephrotoxins, vomitoxin and neuro-musculotoxin, some of which are potentially carcinogenic and mutagenic. Aflatoxin, for example, is the most potent hepatocarcinogen and mutagen among mycotoxins. Therefore, the contamination of mycotoxins should be minimized by designing a series of measures of prevention and control.

15.1. FOOD-BORNE MYCOTOXINS

There are five groups of mycotoxins that occur quite often in food, viz.:

1. Deoxynivalenol/Nivalenol
2. Zearalenone
3. Ochratoxin
4. Fumonisins, and
5. Aflatoxins.

Table below summarizes the staple food commodities they affect, the fungal species that produce them, and the main effects observed in humans and animals. T-2 toxin is also found in a variety of grains but its occurrence, to date, is less frequent than the preceding five mycotoxins.

The food-borne mycotoxins likely to be of greatest significance for human health in tropical developing countries are the fumonisins and aflatoxins.

15.1.1. FUMONISINS

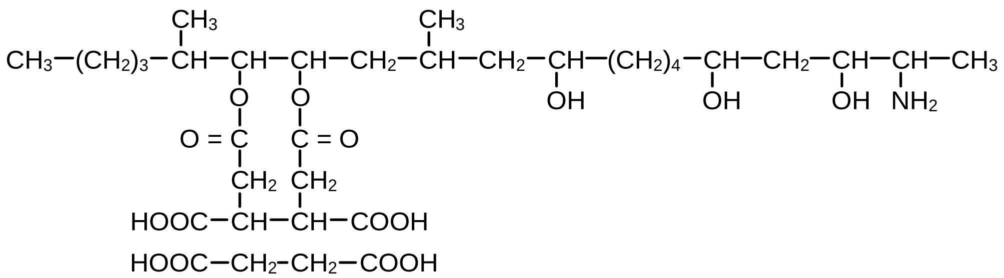
Fumonisins were discovered as recently as 1988 so there is little information on their toxicology. To date, there is sufficient evidence in experimental animals for the carcinogenicity of cultures of *Fusarium moniliforme* that contain significant amounts of fumonisins; and there is limited evidence in experimental animals for the carcinogenicity of fumonisin B1.

F. moniliforme growing in maize may produce fumonisin B1, a suspected human carcinogen. Also, fumonisin B1 is toxic to pigs and poultry, and is the cause of equine leucoencephalomalacia (ELEM), a fatal disease of horses.

Table 1. Mycotoxins in staple grains and seeds.

Mycotoxin	Commodity	Fungal source(s)	Effects of ingestion
Deoxynivalenol / nivalenol	wheat, maize, barley reported from	*Fusarium graminearum*	Human toxicoses. Toxic to animals, especially pigs
		Fusarium crookwellense	
		Fusarium culmorum	
Zearalenone	maize, wheat	*F. graminearum*	Possible human carcinogen. Affects reproductive system in female pigs
		F. culmorum	
		F. crookwellense	
Ochratoxin A	barley, wheat, and many other commodities	*Aspergillus ochraceus*	Suspected as human carcinogen. Carcinogenic in laboratory animals and pigs
		Penicillium verrucosum	
Fumonisin B1	maize	*Fusarium moniliforme* plus several less common species	Suspected as human carcinogen. Toxic to pigs and poultry. Cause of equine eucoencephalomalacia (ELEM), a fatal disease of horses
Aflatoxin B1, B2	maize, peanuts, and many other commodities	*Aspergillus flavus*	Aflatoxin B1, and naturally occurring mixtures of aflatoxins, identified as potent human carcinogens. Adverse effects in various animals, especially chickens
Aflatoxin B1, B2, G1, G2	maize, peanuts	*Aspergillus parasiticus*	

Fumonisins have been found as a very common contaminant of maize-based food and feed in Africa, China, France, Indonesia, Italy, the Philippines, South America, Thailand, and the USA. Strains of *F. moniliforme* from maize from all over the world (including Africa, Argentina, Brazil, France, Indonesia, Italy, the Philippines, Poland, Thailand, and the USA) produce fumonisins. At present, strains of *F. moniliforme* isolated from sorghum are considered to be poor producers of fumonisins.



Chemical structure of fumonisin B1

15.1.2. AFLATOXINS

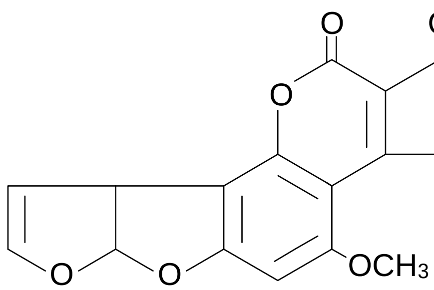
The aflatoxins are a group of secondary fungal metabolites which have been epidemiologically implicated as environmental toxin and carcinogens in man. They are substituted coumarins containing a fused dihydrofurofuran moiety. There are four primary aflatoxins, named B1, B2, G1 and G2, from their blue and green fluorescence, respectively, on thin-layer chromatographic plates. As was generally known to be the case with aflatoxin toxicity and carcinogenicity, a similar potency series, namely AFB1 > AFB2 > AFG1 > AFG2 has been established for aflatoxin-induced mutagenic activity and DNA damage.

Aflatoxins were discovered in 1960 following the deaths of 100,000 young turkeys in England, and high incidences of liver disease in ducklings in Kenya and hatchery reared trout in the United States. Ever since, aflatoxins have been subject to a great deal of research. They are potent human carcinogens and interfere with the functioning of the immune system. Among livestock, they are particularly toxic to chickens.

In 1993, the International Agency for Research on Cancer (IARC) assessed and classified naturally occurring mixtures of aflatoxins as class 1 human carcinogens. Aflatoxins B1, B2, G1, and G2 have been found to occur in commodities in the Americas and Africa, and have been detected in human sera. Residues of aflatoxin B1 and/or its metabolite, aflatoxin M1 can occur in animal products, including milk. Aflatoxin M1 is also found in human milk if the mother consumes food containing aflatoxin B1. IARC has given aflatoxin M1 a lower carcinogenicity rating than aflatoxin B1. When aflatoxin G1 is ingested by cattle, aflatoxin M2 is formed.

It is clear that exposure to aflatoxins is hazardous to human health. For that reason, most countries have regulations governing the allowable concentrations of aflatoxin in food and feed. The tolerance limit of aflatoxin, as given by WHO and FAO is 30 ppb. Adult dog and adult rat have LD_{50} of 0.5mg/kg body weight and ~ 9mg/kg body weight. For humans, LD_{50} has been guessed to be between that of dog and rat. This has been based from the fact that in 1974, an outbreak of hepatitis that affected 397 Indian people, of whom 106 died, was traced to corn heavily contaminated with *Aspergillus flavus* and containing up to 15 mg/kg aflatoxins. Consumption by some of the affected adults was estimated to be 2-6 mg in a single day.

Aflatoxin B1, the most toxic of the aflatoxins, causes a variety of adverse effects in different domestic animals. Effects on chickens include liver damage, impaired productivity and reproductive efficiency, decreased egg production in hens, inferior egg-shell quality, inferior carcass quality, and most important from a human perspective, increased susceptibility to disease.



Aflatoxin B1

15.2. MYCOTOXIN CONTAMINATION OF FOODS AND FEEDS IN NEPAL

(By T.B. Karki and B.P. Sinha, CFRL, Nepal)

Monitoring of mycotoxins in food commodities was first initiated in Nepal in the year 1978 as a consequence of FAO/UNEP Regional Monitoring of Food Contaminants Project involving four countries in which Nepal and India were placed in one group and Pakistan and Sri Lanka on the other. Since then 850 food samples mainly comprising of Cereals, Pulses, Oilseeds and Spices and about 150 samples of feed and feed ingredients were monitored for aflatoxin content covering the period of 1980 -1987. Result has indicated that corn and peanut are the two commodities most prone to aflatoxin contamination. Ecologically, Terai Southern Plain area is more susceptible to aflatoxin hazard compared to hills and mountainous area. Coincidentally, toxigenic fungi (*Aspergillus flavus*) predominated in Terai since from the onset of storage as contrary to hills and mountainous areas. Further, *A. flavus* spp. isolated from Terai area produced higher amount of aflatoxin B1 (634 ppb) than from the hills and mountains. Thus, the potency of the strains has shown altitude bias. Maximum level of aflatoxin B1 was found in corn (321 ppb) and peanut as raw shelled (634 ppb). Aflatoxin contents in feed and feed ingredients are relatively higher because low quality cereals or damaged grains are usually used for feed and feedstocks. Maximum level of aflatoxin B1 in poultry feed was found to be 1100 ppb.

Out of total 582 samples of corn, peanut products, wheat flour and parboiled rice, 18.7% were found to be contaminated with aflatoxin. Further, 6% of the samples were found to exceed the permissible limit of 30ppb of aflatoxin B1 (as suggested by FAO). Of the poultry feed tested, 47.4% was found to contain aflatoxin, with 12.9% exceeding the permissible limit.

The effect of traditional storage of maize on aflatoxin production was also studied. No aflatoxin was detected on the sample stored in *Thangro* (outdoor open storage system around a pole and four support bases). The sample stored in *Bhakari* (bamboo bins) contained 1.5 ppb aflatoxin B1. However, the aflatoxin B1 content in Ghyampo (clay jar) and metal bin was found to be 40 and 125 ppb respectively. This clearly indicates that *Thangro* seems to be an appropriate storage system for corn as evidenced by absence of *A. flavus* and aflatoxin production. Furthermore, Bhakari type of storage can be improved for preventing mold infection and relative toxin production. It needs further elaboration in different agro-climatic regions.

15.3. PREVENTION AND CONTROL OF MYCOTOXINS

Toxin-producing fungi may invade at pre-harvesting period, harvest-time, during post-harvest handling and in storage. The prevention of mycotoxins in our environment is a big task. In general, prevention of the contamination of fungi and their mycotoxins in agricultural commodities can be divided into these following three levels.

1. PRIMARY PREVENTION

The step of prevention should be initially carried out before the fungal infestation and mycotoxin contamination. This level of prevention is the most important and effective plan for reducing fungal growth and mycotoxin production. Several practices have been recommended to keep the conditions unfavorable for any fungal growth. These include using fungal-resistant varieties of growing plants, control of field infection, proper drying and storage of grains, etc. In particular, mycotoxin producing fungi do not grow at water activity (a_w) < 0.7.

2. SECONDARY PREVENTION

If the invasion of some fungi begins in commodities at early phase, this level of prevention will then be required. The existing toxigenic-fungi should be eliminated or its growth to be stopped to prevent further deterioration and mycotoxin contamination. Several measures may be used, for example, redrying of products to stop the fungal growth, removal of contaminated seeds, inactivation or detoxification of mycotoxins, etc.

3. TERTIARY PREVENTION

Once the products are heavily infested by toxic fungi, the primary and secondary preventions would not be then feasible. However, some measures should be done to prevent the transfer of fungi and their health hazardous toxins highly contaminated in products into our daily foods and environment. Some of the few practices include complete destruction of contaminated products, detoxification or destruction of mycotoxin to the minimal level.

15.4. FUNGAL GROWTH INHIBITION

How to prevent growth and invasion of pathogenic fungi in agricultural commodities is very important in preventing mycotoxin contamination. The inhibition of fungal growth can be achieved by physical, chemical and biological treatments.

After the crops have been harvested, drying and proper storage and suitable transportation of the commodities are of prime importance. Several favorable factors contribute to the growth of fungi and aflatoxin production, namely high moisture content, humid climate, warm temperature (25-40℃), insect infestation and pest damage. Many mea ns and measures to prevention of fungal contamination have been emphasized and practically done. Drying seeds and commodities to the safe moisture levels (< 9% for peanut kernel, and < 13.5% for corn), maintenance of the container or warehouse at low temperature and humidity, keeping out insects and pests from the storage, and Gamma-irradiation of large-scale commodities are some of the physical treatments proposed.

In the chemical treatments with synthetic fungicides, use of organic acids (propionic, butyric, malonic, benzoic, sorbic, lactic, citric and their sodium salts), sodium chloride, fumigants (ammonia and phosphine), plant herbs (*Plumbago indica*, black pepper, etc), onion and garlic extracts (allicin and related substances), chitosan, etc., are some of the techniques available.

15.5. DECONTAMINATION OF MYCOTOXINS

Contaminated mycotoxins in foods and feeds should be removed, inactivated or detoxified by physical, chemical and biological means depending on the conditions. However, the treatment has its own limitations, since the treated products should be health-safe from the chemicals used and their essential nutritive value should not be deteriorated. The following methods are suggested to be applied for effective decontamination of some mycotoxins.

Physically, fungi-contaminated seeds can be removed by hand picking or photoelectric detecting machines. The method would consume time and labor or expensive.

Organic solvents (chloroform, acetone, hexane and methanol) have been used to extract aflatoxins for agricultural products, but mainly in vegetable oil refining process

Heating and cooking under pressure can destroy nearly 70% of aflatoxin in rice compared to under atmospheric pressure only 50% destroyed. Dry and oil roastings can reduce about 50-70% of aflatoxin B1. Only about 10% of total 1242 ppb of aflatoxin B1 is decreased in naturally contaminated peanut by heating at up to 100℃. Sinc e aflatoxin resists to higher temperature up to 260℃, long-time cooking and overheating would dest ruct essential vitamins and amino acids in treated foods.

Ionizing radiation such as gamma-rays can stop growth of food spoilage organisms, including worms and insect pests but cannot completely destroy the toxin and its mutagenicity at normal dose of 1-5Mrad.

Chemical treatment has been used as the most effective means for the removal of mycotoxins from contaminated commodities. The method should be sure that the detoxification system is capable of converting the toxin to a nontoxic derivative(s) without deleterious change in the raw product. Many common chemicals have been brought to test the effectiveness in detoxification of aflatoxin. These chemicals include acetic acid, ammonia, formaldehyde, hydrogen peroxide, methylamine, phosphine, phosphoric acid, etc.

15.6. IDENTIFICATION OF AFLATOXIN (EXAMPLE: CORN)

Identification and quantitative assessment aflatoxin generally require sophisticated sampling, sample preparation, extraction, and analytical techniques. The sampling technique is relatively involved. An example is given below:

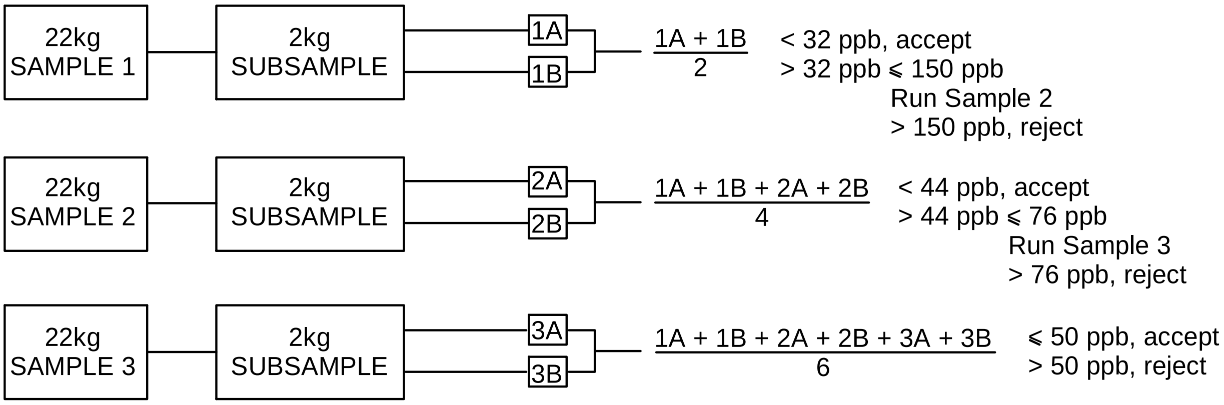


Fig. Protocol for the testing of aflatoxin

A detailed treatment regarding the same has been described by:

R.L. Semple, A.S. Frio, P.A. Hicks and J.V. Lozare in

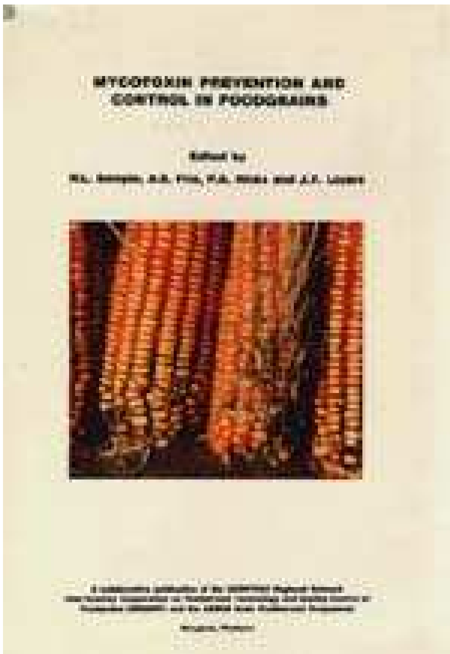
Mycotoxin Prevention and Control in Food grains

A collaborative publication of the UNDP/FAO Regional Network Inter-Country Cooperation on Preharvest Technology and Quality Control of Foodgrains (REGNET) and the ASEAN,

Grain Postharvest Program,

Bangkok, Thailand.

The book can be downloaded for free at http://www.fao.org/inpho/



There are three approaches to aflatoxin estimation in corn: (1) a presumptive test to identify corn lots that may contain the toxin and to determine whether a corn lot should be analyzed for aflatoxin or not (2) rapid screening methods to establish the presence or absence of the toxin and to know the range of aflatoxin level; and (3) quantitative methods to determine types and, aflatoxin contents.

15.6.1. PRESUMPTIVE TEST (the BGYF test)

Since most samples do not contain a detectable amount of aflatoxin, there is a need for a method which correctly identifies the many negative samples with minimum expenditure of time and money. Such a method is known as the BGYF test or black light test. Corn is inspected under the UV lamp (365 µm.) for a characteristic bright greenish yellow fluorescence in broken and damaged kernels. The test takes 5 minutes or less.

The basis of this test is that the characteristic Bright Greenish-Yellow Fluorescence (BGYF) seen under long-wave ultraviolet light (365 nm) is associated with the presence of kojic acid produced by *Aspergillus flavus* or *A*. *parasiticus* (aflatoxin producing fungi) or possibly mycotoxin itself.

PROCEDURE FOR BGYF TEST

About 4.5 kg of sample (corn) is coarsely ground and spread in a monolayer on a black tray and observed at 365µm through a protective hood. BGYF has a bright glow (firefly glow) that differentiates is from other fluorescent materials in the corn.

15.6.2. RAPID SCREENING TEST (the MINICOLUMN test)

This method is semi-quantitative but is adequately sensitive to less than 10 ppb of aflatoxin. The whole process requires about 15 min to 2 hr, and is easy and cheap to operate. The final extract from this process can also be used for quantitative analysis by TLC.

PROCEDURE FOR MINICOLUMN TEST

A clear, thin polythene straw of 6.0 mm diameter and 250 mm length is packed with materials as shown below. Extract 50g of ground sample in 200ml of solvent (methanol:5% salt solution in the ratio 60:40) by blending for 3 min in a medium speed blender. Filter the contents, take 40ml of filtrate add 20ml of zinc acetate solution (aqueous solution containing 12.5% zinc acetate, 6.25% ammonium sulfate and 0.1% glacial acetic acid). Stir and stand for 1min. Then add 40ml of 0.1M phosphoric acid, mix well and stand again for 5min. Add 5g celite, mix well and filter. Take 50ml filtrate, add 4ml benzene, shake well and stand to allow separation of layers. Collect the upper benzene layer (use separating funnel) and dry it with 1-2g of anhydrous sodium sulfate.

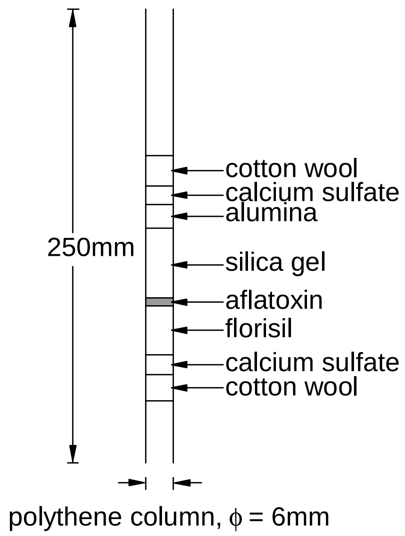


Fig. Assembling of minicolumn

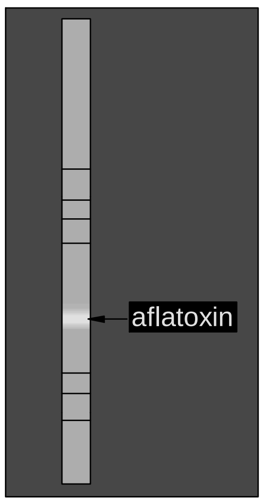


Fig. Appearance under UV light

Place 1ml of benzene extract in the minicolumn and let is run down. Add eluting solution (chloroform:water = 90:10) 4 times, 1ml each time and let all the solvents to run down. To hasten the flow, a rubber pressure bulb may be used. Inspect the minicolumn in UV light at 365 nm against standard minicolumns containing 20, 50 and 100 ppb of aflatoxin B1. If the minicolumn shows higher intensity of fluorescence than 20 ppb standard, the aflatoxin content in the sample is more than 4 ppb but less than 20 ppb. Similarly, if the fluorescence is greater than 20 ppb but lower than 100 ppb standard, the aflatoxin content in the sample is more than 20 ppb but less than 100 ppb. The figure of minicolumn assembly is shown above.

15.6.3. QUANTITATIVE METHODS

Quantitative tests can be done by Thin Layer Chromatography (TLC), High performance Liquid Chromatography (HPLC), Enzyme Linked Immunosorbent Assay (ELISA), Radio Immuno Assay (RIA). However, TLC is the most widely used technique and is also the official technique of AOAC.

15.6.3.1. TLC METHOD

TLC plates are available in readymade form or may be prepared in the laboratory. A 0.5cm×20cm×20cm glass or aluminum plate is coated with Silica gel (chromatography grade) with suitable binder to a thickness of 250 to 300 nm. The plate is activated at 120℃ for 1hr. Sample extract as well as the internal standards are co-chromatographed using appropriate solvents such as ether-ethanol-water, benzene-ethanol-water, ether-methanol-acetic acid-water, etc. While spotting, 1-50μL may be used but the amount of aflatoxin should be around 0.2-1 ng/μL.

Quantitative and qualitative information on the toxin is obtained by comparing the Rf value and fluorescence of sample extract with those of the standard. The comparison of intensity can be done visually or by fluoredensitometers.

In case the separation is not fruitful by a given solvent combination, a two dimensional TLC can be used. Here the plate which has already been developed in one solvent system is developed again with another solvent system by turning the plate at 90°.

15.6.3.2. HIGH PERFORMANCE LIQUID CHROMATOGRAPHY (HPLC) METHODS

Aflatoxin analysis using HPLC for separation and detection is quite similar to TLC because similar sampling and extraction procedures are used. The major advantages of HPLC over TLC are speed, automation, improved accuracy, and precision.

Reverse-phase HPLC separations of aflatoxins are more widely used than normal-phase HPLC separations. However, the fluorescence intensities of B1 and G1 are diminished in reverse-phase solvent mixtures so the derivatives B and G are generally prepared before injection. Analysts should be aware that derivatives B and G are not stable in methanol, which should be used with caution, especially in the injection solvent. Acetonitrile-water mixtures do not degrade B and G rapidly and are preferred to methanol-water mobile phases.

HPLC, however, is not routinely used for quantitation of aflatoxin.

So much for this year. Actually, I am very tired and sleepy at the moment.

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