Food Storage Technology
Preface

This note on “Food Storage Technology” is based on the syllabus of B.Tech. (Food) 4th year. I have tried my best to collect and put together information as precisely as possible and there may be some mistakes as well. I would like to thank Mr. Tekraj Bastola for providing his note copy for the preparation of this digital version. This book is for educational purpose and there is no restriction in its use and distribution.

All the views and comments about the book are most welcomed and are requested to address at amicableosp@gmail.com or amicable_sp@yahoo.com.

Sandesh Paudel
Central Campus of Technology
Hattisar, Dharan
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INTRODUCTION TO THE STORAGE OF FOOD MATERIALS

Introduction

Everything undergoes a changing process, which may be physical, chemical, biological or all of them. Nothing remains permanent. The changes may be beneficial (e.g.: fermentation and curing) and destructive, which causes loss. Various variables that affect grain & their quality are temperature, moisture, and geographical location, physical, chemical & biological properties of grain bulk, moisture, mites, rodents & birds.

Thus, storage means building in which art and technology are being utilized in such a way that thing can be kept safely for a period of time.

Functions of Storage

Mainly storage is aimed to reduce and control the rate of deterioration. Storage is repeated phase in the complex e.g. transporting grain from producer to producer and grain product from producer to consumer.

Storage of grain and control of quality occurs in 3 main steps:
1. On the farm.
2. At collection point where grains from number of farms are received.
3. At terminal points where grain is processed or moved forward in still larger bulks.

However, with the introduction of many stringent marketing criteria, economic losses is increasingly co-related with the presence of small number of insects and contaminants such as insects fragments, pesticides and mycotoxin is essentially around commodity.

Importance of Storage

Storage is necessary because the farmer strive to achieve 3 main objectives:
1. To retain supply of food for the family to expand the time period between harvest.
2. To service trading system when crisis go up and to prevent wastage of surplus.
3. To retain seed for planting in ensuring cropping season i.e. as a famine results.

Storage is an integral part of the food processing chain such as production, transportation, storage, marketing, consumption and human & animal health without proper regulation of agricultural production linked to food preservation, processing & storage policies. Storage is carried out by: Traders, Food processors and Exporters. The use of appropriate storage technology is an important way of reducing famine in the months preceding harvest by controlling and reducing the rate of deterioration. It reduces the possibility of biological damage by insects, rodents and microorganism, chemical changes through rancidity development and flavour changes, etc. and physical changes through crushing, breaking, etc. Good storage thus involves controlling temperature, moisture, light, pest, etc.

Quality in grain storage and handling is associated with laboratory equipment and technique. Technical and management personnel should be aware of receiving, drying and storing. As soon as the grain is put into storage, its quality cannot be improved but it can be maintained. Quality control serves as an alarm that will indicate the procedure.
What is Warehouse?

Warehouse is a building for storage of goods before distribution to retailer. In general, we consider only food storage facilities. Storing large amount of foods either for a long or short period for distribution in normal food channel tends to be a warehouse. There are wide varieties of names associated with food storage facilities such as:

- Wholesale grocer
- Branch warehouse
- Public storage warehouse
- Distribution center
- Manufacturers warehouse
- Case and carry storage

Types of grain storage facility
The types of grain storage in the country could be grouped into:

- Individual – farm level storage
- Co-operative storage
- National level storage
- Special project storage

Storage is not a new idea for farmers since they have been developing ways of storing produce for hundreds of years. Food security is particularly important since

- they are often the last to eat in a household for times of famine
- selling foods generate income

For both situations, it is valuable to be able to store food after harvest so as not to be compelled to sell at lower prices. Appropriate storage techniques can prolong the life of food stuff and/or protect the equality thereby keeping it for long time of the year.

The Production System Concept

In considering the prevention of storage losses, it is usual to think of storage as an ecosystem and to identify those components of a system that influence deterioration. However, storage is only a part of system comprising production, harvesting, handling, transportation, storage, marketing and processing. The prevention of loss involves the methodological consideration and management of output, input and constraint of pest control as a subsystem of much larger production system.

Output of Production System

The desired output or objective is to provide sound grain that is free of pests, diseases and contaminants such as weeds, seeds, mycotoxins & excessive pesticide residues.

Input of Production System

Biotic & abiotic components and control operation process such as hygiene, inspection, sampling and irradiation. The most important components of the system are biotics and abiotics.

1. Biotics
   - The grain
   - Weed seeds, chaff, straws and grain fragments
   - Bacteria, yeasts and molds
- Insects and mites
- Rodents and birds

2. Abiotics
   - Storage structure & associated handling and transportation facilities
   - Temperature, moisture and intergranular atmosphere
   - Contaminants such as soil, stones and insecticides

Such components are mostly interdependent. This is particularly true for the condition of grain itself and the organism that exploit it. This relationship is so strong that no soundly based system of pest management can ignore the factors that influence the keeping quality of commodity itself.

**Biotic inputs and their manipulation**

The grain is living but resting organism whose viability and metabolic activity, particularly respiration and germination, may be profoundly influenced by storage environment. Keeping metabolism at low level, by holding grain moisture and temperature at low level, is essential to minimize the possibilities of exploitation of grains by pests. The consequence of respiration is loss in mass and production of heat, carbon dioxide and water or in the absence of air, ethanol. The more stable changes during storage may involve an increase in free fatty acids and breakdown of protein and carbohydrate and vitamins. The maintenance of α-amylase and protein levels is of main importance in cereals destined for dough and bread making, as is the prevention of germinability of grains for malting and for seed. Under very poor storage conditions, the grain may germinate and become unsuitable for consumption.

**Abiotic inputs and their manipulation**

The purpose of storage is to protect harvested grain from damage by weather, attack by pests & micro flora and from being stolen. Storage influences grain moisture, temperature and intergranular atmosphere.

The design of a storage system and associated facilities determines the ease with which inspection and pest control can be achieved. Keeping the grain dry and cool is crucial. The siting, orientation and construction of the storage are important in this regard. The provision for access of cleaning and inspection should be integral part of storage design.

**Temperature:** Low temperature and High temperature

*Low temperature:* For pest control, temperature should be maintained 15-17°C at which level most species either cannot complete development or increase very slowly. To suppress mites and fungi, temperature of less than 5°C may be needed.

*High temperature:* IR & microwave heating are effective in disinfecting grain.

**Moisture:** Moisture has both direct and indirect influence on many of the components of grain storage. Low humidity (< 65%) and moisture 14% are generally preferred. In case of low moisture content, 11% or less is desired.

**Intergranular atmosphere:** The building or modification of storage is required. The physio-chemical process involves an influence of materological conditions of the atmosphere and commodity.
FOOD LOSSES AND DAMAGES DURING STORAGE

Introduction

There have been many attempts to define loss and much confusion has arisen since loss has frequently been used synonymously with damage. Loss is a measure of decrease in food stuff i.e. weight loss, loss in quality, nutritional loss, loss of viability and commercial loss. Post harvest loss begins during the process of collecting or separating food edible quality from its site of immediate production and ends when the food enters the mouth.

Losses of growing crops are immediately apparent because there is less produce to harvest. On the other hand, losses of stored foods are not apparent and the extent of deterioration in the quality of produce is seldom fully appreciated. Deterioration of stored food may begin while the crop ripens, i.e. before harvesting. Bacteria, fungi and termites attack various parts of plant while beetles & moth fly out of farm buildings, etc. Deterioration of products in the form of weight loss, chemical changes in protein, carbohydrate and oil content and of contamination by chemical toxins, insect fragments, and due to rodent urine and faeces is common in tropics and subtropics.

An FAO estimate of worldwide annual losses in store has been given as 10% of all stored grains, i.e., 13 million tons of grain losses due to insects or 100 million tons of failure to store properly but losses in the temperate regions of the world can be expected to be lower than in the tropics and subtropics. Current losses of about 30% are apparently occurring throughout large areas of the world. Prevention of these losses would result in:

1. More food for consumption by the farmers
2. More food available for farmers to sell
3. Higher living standards for farmers
4. More food available for non-farming population
5. Higher quality and competitiveness of export commodities in world trade
6. Sounder economy for the country and improvement of its international standing.

Loss means any changes in the availability and edibility, wholesomeness or quality of food that prevents it from being consumed by people. Food loss may be direct or indirect. Direct loss is the disappearance of food by spoilage or consumption by rodents & birds and indirect loss is the lowering of quality to a point where people refuse to eat. If the food is consumed by people, it is not considered as loss. On the other hand, if it is not consumed by people for any reason, then it is considered as post harvest loss.

Levels at which losses occur

Losses occur at different stages in the movement of food from the field to the consumer. There is deterioration while the product is growing in field; before harvest and after, while it is in the producer’s hand; again in the traders’ transports vehicles and stores; while it is being processed (e.g. by millers); and, finally, in the port transit sheds and on ships. Transit sheds must be designed with a view to make possible quick movement of produce without considering the possibility of incorporating a system which would also:
a. Prevent rodent infestation;
b. Prevent cross infestation of insects from one parcel of produce (e.g. palm kernels, ground-nuts) to another (e.g. flour);
c. Minimize temperature gradients and the movement of air of high humidity through the warehouse and so prevent the development of molds and other microorganisms;
d. Enable insect disinfestations techniques to have maximum effect.

Storage Losses

Losses to harvested produce may be of quantity or quality and may occur separately or together. The higher the qualities demanded or lower the acceptable tolerance, the greater the loss potential. A consignment of rice consisting mostly of broken grains or of grains which are either discoloured or chewed by insects is of lower quality than undamaged whole grains of normal colour for the same variety of rice. A sample of maize meal which is dark in colour, of coarse texture and rather rancid in flavour is of low quality. A grain or kernel seed may be chewed by an insect or rodent so much that only half of the original amount of food harvested remains; the portion which is left may, of course, be of good quality but it may have been contaminated by frass and secretions and therefore have a higher acidity than an uninfested, unbroken grain or kernel.

The various ways in which produce deteriorates between time of harvest (or before harvest) and consumption result in changes in the appearance of the products which are normally detectable by human senses, e.g., sight (appearance); sound (the sound of the produce when shaken in a tin); smell; flavour; and touch (the feel obtained by pressure of the nail on the grain). A study of the factors involved in the deterioration of produce indicates that particular consideration has to be given to a wide range of factors including:

1. Chemical changes in produce;
2. Growth of microorganisms on produce;
3. Development of insects and mites on produce;
4. Feeding on produce by rodents;
5. Human mishandling of produce, affecting quality and causing loss through spillage;
6. Use of poor containers and stores;
7. Exposure of products to extremes of temperature and moisture.

Losses can be considered in 3 ways:

1. Loss related to efficiency of system
   This is most clearly seen in processing e.g. threshing. The lowest loss comes from the most efficient system. The loss of product is not however the only measure of efficiency.

2. Loss related to the natural wastage
   From the moment of harvesting, the natural process is towards decay and loss of quality and quantity. There must be some loss. The aim of good post harvest practice is to keep the loss in post harvest weight. It is not necessary for the best system to adopt.

3. Losses related to the unnecessary waste
   Every step in the post harvest system can result in losses due to spillage, breakage, formation of dust and pest attack.
Causes of post harvest losses
The causes of post harvest losses are divided into 2 groups:

A. Primary causes
   1. Biological or microbiological losses
      - Damage by insects, mites, rodents, birds & large animals, fungi and bacteria.
      - Pilferage (theft by human).
      - Concealment of losses, dust and broken grains, dead bodies of insects and rodents, cracked and broken grains.
      - Dubious (doubtful) trade practice.
      - Birds and rodents damage the grains by consuming, scattering and fouling of grains.
      - Insects and mites are the destructive agents of grains and seeds.
         Though in some cases, insurance of grains is found to be practiced but this is not the actual preventive measure of grain damage because it provides recovery in terms of money rather than in terms of food.
   2. Chemical & biochemical losses
      - Undesirable reaction between chemical components present in foods.
   3. Physical/ Mechanical losses
      - Excessive or insufficient heat or cold and improper atmosphere.
      - Abrasion, bruising, excessive polishing, peeling etc.
      - Shredding-due to birds and animals.
      - Post harvest operation-field curing, threshing, winnowing or sieving.
   4. Physiological losses
      - Sprouting of grain stuffs.
      - Sun cracking due to physical stress set up in rice and other grains.
      - Rapid changes in moisture.

Table: Biological and chemical activities in various moisture content and relative humidity level

<table>
<thead>
<tr>
<th>Moisture</th>
<th>RH at 20-30°C</th>
<th>Biological activities</th>
<th>Chemical activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 8%</td>
<td>30%</td>
<td>Not significant</td>
<td>Lipid oxidation, increase in peroxidase content</td>
</tr>
<tr>
<td>8-14%</td>
<td>30-70%</td>
<td>Possible insects infestation</td>
<td>Increase in uric acid content, Maillard type reaction</td>
</tr>
<tr>
<td></td>
<td>&gt; 60%</td>
<td>Mites infestation</td>
<td></td>
</tr>
<tr>
<td>14-20%</td>
<td>70-90%</td>
<td>Insect infestation, growth of storage fungi</td>
<td>Production of mycotoxins, lipolysis (increase in free fatty acids &amp; off-flavour)</td>
</tr>
<tr>
<td>20-25%</td>
<td>90-95%</td>
<td>Insect infestation, mold &amp; fungal growth</td>
<td>Increase in microbial production of toxins</td>
</tr>
<tr>
<td>Above 25%</td>
<td>-</td>
<td>Bacterial growth, germination</td>
<td>Loss of physiochemical forms of growth, spoilage, depolymerization of starch and proteins</td>
</tr>
</tbody>
</table>
B. Secondary causes
1. Inadequate drying equipment and poor drying seasons.
2. Inadequate storage facilities to protect food from insects, rodents, birds, rain and high humidity.
3. Inadequate transportation and handling losses.

On the farm, the loss may be 3-4%, on the storage up to 15% and in central storage 1-3% loss may occur. However, sometimes 50-55% losses are also found.

Types of Storage Losses
A. Weight loss or Direct damage

This is the most obvious and typical type of damage that occurs when the pests eat part of seed grains or fruit or whatever. Loss in weight is generally due to
- evaporation of moisture
- component parts of a product being eaten by insects, rodents and birds
- attack by microorganisms
- spillage from the container in which the produce is transported or stored
- mechanical damage and insufficient processing

Weight loss also occurs in all post harvest processes of drying, threshing, transportation, storage and milling. It also occurs at markets; in trader’s stores and at large collecting centers (including ports); and in warehouse controlled by produce boards, port authorities, etc. Shredding, hand and mechanical threshing, rapid changes in moisture content and reduction in milling quality of rice as well as other foods is a loss in terms of both weight and financial terms. With cereals and pulses, the % of weight loss is directly related to the % of damaged grains but not constantly related. It is always less than the % of damaged grains, since the grains are seldom entirely consumed. Weight loss may be undefined when traders deal in volume.

The objective of study of weight loss measurement is to identify the causes of weight loss and the stage of post harvest system where they occur and to determine the magnitude of loss of each stage. Changes in moisture content causes changes in weight which may assure weight loss and effect of different moisture content has to be taken into account.

Assessment
To determine the weight loss, it is essential to know the weight of every unit of produce at the beginning and again at the end of the storage period. The reduction in weight registered over the storage period does not always provide an accurate record of the actual weight loss of produce. The assessment of weight losses occurring in product storage is often based on the data obtained from scientifically controlled experiments.

When products are contained in bags, a weight allowance has to be made for the bag; a tare figure (based on the weight of a dry bag) is used. In addition, the variation in moisture or oil content of the bag fibers, re-absorption of moisture by the product in the bag from the humidity in the atmosphere, from water either deliberately added or from condensation on the fabric, the building or the container with which the product is in contact should be taken into account. Another factor is the composition of the contents of the weighed bag which may include dusts and insects. The weight of the dust (more hygroscopic than cereal grains or oilseed kernels), which may consist of
powder from the product, insect and rodent frass, stems, leaves, grass seeds, stones and earth, plus the weight of any insect present, should be deducted from the weight of the product which is sold. It has been shown that the extraneous matter is a major factor in causing heating and creating favourable conditions for insect activity.

B. Food loss or Nutritional loss

Weight loss during storage not due to a loss of moisture is a measure of food loss. A number of different insects (both beetles and moth larvae) and also some mites show a feeding preference for the germ (embryo) region of seeds and grains, thus reducing large amount of proteins and vitamins. This type of loss may result from
- exposure of the product to extremes of temperature and humidity during drying, processing and storage
- from the development of fungi
- from the attack of insects, rodents and birds
- overexposure to sun destroys certain vitamins and causes oxidation of carotene

The effect of insect infestation on the nutritional value of produce varies with the composition of the products affected and the species of insects (depending on its feeding habits). Weevils, which feed mainly on the endosperm, reduce carbohydrate but have little effect on protein & vitamins. In legumes, in which the proteins and vitamins are more evenly distributed throughout the grains, infestation of beetles can cause a loss of about 12% of the available proteins. Beetles are also responsible for consuming up to 50% of peas and beans of which some 25% of the dry matter is crude protein. Many pests eat the bran of cereals and reduce vitamins. Other storage factors such as moisture and fungal infection may also lead to change in vitamin content.

When grains are attacked by insect species which feed selectively on the germ leaving the endosperm almost untouched, food loss is not apparent; weight loss is also very small compared to the loss of vitamins, etc. In the case of insect species of which the young stage (larva) is not confined within a grain, feeding is general and therefore considerable quantities of the outer bran layers of the grain as well as the endosperm are eaten.

Damage to cotyledon doesn’t affect the viability of seed but damage to germ (embryo) reduces the germinative capacity of seed grain. So, pests not only seriously affect the viability of stored seed but when attacking food grains, they seriously reduce nutritional quality as well. A comparison of the reduction in nutritive constituents of different food stuffs under various storage conditions is required. There are considerable data available showing that insect infestation is responsible for severe losses of nutritive values in food.

C. Seed loss or Viability loss

The importance of the availability of good seed is recognized by all farming communities and, irrespective of the level of farming, seed is given special attention. Despite this, considerable losses of seed occur mainly due to lack of information about the factors causing poor germination and to poor facilities for safe storage.
Embryo of grain is consumed by mites and larvae of moth and thus causes a serious loss of germination capacity. This germinating factor is important particularly in seed & grain for malting. Insect attack on embryo may not always adversely affect germination.

Loss of seed results from both external and internal factors. Physical factors such as light, moisture & moisture are important in causing losses. When the seed coat is damaged, respiration of grain increases especially at normal oxygen concentrations and causes loss of viability. Chemical factors in the hereditary makeup of seed as well as chemicals used to control deterioration due to presence and development of microorganisms must be considered. Insecticides and fumigants not only have effect on germination but also on growth of rootlets & the strength of the resultant plant.

Seed loss is apparent through reduced germination, abnormal growth of rootlets & shoots, and reduced vigour of the plant.

D. Quality loss

Selective eating of the germ region of the seeds results in overall loss of quality of the grain, both in respect to the germination and dietary value. Both direct damage to the product and contamination will cause an overall loss in quality of most types of product especially that for export or sale, for it may be downgraded, could even be rejected and this would represent a financial loss.

The losses caused by pests are greater than those caused by chemical changes in nutrient fraction. Enzymes produced by fungi enhance lipolysis and development of rancidity. Most stored products slowly undergo chemical changes that alter their flavour and nutritional value. The change tends to be greatly accelerated by attack of pests, due to the production of dust and broken grains thus accelerating the rate of oxidation. Some fungi can apparently enhance the nutritive value of some food stuffs and few species of microorganisms produce mycotoxins and other toxins that are, in fact, lethal to man and other vertebral animals.

Contaminants odour are usually associated with cockroach infestation and smell of rat urine is quite unpleasant and very distinctive. In absence of infestation, cereal may remain sound for many years with little decrease in protein and very little change in sugar and polysaccharides. Infestation in peanut, maize cause increase in free fatty acids and thus leads to rancidity.

Quality of produce is assessed and the products are graded on the basis of appearance (uniformity of shape, size and colour, texture and dirt content) but smell and flavour are included as quality criteria, particularly for such products as spices and beverages. In particular instances, chemical data such as oil content, acidity, and moisture content & the presence or absence of toxins are included. Foreign matter contents and contaminants are also factors in loss of quality. Foreign matters include insects, fragments, grass, rodents’ hair & excreta, weeds & seeds, parts of plant, earth and glass, etc. Contamination is usually visual in that insects or rat dropping can be seen or recognized. Live insects, dead insects, larva, & pupa together with fecal matter and food fragments are the main visual contaminants in stored food products.

Harvesting under conditions which ensure that the produce is undamaged (i.e. not bruised, cracked or broken) followed by immediate and efficient drying to safe moisture content for storage will ensure that chemical changes within the plant cells are negligible; respiration of the grains or kernels will be almost imperceptible (very slight).
E. Commercial losses

Commercial losses are divided into following categories: Monetary loss, Loss of goodwill (international reputation) and Loss due to legal action.

1. Monetary loss

Monetary loss is an economical loss in any downgrading of produce due to poor quality. In one of the poor storage facilities, a man has to sell food immediately after harvest, when there is surplus of food and price is low and he has to buy it back for food when the price is high. Losses due to packaging and cost of repacking because of damage by rodents and handling practices, repair, stoppage in machines and damage to the fabrics of store are all economic losses in which affect of infestation is evident.

Knowledge and the facilities for drying products thoroughly and storing them successfully provide the farmer with means to overcome a situation which forces him to sell at low prices. Similarly, knowledge of the range of market prices within an area would help the farmer to send his products to the most favourable market, so as to obtain maximum monetary return for them.

2. Loss of goodwill (reputation)

This is not directly accountable but the loss is very important especially with regard to rising quality standard. With some countries having export or import produce through other countries, it is essential that all countries within a continent maintain equally high standards of hygiene and quality of produce. If a product from a particular country is regularly found to be infected, then this information spread internationally. Hence other countries will tend to assure contamination and produce will either not be accepted at all or prior fumigation will be required.

Industrial organizations in the developed part of the world will increasingly place reliance on the good name of produce from areas of the tropics and subtropics and will inevitably purchase from those areas which can provide products of the highest quality uncontaminated by toxins, insects, etc.

3. Loss due to legal action

This may include human health, mycotoxin, poisoning, contamination and infestation.

F. Loss of quality due to heating (heating of bulk grain)

Shelf heating of bulk stored grains is caused by insects and molds. In bulk grain, air is stagnant & in areas of high insect density, the air will become heated as a result of insect metabolism and hot spots will develop. The moisture from insect body is condensed in the cooler grains at the edge of hot spot. There will be fungal development and moisture can cause some grains to actually germinate. All these biological activities generate more heat, produce more water so that hot spot enlarges and temperature will increase. If insects are responsible temperature may reach 42-46°C, and if molds are responsible temperature may reach 55°C or higher.

When oil seeds are heated, direct chemical reactions may proceed fast enough to cause carbonation and even combination. Continuous high temperature accelerates chemical degradation which results especially in destruction of vitamin and development of rancidity. It also hastens the physiological decline causing a loss of germination capacity. Heating occurs more readily in granular products such as cereals and legumes.
G. Sack damage and infestation (Spillage)

One particular problem with rodent infestation is that the animals often make holes in sacks and cardboard boxes and other soft containers and this leads to product spillage. Birds peck holes in bags and the amount of produce eaten plus that which pours out of the bag (especially small grains such as sorghum and millet) can result in a loss of some 70% of the original weight of the bag. Rodents chew holes in bags, causing an excessive amount of spillage which becomes contaminated with rodent, excreta, dust, etc.; the quantity of produce contaminated by rats is considerably greater than what they eat.

H. Cross infestation

A major problem in produce storage and shipment is that of cross infestation. It happens in two major ways:
1. Either clean produce is brought in infested food store or
2. Clean store containing infested produce receives.

When infested produce enter clean store, then the insects spread into previously uninfested material. Many of serious pests are sufficiently polyphagous to spread easily from one food stuff to another.

Some of the large regional stores or godown and warehouses have daily routine of removal of produce and introduction of new produce in the store and there is continued cross infestation.

Damage

A stored grain bulk is an ecosystem made in which deterioration results from interaction between living organisms and their non-living environment.

Deterioration of stored grain results from interaction among physiological & biological variable. In the ecosystem, most important living organism is the grain itself. Both the grain and grain bulk have several physical (e.g. pore nature) and biological (e.g. respiration) attributes, the importance of which depends mainly on surrounding medium.

Abiotic environment of grains include physical (temperature, CO₂, O₂) variables, physiological variables and organic compounds which are by-product of biological activity.

Biotic variables include microorganisms (fungi, actinomycetes and bacteria), anthropoda (mites and insects) and vertebrates (rodents and birds), etc. Although deterioration is slow and less dramatic in the beginning, complete loss can occur if the correct correlation of variables are not maintained in an undisturbed bulk.

Post harvest maturity involves protein synthesis of kernels which occurs best at moisture content below 14% and moisture content of 16-45% is crucial to storage stability. To obtain the shortest period of maturity (15-20 days), damped grain should be artificially dried within 1-2 days after harvest at 30% RH and 45°C. Since spoilage of grain results from many ecological relationships between/among several biotic and abiotic variables over a period of time, it can only be understood and prevented in long run by adopting a multi-disciplinary approach.

In grain storage, great effort should be made in gathering information on as many single facts of the problem as possible to make a synthesis of data. Wherever possible, management decision should follow rather than precede this synthesis.
A stored product entomologist should try for e.g. to learn about the protein content, the possible food value and toxicity of molds associated with the grains before making recombination for storage or dispersal. This recombination should of course be based primarily on his knowledge of insect infestation.

**Types/Causes of Damage**

A. **Physical or Mechanical damage**
   - Cracking of the endosperm of the grain due to violent mechanical handling.
   - Rapid change in moisture content during drying.

B. **Biological damage**
   - Reduction in food value and protein content due to consumption by insects.
   - Decrease in thiamine by 60-70% in infested stored grain bulk.
   - Reduction in germination power caused by larvae of moth and mites.
   - Contamination with rodents and insects fragments, rodents hair and excreta, causing down grading of grain.

C. **Chemical damage**
   - Stored products slowly undergo chemical changes that alter the flavour & nutritional value.
   - Broken grain and dust accelerate the rate of oxidation.
   - Breaking down of fats causes an increase in free fatty acids and oxidative rancidity, this causes off-flavours.
   - Reducing sugar usually increases slightly during storage.

D. **Loss of Palatability**
   - Adverse changes of flavours caused by presence of insects and mites and their excreta.
   - Chemical deterioration.

E. **Heating**
   
   Shelf heating of bulk stored grains and seed is due to insects and molds. If there are enough insects and molds or both actively growing, they generate heat more quickly & the temperature rises and may reach between 42-46°C (if insects are responsible) and > 55°C (if molds are responsible). Continuous high temperature accelerates chemical degradation, especially the deterioration of vitamins and development of rancidity.

F. **Other Damages**
   
   Other damages may include damages to package, cartoons, boxes, sacks, building and machinery.

**Health Hazard**

Specially microbiological and chemical changes are more health hazardous than other. Molds e.g. *Aspergillus flavus* may produce aflatoxin in cereal grain and legumes. Similarly other food poisoning microorganisms may cause health hazard.

The obvious risk of human disease is associated with infestation by rats. Potential hazard to health of people employed in the grain industry comes from grain dust, its biological contaminants, chemicals used in the treatments and from equipment and storage procedures. The health hazards
from seed with born fungi may increase as grain is stored for prolonged period and storage method are introduced.

Evidences indicate that excessive exposure to grain dust leads to chronic respiratory disease. Grain dust harms the lungs both by direct action and immunologically.

**Direct health hazard**

The harmful influence that grain can exert on health is almost entirely due to the dust that that is associated with it. The dust is composed of integration product of the grain itself, soil, fungal spores, bacterial spores, insects, mites and their residues, chemicals and other contaminants that are associated with grain.

**Methods of measuring losses**

**Indirect method**

To determine the conversion factor, take a random sample of 100-1000 grains from the sample which contains 10% or more damaged grains and calculate the % weight loss using gravimetric method and count the % of bored grains.

For cereal, Conversion factor = \( \frac{\text{wt of bored grain}}{\% \text{ of wt loss}} \)

For pulses, Conversion factor = \( \frac{\text{No of bored grain}}{\% \text{ of wt loss}} \)

And,  
\[ \% \text{ Weight loss} = \frac{\text{Total number of holes}}{\text{Conversion factor}} \]

**Disadvantage**

This method assumes that insects choose grain at random which may not be true. It also doesn’t account for hidden infestation because grains containing such infestation are grouped as under-damaged. Both these cause misleading and give negative result i.e. very low level of infestation.
DEFINITION & MEASUREMENT OF PHYSICAL FACTORS AFFECTING STORED GRAIN

Introduction
The physical properties of grains are important for simulating the heat and mass transfer phenomena during drying and storage. The physical dimensions and 1000 grain weight are used to describe the physical characteristics of grains and their influence on drying. Bulk density, specific heat, latent heat of vapourization, shrinkage, and heat transfer coefficient of a grain bed are essential in any simulation of the heat and mass transfer during drying. Beside these, thermal conductivity as well as coefficient of friction of cereal grains in themselves and that on various surfaces is essential.

Structure of cereal grains
Knowledge of structure of cereal grains is useful for interpreting the drying rate in terms of biological structures. The anatomical structure of all cereal grains is basically similar, but can differ from one another in details.

Grains like wheat, maize, rye and sorghum consist of pericarp and seed. The seed is composed of testa, embryo and endosperm. Grains like rice, barley and oats are covered with an additional coat of palea and lemma which constitute the husk.

During drying, moisture flows from the interior to the surface of the kernel and the flow of moisture from various parts of the kernel depends on the internal characteristics of the endosperm, the permeability of the aleurone layer, and testa and pericarp, and extent of damage to these layers.

Physical or Mechanical properties of cereal grains
Bulk grains at times behave as a solid or liquid or in between. These two considerable variations occur in the properties according to the degree of packing. The amount of foreign matter, moisture content and variety involved and the values quoted should be regarded as a guide only.

A grain bulk has 5 main physical properties: porosity, flow, wall loading, segregation/layering and sorption.

A. Porosity
Porosity is due to the colloidal nature of grain kernel itself and position of Intergranular space within grain bulk. Approximately, 10-50% of grain bulk is intergranular air space providing passage for the movement of air, convection current, insects, fumigation, and forced air flow for drying and cooling. The extent of porosity depends upon the size, shape of the grain, elasticity, surface state, dockage level, weight, compactness, storage period and distribution of moisture in the bulk. The physical characteristics in turn influence the movement of air, heat and moisture.

Together, of course, they affect storage stability of grain. Porosity is influenced by packing, increases with the boundaries of the container.

\[
\text{Porosity} = \frac{\text{Density} - \text{Bulk Density}}{\text{Density}} \times 100
\]
Density

Density is one of the physical properties of substances (grains), defined as the mass contained in a given volume. A known weight of sample is taken and placed in a measuring cylinder containing known volume of water. The volume of water displaced is noted and then the density is determined as:

\[
\text{Density} = \frac{\text{weight of grains}}{\text{volume of water displaced}}
\]

Bulk density

Bulk density is the weight per overall unit volume of a substance. It is used in particular for porous substances where density is affected by pore volume and can be increased by the presence of pore fluid. Bulk density is one measure of quality. The bulk density of cereal grain is usually determined by measuring the weight of grain sample of known volume. The grain sample is placed in a cylindrical container of known volume and the uniform density in the cylinder is obtained by gently tapping the cylinder vertically down on to a table several times in the same manner. The excess on the top of the cylinder is removed by sliding a string along the top edge of the cylinder. After the excess has been removed, the weight of the grain sample is measured by an analytical balance. Dry weight of the grain is determined from the weight of the grain and the moisture content.

Table: Intergranular space of some granular stored foods

<table>
<thead>
<tr>
<th>Product</th>
<th>% Moisture content</th>
<th>Porosity%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Loose packing</td>
</tr>
<tr>
<td>Rice</td>
<td>14</td>
<td>-</td>
</tr>
<tr>
<td>Small yellow maize</td>
<td>13.3</td>
<td>44.4</td>
</tr>
<tr>
<td>English wheat</td>
<td>16.7</td>
<td>44.9</td>
</tr>
<tr>
<td>Hard water wheat</td>
<td>21.3</td>
<td>48.3</td>
</tr>
<tr>
<td>Ground nut</td>
<td>12.6</td>
<td>42.5</td>
</tr>
<tr>
<td>Coffee bean</td>
<td>5.6</td>
<td>-</td>
</tr>
<tr>
<td>Barley</td>
<td>12.6</td>
<td>56.9</td>
</tr>
</tbody>
</table>

B. Flow

The flow property of the grain is determined by the coefficient of friction and the angle of repose. The coefficient of friction of cereal grain on themselves and that on various surfaces are essential for rational design of grain bins, silos and other storage structures. These properties are also important in the design of handling and processing equipment.

Coefficient of friction

Coefficient of friction between granular materials is the tangent of the angle of internal friction or the angle at which the grain began to flow. The coefficient of friction is approximately independent of the area of contact, the sliding velocity and the intensity of pressure. There are two types of friction, static (encountered at the start of motion) and dynamic (present during motion).
Angle of internal friction and Angle of repose

The angle of repose is the angle which the side of the piled material makes with the horizontal. In other words, angle of repose of angle of natural slope is the angle between the base and slope created by fall of a parcel of grain on the feet surface at zero velocity. For any material, the angle of repose varies with moisture content and the amount of foreign materials present and increases with the increase in either.

There are two types angle of repose: static and dynamic. Static angle of repose is the angle of friction taken up by a granular solid about to slide by itself and dynamic angle of repose is the angle of repose when the bulk of material is in motion such as movement of solids from bins.

To determine the angle of repose, grain bulk is allowed to fall slowly (on a circular base plate) to make a heap and then the angle is determined as:

\[ \tan \theta = \frac{h}{\sqrt{d}} \]

or, \[ \theta = \tan^{-1} \left( \frac{2h}{l} \right) \]

Where, \( \theta \) = angle of repose
- \( h \) = height of the heap (cm)
- \( d \) = diameter of the heap/plate (cm)

Angle of repose is found to increase with the increase in moisture content of the material. This variation of angle of repose with the moisture content occurs because surface layer of moisture surrounding the particle holds the aggregate of grain together by the surface tension.

Also, Angle of friction = 180° – angle of repose

Internal angle of friction is the important property of grain mass that affects the grain flow. The internal angle means the angle of friction between the grain particles within the grain bulk.

C. Wall Loading

Loading behaves in quite unexpected ways. Wall pressures differ from those which a liquid of density as the grain would give. Pressure increases greatly from the static value during emptying of the bin and in a tall vertical site; most of the weight of grain is supported not by floor but by the vertical wall.

D. Segregation or Layering

Segregation or natural layering by grain movement is an important property of grain bulk. Any movement of free flowing granular material will tend to result in segregation of the various components of the mixture according to the particle size and shape. When the grain is loaded into a
bin or granary, heavy seeds and impurities with high specific gravity and terminal velocities drop vertically and settle quickly as the floor of the bulk. Lighter kernels & lighter dockage components such as chaff with low specific gravity and low terminal velocity drop slowly and are carried out by air currents towards the wall of granary or settle near the surface of slope.

Each time grain is transferred from one granary to another, lighter kernels & most of the lighter dockage materials circulate along the wall of the bin and the larger & heavy kernels remain near the central column of newly formed grain bulk. This gravity principle is applied every time the grain is moved. The nature of layering also depends on the slope of bin, the ratio of height to cross-section and location of the discharge opening.

E. Sorption

Sorption is an inherent (existing in a thing as a natural or permanent quality) property of all cereal grain bulk. This term includes 3 processes:

i. adsorption
ii. absorption
iii. chemisorption

Because of the porous structure of seed capillary, it can take up and hold moisture and vapour of other components from the ambient air. Sorption also includes the phenomenon of capillary condensation and chemisorption. In addition of inherent characteristics of grain kernel, sorption also includes rapid absorption and usually slow desorption of various gases such as NO₂, CO₂ & NH₃ and phenol vapour. Once absorbed, it is difficult to remove from grain bulk.

Chemical reaction or chemisorption between the absorbed and adsorbed gas often happens e.g. fumigation. Most grains absorb moisture and release it to the ambient atmosphere until equilibrium is reached. The quantity of water in air equilibrium with the grain is usually less than it would be if air was in equilibrium with free water. The more tightly the absorbed water is bound to the grain, the less it affects the ambient air. Therefore, the RH of air in equilibrium with grain is lowest at low moisture content but increases near 100% as moisture increases. The equilibrium moisture content for all stored cereals ranges in between 7-36%. In most grain, an increase in RH does not uniformly increases the moisture content of grain. Above 70-75% RH, slight increase in RH of surrounding air corresponds to large increase in moisture content of most stored grains.

In planning safe storage of grain, information of moisture content and RH relationship for a particular cereal type is crucial. The oil seeds which are higher in oil content and lower in hydrophobic acid contents have uniformly low moisture content.

Lack of uniform distribution of moisture content in a grain bulk is an important factor. This phenomenon is due to:

i. non-uniform moisture distribution in parts of bulk due to anatomical peculiarities of grain
ii. the variation in the absorption capacity among grains of different shape, size and maturity
iii. the RH of the ambient air
iv. the evolution of heat by various biotic components of the bulk grain
v. the condition of granary
vi. the difference in temperature resulting in varying thermal conductivity in various parts of grain
The other important physical properties of grain are:

Physical Dimensions

Physical dimensions of a cereal grain are of vital importance in the design of cleaning & grading equipments. Furthermore, the dimensions of grain have an important influence on its drying characteristics. The length and width of a cereal grain are usually obtained by direct measurement through an accurate microscope and the thickness is measured by a micrometer screw gauge. In general, the length is determined by taking the mean length of 10 kernels arranged in row. The l/b (length/breadth) ratio is also important.

1000 grain weight

The 1000 grain weight is also of importance in the design of cleaning and grading equipment. It also has application in the determination of effective diameter of the grain.

The 1000 grain weight is usually determined by multiplying the weight of 100 randomly selected grains by 10 and the weight of 100 grains is measured by an electronic precision balance.

Shrinkage

Shrinkage of an agricultural product during drying is an observable phenomenon and it may have significant effect on drying rate and temperature distribution especially during deep bed drying of agricultural crops. The rate of shrinkage of grain bed is usually determined by simultaneously monitoring the changes in weight and depth during drying in a bin at constant temperature and mass flow rate of air.

The shrinkage of a grain bed at any instant during drying is the cumulative effect of the free shrinkage of the cells due to the loss of moisture and elastic shrinkage, if any, due to constraints on the free shrinkage exerted by the adjacent cells of the grains in bed. The rate of shrinkage of the cells in the grains decreases as the moisture content approaches a low value. Thus, the rate of shrinkage in the grain bed decreases to almost zero at very low moisture content.

Thermal properties of cereal grains

A mass of cereal grain is very good thermal insulator and the temperature changes in the interior of the bulk. Also heat generated by insects and molds within a bulk raises grains temperature more or less irrespective of the outside condition. Interrelation between thermo-physical properties of grain and grain in bulk such as thermal capacity must be considered. Temperature conductivity and the physical variables such as conduction, convection, radiation & evaporation, condensation and absorption are responsible for transfer and exchange of heat and moisture through bulk grain.

Conduction is the transfer of heat due to the contact between surfaces whereas convection is the circulation that occurs in fluid at non-uniform temperature, using variation in density and gravity action. In grain bulk, convection is the transfer of heat through intergranular air.

The important thermal properties of grain are:

A. Specific Heat

The specific heat at a constant pressure is normally used for studying the heat transfer problems during drying and storage of agricultural crops. The pressure dependence of specific heat is very little for both solids and liquids until extremely high pressure is encountered. However, at ordinary
temperatures and over temperature intervals which are not great, specific heat may be considered as constant physical property.

Siebel (1892) proposed that the specific heat of food materials can be expressed as the sum of the specific heat of solid matter and that of water associated with the solid dry matter. Siebel proposed the following equations for food materials such as eggs, meat, fruits & vegetables.

For values above freezing, \(C_{pg} = 0.837 + 0.03349 M_w\) (\(C_{pg}\) = specific heat of grain)

For values below freezing, \(C_{pg} = 0.837 + 0.01256 M_w\) (\(M_w\) = moisture content)

There exists a general agreement among the researchers that the specific heat of wet grain increases linearly with moisture content.

B. Thermal Conductivity

The thermal moisture conductivity of grain is the movement of moisture within the grain bulk owing to the temperature gradient. It is one of the most important factors controlling the rate of deterioration during storage. The rate of change of temperature in a particular grain bulk is determined by the thermal moisture conductivity of grain bulk. It measures the ability of a material to conduct heat between two surfaces maintained at different temperature and is expressed as the quantity of heat conducted in unit time per unit surface area when the temperature changes by one unit (degree) per unit length between the surfaces. According to Oxley, the thermal conductivity of grain at different moisture content was found to be in the order of \(4 \times 10^{-4}\) cal cm\(^{-1}\) S\(^{-1}\). Thermal conductivity of grain is also important in the engineering design of drying, cooling and aeration systems.

There are two main methods for the determination of thermal conductivity of cereal grains. They are: Steady state method and Transient heat flow method.

The low thermal conductivity of bulk grain is often an important contribution factor in a high rise in temperature from minor heat source created by microorganisms and insects in micro-environment within the bulk grain.

The thermal conductivity of wheat and rough rice have been reported to increase with the increase in moisture contents.

In temperate region, spoilage of grain due to accumulation of moisture droplets or condensed vapour transmitted from warmer to cooler parts of grains can be expressed by this phenomenon.

C. Thermal diffusivity

It measures the rate at which temperature changes are transferred through material by conduction (i.e. it is also governed by thermal capacity of grain bulk). The thermal diffusivity of grain is usually in order of \(0.00115\) cm\(^2\) S\(^{-1}\). Specific heat of wheat at 12% mc is 0.50 cal gm\(^{-1}\) °C\(^{-1}\).

\[
\text{Thermal diffusivity} = \frac{\text{Thermal conductivity}}{\text{Density} \times \text{Sp.heat}}
\]

The rate of change of temperature in a particular grain is given by thermal conductivity of grain bulk and for each unit of heat transfer; the temperature change by an amount depends on the product density and specific heat.

Thermal diffusivity also determines the extent at which outside temperature influences the temperature of grain bulk by conduction.
D. Latent Heat of Vapourization

It is the amount of heat required to evaporate unit mass of liquid (moisture) from the product. The energy required to evaporate moisture from grain especially at low moisture content is higher than that of free water and depends on the type of crop. The binding of water in the wheat grain results in a latent heat greater than that for free water, particularly at low moisture content.

The latent heat of vaporization of grain is determined from equilibrium moisture content data. For each temperature, the saturated vapour pressure is found from the steam tables. The vapour pressure of a grain at each moisture contents is determined by multiplying the corresponding relative humidity by the saturation vapour pressure for the given temperature. The logarithm of the vapour pressure of the grain is plotted against the logarithm of the vapour pressure of free water. These should give well defined straight lines. The slopes of the lines, namely, the ratios of latent heat of grain to the latent heat of free water are plotted against moisture content (d.b.). An equation can be developed to describe the ratio of the latent heat of grain to the latent heat of free water as a function of moisture content.

E. Grain Heating (Respiration)

A typical newly filled storage combines wheat with a moisture content which is low but not low enough to make insect reproduction negligible and a temperature which is almost optimum for insect reproduction. The insect population rapidly builds up and the heat produced by insects raises the temperature. Thus, as an unusual result that the insects themselves make their environment uninhabitable. The temperature rises to a value of about 42°C which forces the insects to migrate to cooler areas or results in their death. This is the temperature at which protein denatures. This temperature is the characteristics maximum, which is exceeded only when heat is produced by some other means such as mold activity in high moisture content grain.

Moisture Migration in Grain

Moisture contained in a grain is an indicator of its quality and a key to safe storage. Moisture contained in a grain is of two types:

i. water of composition, called absorbed water which is water contained within the plant cells of which the grain or kernel is composed

ii. adsorbed water which is water present on the surface but not within the cells

The moisture variation within the stored bulk of grain occurs due to:

a. Variation of adsorption capacity among the grains of differing size, shape, maturity, etc.

b. Grain bulk harbors different organisms. They have differing rates of respiration, which in turn leads to moisture variation

c. Condition of granary, storage, and materials

d. Difference in thermal-moisture conductivity

Moisture will move in grain bulk of uniform moisture content if temperature gradient exists in the bulk. If the moisture content is held uniform, then equilibrium RH of the surrounding air rises by increase in temperature. The partial pressure and concentration of water vapour in the air increases and hence RH also increases. Therefore, temperature gradient becomes an indirect driving force for moisture from high temperature & RH region to that of low temperature & RH region.
Vapour is transferred within a bin by convection air currents and moisture content is developed into the grain in bulk due to the temperature difference throughout the bin. When air, which is in equilibrium with the warm grain, passes in cooler grains, the air provides both moisture and heat to the cool grains to come into equilibrium with it.

During summer, moisture migrates from the surface down into the grain bin and up into the surrounding air, but this movement is less than that occurs during winter. Moisture migration is dependent on initial moisture content. Moisture migration is slower in small bins than in large bins because of the relatively shorter flow path from the center to the walls.

In a mix of wet and dry kernels, where conductive air through the grain were not present, moisture exchange is mainly by various diffusion across the intergranular air space instead of by vapour diffusion at liquid flow across the kernel contact point.

In associated grain bins, moisture is transferred more by convective air current than by vapour diffusion because moisture is accumulated near the top of the surface of the bin instead of uniform around the cold periphery of the grain bulk.

The 3 possible mechanisms of moisture migration in bulk grain are as follows:
1. vapour diffusion through the air space
2. moisture diffusion through the kernel solid matter
3. moisture carried by convection air currents - this appears to be the most important

The rate of moisture migration through grain is unlimited by the rate of moisture migration through the intergranular air because this transfer occurs more slowly than the exchange of moisture between air and grain.

**Grain Quality on Storage**

The primary grain quality parameters that should be controlled are variety (inherited), soundness, admixtures & moisture content. Control is exercised throughout the complex legislation system that moves grain from producer to processor and product from processor to consumer. Quality is of concern throughout the whole system but controlling effort is normally exercised where storage facilities are available.

The storage or deliveries of grain and control of quality occurs in 3 different locations:
1. On the farm.
2. At collection point where grains from number of farms are received.
3. At terminal points where grain is processed or moved forward in still larger bulks.

Grains may be handled in sacks without special facilities or in bulk as in flowing commodity within highly mechanized procedures.

Quality control at different stages involves the segregation of classes and varieties, varieties of different qualities, different degrees of soundness, different amounts and type of admixtures and different moisture content. The fair average quality (FAQ) of the system involves maximum segregation and makes most efficient use of bins and elevators and of transportation.

Complex grading system affects better control of quality but complicate inspection and handling procedures. The standards of farming and distribution of collection points, storage and transportation costs, market demands and other economic factors determines where it is best to clean and dry grain and the efficiency of quality control exercised by grading.
GRAIN SAMPLING

Introduction
Sampling is the basic consideration in analytical work. Grain quality accessed by standard test in laboratory is an assessment of sample only.
- The sampling represents whole lot from which the sample has been drawn.
- The reliability of result increases when the sample size is increased.
- The result expressed with respect to sample size is more or less constant e.g. infested grain.
- Probability of selection of unit sample ‘kernel’ increases when sample size is increased.

Sampling plan should be so selected that the cost for sampling or inspection and reliability or efficiency or result are best optimized.

Generally, sample size \( (n) = \sqrt{N} + 1 \)

<table>
<thead>
<tr>
<th>No. of batch</th>
<th>No. to be sampled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 10</td>
<td>every unit</td>
</tr>
<tr>
<td>Up to 100</td>
<td>10 drawn at random</td>
</tr>
<tr>
<td>More than 100</td>
<td>square root of no. of batch at random according to suitable scheme</td>
</tr>
</tbody>
</table>

Types of Sample
1. Primary sample - individual sample drawn from one point
2. Composite sample – combination of primary sample; it is generally large than required and must be reduced
3. Submitted sample – result of correct mixing and reduction of the composite sample to the prescribed weight submitted for analysis
4. Working sample – certain amount of submitted sample taken for analysis

Equipments used for sampling
- Trier suited to the seed to be sampled (probe)
- Seed collection tray or plastic bag
- Mixing tray
- Spatula
- Marker
- Sample packets
- Seals or strings

Heterogeneity
If grain lots were homogenous, the components of the mixture would be uniform and a sample taken from one point would be identical to a sample taken from any other point. In practice, this is not the case and the components are unevenly distributed. The main cause is the difference in weight and size of the components which results in segregation within the bulk.

Methods of Sampling
Methods of sampling include automatic sampling, hand sampling and the use of trier.
1. Hand sampling is the method in which the hand is used to take portions of grain or seeds from open bags or bulk stores. To be accurate, sample proportions must be taken from any place on the surface of grain or seeds and from as deep into the commodity as it is possible to reach.
2. Automatic samplers are usually mechanical devices which take a cut off hulling stream, a grain or seed by transversing the falling stream from one side to another.

3. Sample trier may be of various sizes and consist of single or double hollow tubes of various length. All have knob or handle at one end for ease of handling and have pointed edge on the other end for ease of insertion into bags or grain bulk. Length varies from 0.3 m for bag sampling to 2 m for bulk sampling. Diameter varies from 12 mm for seeds and up to 40-50 mm for drawing large samples from bulk. A common example is spear.

Sampling tools and Container used in grain/product sampling

1. Spear
The most common method of inspection is by the use of sampling spear which is normally 30 cm long. This is the traditional method introduced by trading companies to obtain a sample of a commodity for grading purposes by assessing the quality of the grains or kernels in the sample. The sample is obtained by spiking a number of bags of a consignment with a spear. The standard spear, 3 mm in diameter is pushed into a sack with open face of the spear uppermost, which collects grains only from the outside layer. A slightly more representative sample is obtained with this type of spear by pushing it into the sack with the open face down and, when inserted, turning it upward. Spear sampling methods to access the presence of insects and/or molds in a sack are unlikely to provide an accurate record. With such methods the problem is to know the minimum size of sample which must be taken for given quantities of the produce to be examined. Perhaps the best method to adopt is that of sequential sampling.

2. Dry borer tube
Used for the flour, dried milk and milk products, usually from multi-walled paper board. Instead, stainless steel or aluminium spoon may also be used.

3. Special compartment aligned reclosed probe
This can be opened and closed when necessary. When forced into sack, it is closed and inside sacks, it is opened by rotating and after filling with sample grain, again closed & pulled outside.

4. Conical shaped metal bag probe
For sampling of bags of grains, coffee beans, spices and other similar products stored in bags.

5. Boot or floor trier
For sampling elevator boots (bottom in large flour mills or bakery).

6. Cheese trier and butter trier
To obtain samples from bulk cheese and butter.

7. Probe
For sampling loads of dried grains such as maize or wheat in rails, cars, lorry, etc.
**Sampling intensity**

1. Bulk (up to 500 kg) – 5 primary samples
2. 501 to 3000 kg – 1 primary sample per 300 kg but not less than 5 primary samples
3. 3001 to 20000 kg – 1 primary sample per 300 kg but not less than 10 primary samples
4. Up to 5 bags – each package but not less than 5 primary samples
5. 6 to 30 bags – every 3rd package but not less than 5 primary samples
6. 31 or more bags – every 5th package but not less than 10 primary samples

**Sample dividing**

Sample as drawn from the bulk of grain or seed is too large for convenience and it may be reduced by the method known as quartering. The sample is laid out on a flat surface, mixed and roughly formed to a rectangular or square shape of even depth. It is thus marked out as shown in the figure alongside. Portion A are rejected and portion B are retained for the sample. Note that the portion retained and the portion rejected are diagonally opposite. In this way, the composition of the material is maintained but the sample is halved. The method may be used as many times as necessary to reduce sample to the desired level.

**Sampling grain in store**

A. **Occasional sampling (grain stored in bulk)**

Entire content of store should be sampled. This is done by emptying the store by transferring the content of store to another and sampling is done while transferring. Probe sampling is done and after collecting large number of sample, submitted sample of 1-1.5 kg is obtained by conning and quartering.

B. **Sequential sampling**

Sequential sampling is done for inspection of overall season to determine losses rather than loss in one occasion.

A representative sample of the stored grain is obtained at the beginning of the season. This sample provides reference point against which subsequent samples will be compared. Sample must be taken throughout the storage season. Ideally the sample is collected from each quantity of grain removed. The quantity removed can be regarded as bulk sample and it can be reduced into manageable size by conning and quartering.

The loss of grain by insects and mold can be determined after lost removed i.e. emptying, but summing up the losses during each sampling. The sampling cycle may be varied according to the season. In sequential sampling of stored products, the grains are preferably sampled from where the grain is being removed for consumption or sale.

Sequential sampling of grain (analysis of grain sample for edibility) can be carried out as follows and the figures given (referring to the insects, although comparable data could be suggested for the presence of discoloured grains in relation to hazards from mycotoxins) should not be taken as appropriate to the condition or levels of infestation in any particular country. Each country would have to determine the levels appropriate to its own conditions.
1. Take a number of spear samples from several bags or parts of a bulk until 1 kg sample is obtained. Sieve or examine carefully and count the number of insects present.  
   More than 15 insects: produce is very heavily infested  
   10 to 15 insects: produce is very heavily infested  
   Less than 10 insects: resample  

2. Take spear samples from a number of bags until 3 kg sample is obtained. Sieve or examine carefully and count the number of insects present.  
   More than 9 insects: produce is heavily infested  
   Less than 9 insects: resample  

3. Take spear samples from a number of bags until 9 kg sample is obtained. Sieve or examine carefully and count the number of insects present.  
   More than 5 insects: produce moderately heavily infested  
   Less than 5 insects: produce lightly infested but resample  

4. Take spear samples from a number of bags until 22 kg sample is obtained. Sieve or examine carefully and count the number of insects present.  
   Less than 5 insects: produce very lightly infested  

The above figures are based on the following general assessment of infestations:  
   Number of insects outside grains in 90 kg:  
   Up to 20 insects: very light  
   21 to 50 insects: light  
   51 to 300 insects: moderate  
   301 to 1500 insects: heavy  
   More than 1500 insects: very heavy  

Countries have varying tolerance levels for produce termed fit for export.  

**Packaging, Labeling, Transportation and Storage of Sample**  

1. **Packaging**: According to the type of inspection or criteria of determination, e.g. weight loss, moisture, etc. In general, packaging refers to the filling in container.  

2. **Labeling**: Should be provided with information about the nature of sample, origin of sample, sampling method, date and point of sampling and purpose of sampling i.e. what to be inspected.  

3. **Storage**: Depends upon the inspection parameters.
MYCOLOGY OF STORED GRAIN

Introduction

Fungi have been studied from early times and used for food, medicine and intoxicants. A large number of fungi are found both on and inside food grains; these can be grouped into internal and external micro flora.

Fungi are multicellular plants consisting of branching, intertwined filaments called hyphae. A mass of these hyphae is known as mycelium. Mycelium on cereal grain is termed mold growth. Fungi are plants without root, leaves or chlorophyll; therefore, they are forced to live off other materials such as grain.

All produce is susceptible to attack by fungi and only a few of the numerous fungi species are commonly found in large numbers on any particular sample of produce. The dominant species depends upon the size of the original inoculum, the chemical composition of the product and the temperature condition of the storage. Fungi also have indirect effect since they encourage the development of infestation by some species of insects and mites.

According to Christensen and Kaufmann (1969), major losses caused by fungi in cereal grains are:

- Decrease in germinability
- Discolouration of seed
- Heating and mustiness
- Biochemical changes
- Possible production of toxins
- Loss in dry matter

During growth some fungi produce chemicals which can be toxic to man or domestic animals. These chemicals are known as mycotoxins. One specific group of mycotoxins, aflatoxins has been established as a great potential danger to livestock. Morphologically identical strains vary in their ability to produce toxins and fungi are frequently present on products as contaminants. Moldy products obviously should not be used for human or animal consumption.

Fungi in foods and feed have been problem for many years and numerous cases of ill effect including death from ingestion of moldy feeds are reported. The mold associated with the damp grain heating can produce toxins which are harmful to animals and spores which may cause allergies and respiratory disorder in man.

Fungi on cereal grains are divided into three groups: field fungi, intermediate fungi and storage fungi.

A. Field Fungi

The fungi that invade the developing grains in the field are called field fungi. The major field fungi are species of Alternaria, Cladosporium and Helminthosporium, although Culvularia and Stemphylium also occur. These fungi are of dark coloured spores and cause discolouration of cereal grains often observed in plants exposed to excessive moist weather before harvest. These fungi are not directly involved in grain spoilage but they stimulate respiration.
B. Intermediate Fungi

The fungi that develop on mature heads of the standing or swathed crops are called intermediate fungi. Epicoccum, Nigrospora and Papularia are some examples of intermediate fungi which tend to infect seed at or near harvest.

C. Storage Fungi

Storage fungi usually infect the seed often after the grain has been placed in the storage. The major storage fungi comprise about a dozen of species of Aspergillus, several species of Penicilium, single species of Sporendonema and possibly a few species of yeasts.

Most storage fungi grow very quickly at some point in the temperature range of 20-40°C and above 90% RH. The major conditions that influence the development of storage fungi in stored grains are: (1) the moisture content of the stored grains, (2) the temperature, (3) the length of time the grain is stored, (4) the condition of the grain, (5) the amount of foreign materials present in the grain, and (6) activities of insects and mites.

1. **Moisture content**: No species of storage fungi can grow below 60% equilibrium RH. The most drought resistant of storage fungi, *Aspergillus restrictus* and *Aspergillus halophilicus*, cannot grow at moisture contents below those in equilibrium with a RH of approximately 65%. Thus, for any seed with moisture content in equilibrium with a RH below 65% should be safe from the attack by storage fungi, regardless of other conditions of storage.

2. **Temperature**: Common grain storage fungi can grow most rapidly at 30-32°C & their growth rate decreases as the temperature decreases. Low temperature is as effective as low moisture content in preventing damage by storage fungi.

3. **Length of time the grain is stored**: A moisture content which is safe for a certain time is not safe for longer time. Longer the storage period to be, the lower the moisture content should be.

4. **Grain condition**: The grain which has already been attacked by storage fungi will develop more damages in a given period of time, or will develop a given amount of damage in shorter time and will be subjected to continued invasion by storage fungi and associated damage at lower mc and lower temperature than preferably sound grain.

5. **Foreign materials**: Foreign materials consist of broken kernels, weed seed, small parts of plants, parts on insects, etc. The accumulation of foreign materials smaller than grain kernels increases the air flow resistance and prevents uniform air flow. For long time storage, the less the foreign material, the better is the grain condition.

6. **Insects and mites**: Insects and mites affect the development of fungi by increasing moisture content of the grain and carrying spores of fungi into grain.

**Control Methods**

Control methods for all fungi, insects and other associated organisms in stored grain include lowering temperature and moisture content, limiting the oxygen content or increasing the carbon dioxide content of the atmosphere and treating with chemicals. Time is an important factor because the control becomes more complicated as the length of storage period increases.
BIOLOGY OF STORED PRODUCT INSECTS

Introduction

In the tropics, beetles & moths are the main insect pests causing losses & deterioration to stored food grains. Cockroaches are also a pest; by carrying microorganisms they contaminate foodstuffs, cartons, boxes, crates, etc. containing produce with which they come in contact. Ants and termites are also troublesome in some circumstances.

As a result of insects’ feeding activities, the quality of the remaining grain is lowered, germination is reduced or abnormalities occur during germination. The effect of insect attack on germination of dicotyledonous seeds such as pulses is greater than on the monocotyledonous seeds such as maize.

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. 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 do not breed successfully in environment where the relative humidity is maintained at less than 40% (i.e. for cereals less than equilibrium mc of 8%), and the temperature below 100ºC. Insects can live and reproduce at temperatures between +15°C and +35ºC. Low humidity slows or even stops their development, and a low supply of oxygen rapidly kills them. Each species has a characteristic range of physical conditions for optimum development.

The insects most likely to infest stored products belong to the following families:

a. Coleoptera (beetle & weevil family, damage by larvae and adult insects);
b. Lepidoptera (moth family, damage only by larvae).

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

A. Coleoptera - Some common insects are tabulated below:

<table>
<thead>
<tr>
<th>Insect species</th>
<th>Scientific name</th>
<th>Common name</th>
<th>Products infested</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sitophilus oryzae</td>
<td>Rice weevil</td>
<td>Paddy, rice, wheat, maize, sorghum</td>
<td></td>
</tr>
<tr>
<td>Sitophilus granarius</td>
<td>Granary weevil</td>
<td>Paddy, rice, wheat, maize, cassava</td>
<td></td>
</tr>
<tr>
<td>Rhizopertha dominica</td>
<td>Lesser grain borer</td>
<td>Maize, wheat, sorghum, rice, pulses, oilseeds &amp; oilseed cake</td>
<td></td>
</tr>
<tr>
<td>Trogoderma granarium</td>
<td>Khapra beetle</td>
<td>Maize, wheat, rice, oilseeds, dried fruits</td>
<td></td>
</tr>
<tr>
<td>Oryzaephilus surinamensis</td>
<td>Saw toothed grain beetle</td>
<td>Maize, wheat, flour, ground nuts, milled cereal products, dried fruit, cocoa, animal feed cakes &amp; meals</td>
<td></td>
</tr>
<tr>
<td>Tribolium castaneum</td>
<td>Red flour beetle</td>
<td>Maize, wheat, flour, ground nuts, milled cereal products, dried fruit, cocoa, animal feed cakes &amp; meals</td>
<td></td>
</tr>
<tr>
<td>Tribolium confusum</td>
<td>Confused flour beetle</td>
<td>Maize, wheat, flour, ground nuts, milled cereal products, dried fruit, cocoa, animal feed cakes &amp; meals</td>
<td></td>
</tr>
</tbody>
</table>

Compiled by: Sandesh Paudel
<table>
<thead>
<tr>
<th>Scientific name</th>
<th>Common name</th>
<th>Products infested</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corcyra cephalonica</td>
<td>Rice moth</td>
<td>Maize, wheat, sorghum, rice</td>
</tr>
<tr>
<td>Euphestia cautella</td>
<td>Tobacco/Almond moth</td>
<td>Maize, wheat, sorghum, rice, cocoa</td>
</tr>
<tr>
<td>Sitotroga cerealella</td>
<td>Angoumois grain moth</td>
<td>Maize, wheat, paddy, sorghum</td>
</tr>
<tr>
<td>Plodia interpunctella</td>
<td>Indian meal moth</td>
<td>Maize, groundnuts, dried fruits</td>
</tr>
</tbody>
</table>

### Characteristics of the insects

#### A. Coleoptera (Beetle and Weevil Family)

1. **Sitophilus oryzae** (Rice weevil)
   - Reddish brown to black short weevil, worldwide in distribution
   - 1/8 to 1/16 inch long
   - Consists of round pits on the thorax and two reddish spots on each wing cover
   - Larva is short, flat and whitish
   - Larva and pupa develop within a single grain or kernel of maize
   - Eggs (300-400) are laid inside the grains by female (capable of laying 300-400 eggs)
   - Life cycle; Larva: 4 to 5 weeks at 30°C and 70% RH
     Adult: 4-5 months
   - Destructive phase: both larva and adult
   - Both adults and larva feed on stored produce and are primary (serious) pests of sound, dry cereal grains and their products. As it was first found in rice, it is commonly known as rice weevil. Also, it attacks maize, wheat, sorghum, macaroni, etc.

   ![Fig: Sitophilus oryzae (Rice weevil)](image)

Compiled by: Sandesh Paudel
2. *Sitophilus granarius* (Granary weevil)
   - Small blackish or reddish snout beetle
   - Similar to rice weevil in having a mouth at the end of their snout
   - Weevil rarely exceeds 3/16 inch length and has no wings under the wing cover
   - Thorax consists of many longitudinal punctures
   - Destructive phase: both larva and adult; feed on wide variety of grains
   - Adult female lives for 7-8 months and lays 50-250 eggs inside the grain kernel

![Fig: Sitophilus granarius (Granary weevil)](image)

3. *Rhizopertha dominica* (Lesser grain borer)
   - Easily distinguished from other grain borer by its cylindrical form and smaller size
   - 1/8 inch (3 mm) length and 1/32 inch width
   - Dark brown or black with a rough surface
   - Has a prominent rounded thorax with a rasp-like sculptured surface, largely concealing the head. Head is turned down under the thorax where powerful jaws allow it to chew grain kernels into a fine powder.
   - Eggs (300 to 500) are laid on the surface or in interstices between cereal grains
   - Larva emerges and eats its way into a grain where it feeds unselectively as is shown by the characteristic damage it causes. When fully grown, the larva pupates inside the grain and the adult emerges from it
   - Life cycle: 4 to 5 weeks at 30°C and 38°C
   - Quickest development occurs in 4 weeks at 34°C
   - Destructive phase: larva and adult; both are voracious feeders
   - Serious pests of broken cereals, wheat, rice, jowar (junelo), pulses, corn products, macaroni, etc

![Fig: Rhizopertha dominica (Lesser grain borer)](image)
4. *Trogoderma granarium* (Khapra beetle)
   - One of the world’s most serious insect of stored grain
   - Found in hot particularly dry countries
   - Adult beetle is 1.5-3 mm in length, convex with an oval body, light red to dark brown in color and thickly covered with short hairs (sometimes darker areas visible on the elytra)
   - Has amazing powers of survival in the absence of food, is not killed readily by many of the contact insecticides and often appears suddenly after a long storage period
   - Female lays eggs (40-70) in the infested product and larva which hatch may develop at different rates, some taking over a year for complete development
   - Larva are straw coloured and hairy, have crowding habit and poor locomotion
   - Life cycle; Larva: about 3 weeks at 30°C
     - Adult: short lived; 10-35 days and are unable to fly
   - Destructive phase: larva only
   - Serious pest of broken cereals, wheat, barley, malt, dal, semolina, etc
   - Has preference to wheat and mostly attacks the embryo

   ![Figure: Trogoderma granarium (Khapra beetle)](image)

5. *Oryzaephilus surinamensis* (Saw toothed grain beetle)
   - 1/10 inch length, name based on six-saw tooth projections on each side of the thorax
   - Females lay eggs (about 300) among the foodstuffs. Eggs hatch into worm-like larva, slender and straw coloured with two slightly darker patches on each segment
   - Larva are active and move about freely until fully grown when they construct a cocoon or silken shelter in which to pupate
   - Life cycle; Larva: about 4 weeks at 30°C
     - Adult: may live up to 3 years
   - Destructive phase: both adult and larva
   - Worldwide pests of cereals, cereal products and dried fruit, confectionary, oil seeds, oilseed products, fruit candies and their products and nuts

   ![Figure: Oryzaephilus surinamensis (Saw toothed grain beetle)](image)
6. *Tribolium castaneum* (Red flour beetle)
   - Slightly less than ¼ inch in length
   - Reddish brown in color with constricted knobbed antenna
   - Female lay eggs (400-500) at random in the produce and hatch worm-like larvae which are slender, cylindrical in shape & whitish yellow in colour, giving a faint striped effect
   - Life cycle; Larva: about 5 weeks at 30°C
     Adult: may live up to a year or more
   - Destructive phase: both adult and larva
   - Primarily a pest of milled grain but often found in stored grains
   
   ![Tribolium castaneum](image1)
   
   Fig: *Tribolium castaneum* (Red flour beetle)

7. *Tribolium confusum* (Confused flour beetle)
   - Similar to red flour beetle in habit and appearance
   - Reddish brown, shiny and somewhat flattened, prefers temperate climate
   - Female lays about 450 eggs, scattered loosely in the food material which it infests
   - Life cycle; Larva: about 5 weeks at 30°C
     Adult: may live up to a year or more
   - Destructive phase: both adult and larva
   - Serious pests of flour mills, warehouse and grocery houses; feeds upon grain, beans, dried fruits, nuts, chocolates and other foods
   
   ![Tribolium confusum](image2)
   
   Fig: *Tribolium confusum* (Confused flour beetle)

8. *Alphilobius piceous* (Black fungus beetle)
   - Doesn’t attack the sound grains but feeds on the grains heavily infested by molds
   - The very presence of this pest indicates bad hygiene
   - Destructive phase: both larva and adult
   - Adult very active for 6-14 months
9. *Stagobium penicium* (Drug store beetle)
   - Also known as spice beetle or biscuit beetle, having 2-4 mm length
   - Reddish brown in colour with fine hairs on the body
   - Serious pest of spices, confectionary, processed foods and drugs

   ![Stagobium penicium](image)
   
   Fig: *Stagobium penicium* (Drug store beetle)

10. *Lasioderma serricorne* (Tobacco/Cigarette beetle)
   - Small, oval, light-brown beetle of 1/10 inch length, with smooth wings covers; adult flies readily
   - Female deposits as many as 100 eggs in tobacco, grain milled cereals & other products
   - Larva is yellowish white covered by hairs with a light brown head & about 1/6 inch long
   - The life cycle requires 6-12 weeks and there may be 5-6 overlapping generations per year in warm localities but only one generation in cooler areas
   - Primarily the pest of tobacco but also feeds on many other products such as feeds, dried plants, black & red pepper, rice and many other commodities

   ![Lasioderma serricorne](image)
   
   Fig: *Lasioderma serricorne* (Tobacco beetle)

11. *Laemophloeus minutus* (Olive flat grain beetle)
   - Smallest of the grain infesting beetles having 1/16 inch length
   - Most common pests of the stored grains. Serious pests of broken grains, cereals, pulses, oil seeds and deteriorating processed foods
   - Feeds on the dusty particles produced by other pests
   - Adult very active but unable to attack sound grain

   ![Laemophloeus minutus](image)
   
   Fig: *Laemophloeus minutus* (Olive flat grain beetle)
12. *Tenebroids mauritanicus* (Cadelle, yellow meal worm)
- ½ to 1/3 inch long; large elongated black beetle with the head and prothorax attached to the remainder of the body by a narrow joint
- Cadelle usually attacks the grain germ or embryo
- Cadelle feeds upon grain and grain products and does much damage to bolting silk in flour mills
- Destructive phase: both adult and larva
- Larva may cause damage by boring into the floor, walls of wooden beams
- Specially injurious in poorly sanitized mills

13. *Araecereus fasciculatus* (Coffee bean weevil)
- Serious pest of coffee beans, also attacks banana chips, cotton seeds and all leguminous seeds if moisture content is high and if the seed is soft
- Adult: good flier, short lived and 3/10 inch long
- Destructive phase: larva only

14. *Calosobruchus chinesis* (Pulse beetle)
- Serious pest of stored pulses
- Attack only whole pulses but is capable of infesting dal when dal is stored along with infested pulses
- Adult: good flier, short lived, 1/8 inch long with characteristic faint spots on the back

B. *Lepidoptera* (Moth Family)
1. *Corcyra cephalonica* (Rice Moth)
- Adult moth is about ½ inch long and is pale grayish brown in colour, with faint dark lines along the length of the wings
- Serious pest of rice and other cereals and also infest oil seeds & processed foods such as biscuits and cakes
- Destructive phase: larva, which attacks a wide variety of foodstuffs. Infestation is characterized by the presence of silken lumps to which grains produce adhere. The cocoon prepared by matured larva is dirty white and very tough
- Adult is very active
- Life history: 6-12 weeks

2. *Ephestia cautella* (Tobacco/Almond moth)
- Adult moth (13 mm long) is grayish in colour with transverse strips on its outer wings
- Abundant in tropical countries on a wide range of foodstuffs
- The adult avoids strong light, rests in dark places during the daytime and has flight rhythm with periods of active fly from 5-7 pm and also at 6 am
- Female moths lay egg (about 250) in the produce, the larva which hatches is caterpillar like in appearance, grayish white in colour with hairs rising from dark spots along the
body. The head is dark brown and there are two dark areas on the first segment behind the head
- Destructive phase: larva, prepares silken tubes in which they live and produce weavings
- Life cycle; Larva: 6-12 weeks at 28-30°C
  Adult: short lived; less than 14 days
- Serious pests of oil seeds, legumes, dried apple, almond, figs, walnuts, chocolates, cocoa, beans, biscuits, broken cereals, broken pulses and their products

3. Sitotroga cerealella (Angoumois grain moth/Paddy moth)
- Adult: good flier and short lived; about 1-2 weeks
- Destructive phase: larva, which feeds mainly on endosperm or germ
- Attacks all cereals, grains both in fields and granaries

Fig: Sitotroga cerealella (Angoumois grain moth)

4. Plodia interpunctella (Indian meal moth)
- Adult moth: about 12 mm length, good flier, characterized by the colour pattern of the front wings; along a third of their length they are pale yellow and along the rest reddish brown with a coppery sheen & faintly visible darker transverse lines. It has peculiar markings on the forewings which renders it easily distinguishable from other moth
- Eggs (200-300 per female) are laid on the produce either singly or in groups and the larvae which hatch are dirty white in colour but without the dark spots
- Larva constructs tunnel and live inside and also produce silken threads
- Destructive phase: larva only, they feed first on the embryo or germ of the grain and while eating spin a silken thread on which the droppings of the larvae accumulate
- Lives on variety of food grains and are cosmopolitan in food habits
- Life cycle; Larva: 3-6 weeks at 28-30°C
  Adult: short lived; less than 14 days

Fig: Plodia interpunctella (Indian meal moth)
**Infestation of stored food stuffs (by insects)**

Food needs to be stored for different reasons:

1. To expand period between harvests
2. To prevent loss of surplus
3. As a famine reserve

Insects attacking stored grains can be divided according to their method of damaging of grains into primary grain feeder and secondary grain feeder.

The primary grain feeders include those insects which are capable of attacking whole sound kernel, such as moth, weevils, lesser grain borer and cadelle.

The secondary grain feeders include those insects which do not attack whole, undamaged kernel rather than they feed on insect damaged kernels, broken kernels, particles of grain, grain dust and cost of primary insects. Some of the insects in the group also feed on mold and fungi that are developed in moist grain. This group of insects is known as bran beetle. It includes saw-toothed grain beetle, red flour beetle, confused flour beetle, flat grain beetle and some moths such as almond moth, rice moth and Indian meal moth.

All these insects cause several kinds of damage to seed or grain. The most serious problem is that they chew out the grain germ which is rich in food value, thereby decreasing the food value as well as germination power. Some insects live inside the seed and feed primarily on endosperm. The germ may not be directly damaged, but the partial or complete reduction of endosperm lowers the viability of the seed or the seedling may be weak and unable to survive.

The moth larva spins large amount of weaving which entangles seed in a ropy mass, forming sticky threads. The weaving may be built up into unsightly films over the surface of bags of seeds or on the top of seed stored in bulk. It is a sign of potential damage to grain. Some of the seed infesting insects chew holes through fabric films and paper containers. Most of the insect infestation originates after the seed is placed into storage. The kinds of insects involved are widely distributed abundant and feed on a wide variety of grains, cereal products, animal feeds & other commodities. These kinds of insects occur commonly in warehouses, storage bins, field shades and homes. Seeds may become infested during temporary storage, on the farm or during warehousing storage, if it is near infested product or put into infested bin or structures.

Many of the insects are strong fliers and can come into storage structures if preventive measures are not carried out. Used bags may also be the source of infestation if they are not cleaned thoroughly and/or fumigated before refilling. Bags or package seeds carried out from one season to the next provide an infestation hazard. The presence of insects inside the containers may not be detected.

Adult beetles or moths lay their eggs near or on packages. The tiny newly hatched larva can crawl in through minute openings of the container, especially sacks. The first external evidence of trouble may be when the matured insects cut holes in the package through which they emerge after their development is completed. By this time, extensive damage may have been caused and moth larvae will have spun weavings.

The necessary reserve stocks of seeds are other source of difficulty. The larger storage period provides time for the development of more generations of insects and possibly a tremendous
increase in numbers. The older seeds may also become more susceptible to attack if stored conditions have not been proper. Seeds become infested in the fields before harvest, notably by rice weevil and the angoumois grain moth. They can complete their development and continue to reproduce after seed is put into storage. Damage by field infestation can be kept at minimum by prompt harvesting and proper handling which may include drying or fumigation or both. Temperature and moisture are important factors in relation to infestation. As the temperature and moisture are lowered, the rate of insect activities such as feeding, development and reproduction are reduced. Low temperature and moisture also helps to keep seed into dormant condition that is necessary to maintain quality. One can take the advantage of these conditions to preserve seeds and sometimes to prevent insect damage. Clean seeds are less susceptible to infestation.

**How do insects affect grain quality and grade?**

Insects affect grain quality and grade in the following ways:

a. There is loss in weight and food value of insect damaged grains.

b. Insects may cause increase in grain moisture content, which results cracking, sprouting, musty and/or sour smell (microbial) and toughness to grain.

c. Several species of insects eat the grain germ, causing a loss in germination power.

d. Government loan can’t be secured on grain that is graded weevily.

**How bacteria cause disease?**

Bacteria enter plant through wounds and/or through natural openings. Inside, bacteria reproduce intracellularly. Bacteria produce enzymes that cause maceration of tissues that leads to death of cells. Some bacteria attack vessel of plant, reproduce and secret enzymes which breakdown pectin and other substances. They may cause clogging of the transport vessels in plants. Some bacteria like *Agobacterium* may stimulate cell division and cell enlargement. This may cause overgrowth, galls or tumors in plants.

**Factors affecting insects’ abundance in stored grains**

Food may be needed to preserve for different reasons, which can be done by drying and cleaning of seeds and storing in cool and dry condition. The following conditions must be maintained for safe storage of grains without insect infestations.

1. Grain moisture: 12-13.5% or even less
2. Grain temperature: 35°F, 2 weeks (below 65°F) – temperature ceases laying of eggs when the grain temperature drops below 65°F. Most adult insects are killed if temperature drops below 35°F for 2 weeks and below 35°F for moths.
3. Dockage: grain must be free from foreign matters

The greater the quantity of dockage, the greater the supply of food for bran insects and the more rapid is their build up. Grain with higher % of insects and damage kernels support the higher population of bran beetle than clean grain free from insect damaged kernel.
Like raw food grains and their products, processed food materials are also susceptible to insect infestation. Processed foods are those types of foods which are processed from raw food materials and can be consumed readily or with little preparation. Some of the common examples of processed foods are:

1. Weaning foods: infant foods, sorbottam, bal ahar
2. Instant mixes: astamandap satu, dosa flour, idly flour
3. Breakfast cereals: corn flakes, wheat flakes
4. Confectionaries and baked foods: chocolates, biscuits, bread
5. Condiments and spices: chilli powder, soup mix, spices
6. Dried foods and their products: mango flakes, chest nuts, wall nuts
7. Dried animal products: dried meat (sukuti), fish flour, meat sausage
8. Dried vegetables: beans, peas, etc.

Processed foods are also preferred by the same species of insects which are found infesting raw food grains. Food preferences of the stored product insects attacking processed foods depend on the following criteria:

a. Composition of the food
b. Physical state of the food
c. Raw materials from which the processed food is prepared.

a. Composition of Food

If the processed food is rich in carbohydrate, the common insects noticed are *Tribolium castaneum* (red flour beetle). If the food material is spiced, *Stagobium panecium* (drug store beetle) and *Ephestiae cautella* (tobacco moth) are found.

If the processed food material is rich in protein, then the expected insect would be *Ephestiae cautella*, *Rhizopertha dominica* (lesser grain borer), *Oryzophilus surinamensis* etc. If the processed food material is rich in fat and oily material, then the expected insect would be *Ephestiae cautella* and *Oryzophilus surinamensis*. If the processed food is dehydrated fruit, candy, nuts, confectionary products, etc., then *Ephestiae cautella*, *Araecereus fasciculatus*, are the infecting organism. Most of the deteriorating processed foods are susceptible to the attack of *Laemophloes minutus* (olive flat grain beetles).

b. Physical state of food

Most of the granular and hard processed foods like macaroni, cereal flakes, and synthetic rice & tapioca chips are susceptible to the attack of *Sitophilus oryzae* (rice weevil), *Trogoderma granaria* (kharpa beetle) and *Rhizopertha dominica* (lesser grain borer). *Tribolium castaneum* (red flour beetle), Corcyra cephalonica (rice moth) are found associated with most of the milled processed foods. The broken material is susceptible to attack of *Rhizopertha dominica*, *Trogoderma granaria* and *Laemophloes minutus*. 
c. Raw materials (from which the processed products are prepared)

Insects originally present in raw material can also attack on the processed products. Such as biscuits, breads, etc. prepared from wheat flour are usually attacked by Tribolium castanum and Corcyra cephalonica. Dosa flour, idly flour, etc made from milled cereals and pulses are susceptible to the attack of Tribolium castaneum and Ephestia cautella. Most of the rice and corn products like corn flakes, wheat flour, and synthetic rice are attacked by Sitophilus oryzae. Some of the Nepalese and Indian multipurpose foods made up of dal and groundnut have been found infested by Ephestia cautella, Oryzaephillus surinamensis and Tribolium castaneum. In spice multipurpose foods, Stagobium penicium is the most common infesting beetle.
RODENTS AND THEIR CONTROL

Introduction
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*)
  - house 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).

Rodents cause excessive damage to both standing crops as well as stored produce. Losses to standing crops from this cause are generally regarded as being of greater importance than losses in store. Cereals are particularly vulnerable to rodents attack, and damage to stored grain is probably greatest while it is still on the farm. In large central storage depots, the rodent population becomes dense enough to cause severe losses.

Rodent damage to stored food is of a threefold nature. First, rodents consume a certain quantity of product; secondly, they foul a much larger quantity with their excretions; and thirdly, they gnaw holes in the containers. Jute bags are particularly susceptible to this form of attack, frequently being damaged beyond repair. Damage to grain stored in bulk is very much less than damage to bagged grain, because rodents cannot burrow into bulk grain and therefore feed only at the surface.

Characteristics of the rodents

1. *Mus musculus* (House mouse)

Pest status
- Smallest of the domestic rodents
- Lives in and around buildings, nesting in walls, cabinets, furniture & stored grains
- It is a nibbler, taking a bite here and there
- Range of travel is 10-15 feet
- In appearance, mice resembles young rats
- Body length is 70-90 mm with tail 60-80 mm and weight 15-25 gm
- Found in cities, town and village throughout the world

**Produce**

- Eats more or less the same food as including all grains, farinaceous material, cheese, meats, potatoes, etc. Insects are also regularly eaten

![Fig: Mus musculus](image)

**2. Rattus rattus** *(Root, Ship or Black rat)*

**Pest status**

- Important urban pest which in addition to a major pest of several tropical tree (palm crop) is also the main host of tropical rat flea, a vector of plague organism
- It is smaller in size but agile climber, generally harboring in the upper floor of the building but occasionally found in sewage
- Range of travel is 50-100 feet
- Weight: 120-350 gm

**Produce**

- An omnivorous rat with preference for fruits, nuts, seeds and other vegetables matters (basically fungivorous)
- Rural, elaborated in adaption and live in trees and usually climb to feed; do not feed on garbage to some extent
- In general, they eat much of the same food as man

**Distribution**

- In temperate region, the distribution is largely confined to port areas and dock lands
- The species is particularly associated with plains
- They are essentially arboreal and prefer to nest aerially

![Fig: Rattus rattus](image)
3. *Rattus norvegicus* (Common/Sewer/Norway/Brown rat)

**Pest status**
- A very serious urban pest distributed worldwide
- Does much damage to stored produce, both in farm and city produce stored
- Also causes damage to some field crops in the tropics
- It is predominantly burrowing rat, which burrows in ground around the dump sewage and buildings close to food and water
- Range of travel is no more than 100-150 feet
- Weight: 150-500 gm

**Produce**
- Totally omnivorous including almost anything edible in their diet and includes a lot of meat. Garbage is also eaten. Diet is basically similar to human diet

**Distribution**
- It was originated in Asia and spreaded mainly along the trade routes, now completely worldwide and mostly in oceanic islands
- In tropics, it is generally associated with port cities

![Fig: Rattus norvegicus](image)

**Damages caused by Rodents**

1. Direct eating of food stuffs, combined with contamination with faeces, hair, etc. Contamination is very important in produce for export as many consignment to the US and part of Europe are rejected after inspection.

2. Damage by gnawing to container, electricity cable, etc. is also important. The collecting of material for nest building may damage fabrics and wooden material as well as grow holes in containers. Food material is often carried away in check points to be deposited in nest and their own food stores, widely in crevices and corner.

3. Carry diseases which are transmittable to man

4. Mice consume less feeds than rats but do a lot of nibbling and gnawing and thus cause wide spread damage.

5. The dead bodies of rodents following the use of poison, baits can cause a problem in food store. But rat can devour and decompose rapidly by blow flies and fly maggots, which devour the carcass quite quickly under warm condition. The presence of blow flies in a store can be used as an indicator of rodent corps.
### Table: Characteristics of selected Rats and Mice

<table>
<thead>
<tr>
<th>Characters</th>
<th>Mus musculus</th>
<th>Rattus rattus</th>
<th>Rattus norvegicus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average adult weight</td>
<td>16 gm</td>
<td>250 gm</td>
<td>330 gm</td>
</tr>
<tr>
<td>Tail length</td>
<td>Usually longer than head and body</td>
<td>Usually longer than head and body</td>
<td>Shorter than head and body</td>
</tr>
<tr>
<td>Ears</td>
<td>Large, some hairs</td>
<td>Thin, translucent, large, hairless</td>
<td>Thick, opaque, short with fine hairs</td>
</tr>
<tr>
<td>Snout</td>
<td>Pointed</td>
<td>Grey, black brown or tawny, may have white belly</td>
<td>Brownish grey but may be black, grey belly</td>
</tr>
<tr>
<td>Colour</td>
<td>Variable brownish grey</td>
<td>Grey, black brown or tawny, may have white belly</td>
<td>Brownish grey but may be black, grey belly</td>
</tr>
<tr>
<td>Droppings</td>
<td>Scattered, thin spindle shaped</td>
<td>Scattered, sausage or banana shaped</td>
<td>In groups, sometimes scattered, spindle shaped or ellipsoidal</td>
</tr>
<tr>
<td>Habits</td>
<td>Sometimes burrows, climbs well, only slight new object reaction, erratic (not predictable) habits</td>
<td>Rarely burrows, agile climber, shows new object reaction, somewhat erratic habits</td>
<td>Burrowing, can climb, swims well, shows new object reaction, can live in sewers, fairly conservative habits</td>
</tr>
<tr>
<td>Distribution</td>
<td>Found in most towns in which recent development has taken place</td>
<td>Found in towns and villages throughout</td>
<td>Only found in ports and in some of the larger inland towns</td>
</tr>
<tr>
<td>English names</td>
<td>Mouse, Home rat</td>
<td>Roof rat, Ship rat, Black rat, Alexandrine rat</td>
<td>Sewer rat, Norway rat, Common rat, Brown rat</td>
</tr>
</tbody>
</table>

### Evidences of Rodents Presence

1. Droppings: Generally widely scattered, but may be concentrated in flavoured areas.
2. Runways: Readily seen only in dusty places, unless the species is particularly abundant.
4. Foot and tail marks: May be found after diligent infestation in dusty places or finely divided foods.
5. Holes: Small 2-3 cm in diameter, not usually obvious, burrows inside sacked food shafts in walls.
6. Nests: Found in the food supply, fabrics of building, may be about 10 cm in diameter when well constructed.
7. Live and dead rodents: Live rodents may be seen running and/or off odours of dead rodents may be present if any dead.
8. Infestation: Damage to products.
Necessity of rodent control

The major rodents of our interest are *Rattus norvegicus*, *Rattus rattus* and *Mus musculus*. Two or more of these species are found in all part of the world and cause the most extensive damage. The tropic species of rodents are usually rats and mice and they live in association with man in all parts of the world.

Godown provides the ideal condition for rodents since the essential elements such as foods and shelters are available for them. Hence, they come into godown in search of food. Also, they damage crops grown by small holder farmer and can be very serious in food produce stores.

The damages caused by rodents are of threefold nature:

a. They consume a certain quantity of product
b. They foul a large quantity with their excretion
c. They grow holes in container

They also carry diseases which are transmittable and harmful to man

The harmful activities of rodents extend beyond direct diseases which are transmittable to human, such as plague. Rats eat about 70% of their weight in food each day as well as contaminate a great deal more with their droppings, urine, fur, etc., thereby rendering it unfit for human consumption. The rat & mice contaminate about 10 times as much as they consume. The amount of filth produced by these rodents is evident by data that indicates that rat deposits about 70% droppings and 16 cm³ of urine per day. A mouse deposits about 48% droppings per day.

The manner by which contamination occurs is illustrated by what happens when a rat is left free to roam in a warehouse for a year. During that time, it would eat approximately 12.2 kg of food and deposit about 25000 droppings which weigh about 0.9 - 1.8 kg (2-4 lb). During the same period, a single mouse would eat approximately 7-8 kg of food and deposits 17800 droppings.

Rodents gnaw through almost anything that comes across their path to obtain food and shelter and to wear down their incisors which grow continuously ~10 cm in a year, otherwise. This gnawing often results in extensive damage to building. It has been estimated that 25% of fuses of unknown origin are sorted by rodents’ damage to electricity wiring.

Mice are more numerous and universally distributed than rats. They are characterized as seed eating and along with non-native mice varieties such as meadow mice live in forest, grass and crop land areas where human population is low. Mice often constantly shed hairs and other forms of filth. Since these species often have a very limited range that may not exceed more than 3-4.5 cm, many of its members spend their life within a small take of food.

Modern mills and food processing plants operate under sanitary conditions and some maintain their own lab to carefully view grain before purchasing. Their cleaning equipments are designed to remove rodents’ pellets before the grain is processed. Most often, the size and shape of the rodents droppings are similar to that of grain and may not be easily distinguishable and be separated. Nevertheless, pellets and their fragments are often found in many finished products and constitute evidence of poor sanitation. Rodents’ damage and contamination to grain have been reduced during the past decade. This is the regulatory pressures from FDA inspection and seizures of contaminated commodities. There has been direct action taken against raw material and rejections of supplements.
that do not meet the required level of cleanliness. Rodents have been considered as a serious problem in production and storage facilities.

The best means of controlling rodents attack in godown is:

a. Prevention of their entry by rodents proofing
b. By practicing rodent baiting or poisoning throughout the years. If acute poison is used for rodent control, pre-baiting should be practiced to get maximum control.

The vehicle used for transportation of product may present problem either by rodents entering during or after loading or by rodents actually living in them. This can be improved by better control practiced around the production and storage facilities and the use of fumigant within the vehicle.

Insects and rodents are major problem of food storage in Nepal. Molds and birds problem also exist but the magnitude of damage caused by them is relatively lower than that caused by rodents. Lack of systematic and organized programmes for control and unhygienic conditions of godown are responsible for infestation problem. The defective design and inadequate maintenance of godowns and improper practice are major causes of grain losses and damage.

**Rodents Control Measures**

A. **Physical Control Methods**

The physical methods for rodents control consist of the following measures: environmental sanitation, rat proofing, repelling and trapping.

1. **Environmental Sanitation**

   General sanitation methods include the removal of additional food sources that might provide food or shelter. Storing garbage and rubbish, the packaging of produce into container should be done, and lumber, packaging and other materials should be stacked 18 inch above the ground and if possible, removal of garbage from the proximity of food stores should be done.

   Food set out for domestic animals and birds are often a food source for rats or mice and should be prevented from rodents by picking up scraps of leftover food and keeping dishes clean.

2. **Proofing**

   The granaries should be constructed by materials such that the rat cannot bite through them. The materials for this may be concrete, bricks, iron sheets, etc. Fine wire mash or metal gauge should be placed over ventilation holes. The sites where pipes pass through the walls and caves of building are especially vulnerable. So, these and the drain which are near to the granaries should be prevented.

   Local granaries constructed from mud are generally rodent proof to some degree, particularly, if they are raised from the ground. During designing the rodent proof granaries, it should be remembered that rodents have poor vision but keen sense of smell, touch, taste and hearing. The methods can be cheaply introduced into granary if it is considered during planning but after being constructed, adding up the rodent proofing method may be costly.

   The Norway rats can be prevented to enter into the storage, if it is first floor storage, by blocking any openings that otherwise may be entrance for rats. Concrete, brick, galvanized hard wire, cloth, hard galvanized metals are recommended in particular critical spots.
Rodent proofing means the preservation of rodents entrance into storage system by proper closing the openings, preventing the rodents from climbing poles and other possible means by proper use of suitable guards around such means so that it becomes the obstacle for rodents. Openings in the foundation, outer walls, flour caves, grills, windows, ventilations, pipes ventilated grating in footpaths and elevators, etc. must be suitably guarded.

It is an elementary precaution with any proofed stores or storage areas to eliminate all rats by poisoning or trapping before the grain is brought in.

3. Repelling (Ultrasonic generators)

Various types of chemicals have been considered as rodent repellents but none have proved completely satisfactory under practical conditions.

A new high frequency device for repelling rats and mice (also birds) has been mentioned which transmits sound waves through special transducers to give signal coverage of a given indoor area. An essential feature of operation is bouncing of erratic high frequency sounds from walls within an enclosed area. The frequency of sound may be 15-19 KHz. Ultrasound (>19 KHz) may also be used.

4. Trapping

Rats are not easy to trap. Also care is taken to distinguish human smells (for e.g. in Ethiopia, rubbing a cut onion bulb over baited trap), which is very effective. Traps are especially useful around the food storage areas, where rodenticides are not permitted or are hazardous and where only slight infestations are predicted. There are 3 main types of traps:

a. Live trap (O trap) – used for catching live rodents, generally used for study purpose
b. Snap/Killer trap – effective for mouse and rat, not expensive and will work for years
c. Caged trap – used for collecting live rats or mice, designed to catch one or several at a time

Traps should be fastened by a string in case the rat is not killed, and because they forage\(^1\) (search for food) so widely, traps should be spaced well apart. Rats are nervous for new object and new food and thus pre-baiting may be necessary for feed nights before the traps are set (this particularly applies to the use of poison baits). Mice are generally easier to trap than rats because they are less cautious. In general, all traps need to be maintained. They should be checked frequently, never less than every 24 hours.

In order to achieve an appropriate degree of control over large infestations, it is necessary to use a high trap density which may not be economic. In addition, the success of trapping is frequently limited by the degree to which the rat population becomes trap shy. Prolonged trapping of an infestation with one type of trap is likely to exert progressively less control over the rat population. Therefore, different types of traps should be alternatively used to get better control.

\(^1\) Forage – go for search of food  
Bait – to put food on trap in order to attract and catch the animal
B. Chemical Control Methods

The chemical methods for rodents control consists of poisoning and other methods which are mentioned below:

1. Poisoning

The basic plan is to mix the poison with the attractive bait material to attract the rat to food. When used correctly, poison baiting is one of the cheapest & most effective methods of controlling rats on large scale. There are, however, certain precautions that should be observed when handling the more toxic poisons. Domestic animals likely to eat bait in quantity or eat dead rats must be kept away from the baiting area. There are two types of poison: acute poison and chronic poison.

a. Acute (quick acting) poison

These are used at concentration in the bait sufficient to kill the rodent at a single dose. Most acute poisons are extremely poisonous and hence considerable care should be taken in their application and their sale to the public should be governed by regulations. It should not be used in grain stores or mills where there is probability of bait spoilage, thus contaminating food products. Examples of acute poison are zinc phosphide, arsenious oxide, sodium fluoroacetate (or 1080), thallium sulphate, yellow phosphorus, aluminium phosphide, calcium cyanide, strychnine, Norbomide, Eastrix, ANTU, etc.

i. Zinc phosphide

- Heavy grayish powder, insoluble in water
- Has an offensive (disagreeable garlic) odour
- Decomposes in the presence of oxygen and water
- It is poisonous to human beings and all form of animals
- Mode of action: heart paralysis, gastrointestinal and liver damage
- Effective against all the rodents of our interest
- Most satisfactory all around material and has fast activity
- Its degree of effectiveness is very good, also acceptance and reacceptance is good
- Lethal dose: 40 mg/kg body weight
- Use at 1% level in the bait
- Antidote: Emetic (causing vomiting) is used as first aid treatment. Vitamin K fits the term of antidote. Speed is essential; 1 lb of salt in warm water is usually effective.

ii. Red squill

- It is one of the best known and less hazardous poisons for the untrained individual to handle
- Its degree of effectiveness and acceptance is fair but reacceptance is poor because it is relatively distasteful and quite milder
- Effective against Norway rats only, not effective against roof rats and mice
- Mode of action: heart paralysis. Normally emetic to most animals and since, rats cannot vomit and cause convulsion and respiratory failure.
- Types of bait mixture: dry, fresh and with water.
- Lethal dose (minimum acceptable level) = 500 mg/kg body weight
- Use in bait: 10%
- Antidote: Its natural emetic characteristic offers to animal capable of vomiting.
iii. **ANTU (alpha napthyl thio-urea)**
- Finely granulated gray powder insoluble in water
- Chemically stable, non-volatile and non-irritating to human skins
- Lethal dose: 8 mg/kg body weight
- Use in bait: 1.5-2%
- Degree of effectiveness and acceptance is fair but reacceptance is poor
- Types of bait mixture: fresh and dry
- Mode of action: pleural effusion (over production of fluid in lungs), acute long dropsy
- Effective against Norway rats only, not effective against roof rats and mice

iv. **Strychnine**
- Highly toxic and single dose poison
- Has bitter taste, which causes many rodents to avoid it
- Should be used more than 6 months after the previous use to get best result
- Lethal dose: 6 mg/kg body weight
- Use in bait: 0.6%
- Degree of effectiveness and acceptance is fair but reacceptance is poor
- Types of bait mixture: dry
- Mode of action: convulsion due to upper stimulation of nervous system, exhaustion asphyxia
- No secondary poisoning and not absorbed through skin
- Effective against mice only

v. **Sodium fluoroacetate (or 1080)**
- Soluble in water but not in oil
- Lethal dose: 5 mg/kg body weight for Norway rats
  - 2 mg/kg body weight for roof rats
  - 10 mg/kg body weight for mice
- Degree of effectiveness, acceptance and reacceptance is good
- Types of bait mixture: fresh and in water
- Mode of action: paralysis of heart and CNS (central nervous system)
- Secondary poisoning occurs but is not absorbed through skin
- Antidotes: ethanol and acetic acid recommended

vi. **Norbornide**
- Fine white powder, slightly soluble in water and ethanol
- Stable under normal storage conditions
- Very selective rodenticide that is effective to all the members of the genus *Rattus*, which includes the Norway rat and roof rat, but safe to non-target species. For e.g. this poison is harmless to the house mouse.

vii. **Pyrinuron**
- Fine yellow powder, stable under normal storage conditions
- Used against Norway and roof rat
- Toxicity to non-target species is similar to that of zinc phosphide
- More palatable than zinc phosphide
b. Chronic Poison (Anticoagulants)

The second group of rodenticides is the chronic poisons or anticoagulants. These are used at such a low dosage that they usually cause death only after the animal has fed on the bait for several days. When ingested these poisons interfere with the blood clotting mechanism, causing hemorrhage (excessive bleeding) and ultimately death of the rodents. Rodents apparently do not associate the cumulative effect of the intestinal hemorrhage with their food intake and therefore they return to take the treated baits again and again.

Warfarin is the best known and probably the most widely of the anticoagulant poisons. Others available are fumarin, dipharunone, proline, warficides, coumachlor, fumasol, etc. Anticoagulants are commercially available either in the form of concentrated powder or ready to use baits and are safest for the untrained individual to use.

Hydroxyl coumarin provides a completely new approach to rodents’ control. It must be used over the extended periods in order to achieve maximum kill. Usually the best kill occurs between 4th and 9th feeding. Anticoagulants are very safe to use & no known human deaths have been reported.

Advantages of anticoagulants
- Avoids the common problem of baits
- Hazards to another animal from single incidental feeding are greatly reduced
- Are effective against both rats and mice
- Are safest for untrained individual to use

Disadvantages of anticoagulants
- Long term use, decrease acceptance, usually the pest death occurs between 4th and 9th feed
- Bait shyness and poor control
- Large quantity should be consumed for effectiveness

Reaction of rodenticides

Not all the animals react equally to rodenticides, even among the same species. Some individuals are considerably more resistant than others. Dosage levels are setup for animals with above their resistances. Increasing these levels is not recommended because it may be objectionable due to decrease in acceptance and increase in hazards to other animals.

Continuous reuse of same poison in the same location and for the same target rodent species generally results in decreased acceptance, bait shyness and poor control. Poison highly effective in one location can be much less effective than adjacent.

Hazards of rodenticides

An increased degree of protection to other animals, when using either zinc phosphide or ANTU, may be obtained by incorporating tarter emetic/antimony or potassium tartarate in the bait mixture. Approximately equal amount when mixed to ANTU or 3-5 parts of zinc phosphide provide about the same degree of protection to other animals as may be expected with red squill.

Anticoagulants are exposed in such a small concentration that accidental poisoning requires consumption of large quantities of baits. A few cases of secondary poisoning have been reported due to pets feeding on dead rats or mice.

Since some rats do not feed on the bait until it is exposed for longer time. 2-3 weeks may be necessary to produce effective rat control. A mouse colony may require as long as 30 days.
Rodenticidal Tracking Powder/Dust

These are poisonous powders, applied to the floor surface, wall space, etc. and the mice pick it up on their feet and later stick it up. Rats are not so successfully stick by using tracking powders. They should not be laid where they can be blown onto food or carried onto foods by rats and mice or where cats or other domestic animals can run over them during treatments. Some of the common recommended tracking powder/dust are Warfarin (0.5-1%), Coumatetralyl (0.3-0.74%), Pindone (0.1-2%) and diphenacine (0.1-2%).

Bait and bait bases (choice of bait)

The success of poisoning depends largely upon the choice and skillful placing of bait and this should be food that is more attractive to the rats than their normal food supply. The selection of bait base is particularly important. However, field experiences and lab tests show that rats and mice readily take the staple cereal of the country in which they live or products derived from the cereals. Rats living in a store containing large amount of grain sometimes cannot be induced to take the normal baits, and in this case, offering them poisoned drinking water often produces results. The chance of success by using water bait can be improved if rats’ usual water supply can be cut off.

As a general rule, the amount of food eaten by rats depends on its calorific value. Therefore, rats tend to eat a greater bulk of wet bait than dry bait. Practical experiences support the use of damp bait whenever possible with chronic poisons. Baits may have to remain in a certain place for sometimes and so need to have better keeping quality. In this case, it is more usual to use dry baits. Bait in the form of meal can be mixed directly with the poison and used dry but whole grain (dry bait) must have a ‘sticker’ added to ensure that the poison adheres to the grain; technical white oil is frequently used for this purpose. The construction of bait box should be such that (i) the reservoir of the poison is retained in the box and (ii) access in the box is restricted to small rodents. The use of acute poison in open area is not recommended but if this is unavoidable, the use of bait boxes should be considered an essential safety precaution.

In order to get best result, poison baits should be placed on runways, in large holes and in fairly sheltered positions as near as possible to holes, resting places and similar harbors. In fact, the object with any poison bait is to try to lay it so that the rats or mice meet it on their way to where they normally feed.

Damp baits often prove more attractive to rats than dry baits but deterioration of the former due to molds and bacteria is more rapid in warm climates; baits that have deteriorated even slightly in this way are often totally unacceptable to rats. Mold can be prevented to a certain extent by the addition of 0.025% para-nitrophenol, but this almost invariably lowers the palatability of the bait.

Baiting Technique

Bait should always be laid in places which are readily accessible to rats and, if possible, they should be positioned between the rats’ harborage and their normal food supply. Baits should not be laid in exposed places as rats will not feed freely in the open.

After mixing with a suitable bait base, acute poisons can either be used directly or with pre-baiting. Pre-baiting involves laying unpoisoned bait at suitable sites for 2-4 days before the poison is laid. In this way, rats become accustomed to feeding on the particular bait that is used and at the site
where the poison is laid. Greater success can be achieved with the prebaiting technique than with direct poisoning because rats are more likely to take a lethal dose of the poison if they have first been conditioned to feed on the bait. Rats normally approach a new food source with caution and sample it only. With direct poisoning therefore, there is a risk that some rats may take a sub-lethal dose and thereafter become bait-shy. That is, they will not eat either the poison bait for several months and in the mean time, it will be necessary to resort to another poison and bait.

Anticoagulant poisons have the advantage that they do not cause bait shyness and therefore need no prebaiting. However, they have the disadvantage of high bait consumption since rats normally need to feed for several days before a lethal dose is ingested. Warfarin is normally used at 0.005 % against *Rattus norvegicus* and at 0.025% against other species.

The following recommendations have been made for rodent baiting in a no. of countries:

a. **Bait mix recommended**
   i. 520 gm maize meal  
   or  
   i. 90% uncooked (broken) rice  
   ii. 28 gm castor sugar  
   ii. 5% castor sugar  
   iii. 312 gm liquid paraffin or technical white oil  
   iii. 5% technical white oil  
   iv. 28 gm Warfarin  
   iv. 1% Warfarin master mix to give 0.025% bait

b. **Baiting methods**
   The bait should be placed on wooden trays or shallow boxes throughout the infested area. Baits should be protected as far as possible, e.g., by sacks or bales of other produce, to reduce the risk to domestic animals. Baiting points should be at frequent intervals, i.e. not more than 2.5 m apart.

c. **Baiting procedures**
   Day 1 – 60 gm baits should be laid at all baiting points.
   Day 3 – visit all points and, if there have been complete takes, put 120 gm of poison down; if there are partial takes top up to the original 60 gm.
   Day 5 – visit all points, as on day 3, doubling to 240 gm. Dead rats should be evident and should be removed.
   Day 8 – visit all points again and, if there is still evidence of takes, proceed as before.
   Day 10 – remove bait except from points where reinfestation might occur.

**Safe uses of bait**
1. Avoid contact with mouth.
2. Wash hand and exposed skin before meals after work.
3. Prevent access of the bait by children and pets, other than rodents.
4. Burn or bury the rat or mouse bodies that are poisoned.
5. Store poison in a tightly sealed container or safe places.
6. Do not place bait where human or other animals’ foodstuff or water will be contaminated.

**Failure of baiting programmes**
Many factors apart from resistance contributing to the failure of baiting practices are:
   1. Poor operating technique
   2. Misidentification of rodent species
   3. Insufficient mixing of poison with the bait
4. Use of too low concentration of poison
5. Use of unalternative/repeated bait
6. Use of bait which is not sufficiently attractive to draw all the rodents away from their normal food supply
7. Placement of insufficient bait at each point
8. Laying of bait on too few places
9. Continued migration of rodents in other areas
10. Consumption of bait by other animals and so on.

2. Other Techniques of Rodents Control

The other chemical methods for rodents control include gassing, fumigation, chemical repellants and chemosterilants.

a. Gassing

It is normally used only against Norway rats living out of door and in farm around. The method consists of putting the cyanide powder into burrow. This powder gives off HCN, which is very poisonous gas when it becomes damp from contact with ground moisture. Do not use cyanide in or near building, in heavy rain, in loose soil and in strong wind.

There are 2 methods of gassing, viz. Spoon gassing and Pump gassing.

b. Fumigation

When in premises ships, stacks of good are more likely infested with rats or mice, and they can be sealed quickly and conveniently the best method of control is fumigation. The fumigants commonly used are ethyl bromide or methyl bromide, chloropicrin, HCN, etc.

c. Chemical repellants

They are generally only effective when rodents touch chemical with their mouth. Therefore, repellants may be of use in protecting equipments such as underground cables. A typical repellant has strong unpleasant odour, which makes it unsuitable for use around the food manufacturing premises or for the treatment of packaging materials.

d. Chemosterilants

An ideal chemosterilants must have the following characteristics
- Orally active and have single dose effectiveness
- Cause permanent sterility in both sexes or at least the females
- Be relatively non-toxic to other non-target species
- Be cheaper
- Immediately effective and easy to administer

α-chlorhydrin is the only chemosterilants which is commercially available as rodenticides. Chemosterilants are potentially very dangerous compounds and should not be used close to stored products.

e. Rats as food

f. Bounty system – a system of reward for killing rodents.
CONTROL MEASURES

Introduction
Food grains are liable to suffer heavy losses during storage as a result of infestation by insects, which commences prior to harvest. In order to get maximum benefit from the harvest, some attempts must be made to control insects and pests during harvest and storage. Generally, the insects control methods in storage system are classified as follows:

A. Traditional Methods:
   1. Regular sunning
   2. Smoking
   3. Admixture of local plants
   4. Admixture of local dusts

B. Physical or Mechanical Methods
   1. Airtight storage
   2. Modified atmosphere storage (MAS) and Controlled atmosphere storage (CAS)
   3. Aeration of grain (cool storage)
   4. Refrigeration storage
   5. Irradiation
   6. Insect proof container
   7. Sounds
   8. Percussion
   9. Visible or UV light

C. Chemical Methods
   1. Contact insecticides
   2. Fumigants
   3. Protectants
   4. Repellants
   5. Space treatment and residual

D. Miscellaneous
   1. Biological control
   2. Legal control, etc.

A. Traditional Methods
Simple traditional methods of control are used by farmers, usually to protect the part of their crop reserved for seed purpose. Some of these methods are:

1. Regular Sunning
By exposure to strong sunlight, the adult insects are activated and become capable to fly. If the infested commodity is spread out in the sun, any adult insects present get activated and they will fly. However, immature stages present will remain enclosed within the grains. Thus, by regular sunning over several months, appreciable effect on control of insects can be achieved.
2. **Smoking**

   It is a very common practice in the tropics to hang unthreshed heads of grain, cobs of maize, etc. from the rafters of dwelling huts, in which position heat and smoke from the fire promotes further drying and reduce insect infestation. In some areas, granary of mud or plant material may be built on raised platform over the cooking fire which is then used for household cooking.

3. **Admixture of local plants**

   Some local plants have repellant effect upon insects and when they are admixed with food produce in granaries (generally small), some control over infestation may be achieved. Some examples of such plants are neem, bojho, etc.

4. **Admixture of local dusts**

   The admixture of wood ash or sand with food grains are carried out in many areas, although it is usually restricted to the storage of small quantities in earthenware pots for seed purposes. This method relies for its effectiveness upon the fact that the materials used fill the intergranular spaces and thereby restrict the insect movement and emergence. A similar method used is the admixture of small cereal grains, e.g. millet (which are themselves barely susceptible to insect attack) with maize or sorghum stored in pots for seed purpose.

   Experiments have shown that diatomite dust also has some effect as a protectant when applied to maize stored in bags. Such mineral dusts, generally known as inert dusts, scratch the thin, waterproofing layer of wax which exists on the outside surface of the insect cuticle, allowing loss of water which leads to death as a result of desiccation. Also, powdered dried rhizomes of the sweet flag (bojho) possess both killing and deterrent properties when mixed with paddy or rice at the rate of 1 to 100 pound of grain.

B. **Physical or Mechanical Methods**

   The preliminary control measures that should be followed are:
   - Harvesting after optimum maturity
   - Proper drying of grain after harvesting
   - Hygienic conditions, etc.

   In granaries, the simple general physical control measures that can be adopted are described below:

1. **Airtight Storage**

   The term is used to describe the process whereby grain is held in airtight silo in which depletion of oxygen from its normal level (approx. 21%) results in suppression of organisms which would otherwise cause grain deterioration.

   In a complete airtight storage, insect pests in dry grain eventually die from lack of oxygen. Damp grain can undergo some chemical changes due to partial microbial fermentation but will not be subjected to serious deterioration due to microorganisms such as bacteria and fungi. However, in practice, difficulties in making structures sufficiently airtight make it more difficult to achieve successful storage under tropical conditions with damp than with dry grain. Thus, sufficient application of fumigants or contact insecticides before storage is adopted.
In some areas, underground storage pits with satisfactory air tightness have been constructed by using plastic sheets, concrete, etc. and improved control over infestation have been achieved. Modern silos and gasketed concrete silos are the modern design of the airtight storage structures. Metal drums with tight fitting lids, specially sealed, can be used very successfully for the storage of small quantities of grains in airtight conditions.

2. Modified Atmosphere Storage (MAS)
Killing of insects with modified atmosphere of CO₂, O₂ and N₂ has long been recognized. MAS may often be taken as an alternative to use of insecticide chemical. This type of storage system has no effect on the germination power and endues properties of grain for 1 year storage period. The atmosphere of air or oxygen is replaced by gases to some or complete extent so as to make the environment lethal to the insects owing to oxygen lacking. The generally used gases for MA creation are CO₂ and/or N₂. The atmosphere not only controls the insects’ infestation but also inhibits the fungal growth thereby controlling the mycotoxin formation. CO₂ has biocidal properties and N₂ also has the same but in small extent. These both are inert and hence do not react to produce deterioration.

A part of existing atmosphere is replaced with CO₂. The level of CO₂ from 35-99% is lethal to all pests of grain storage. Increasing in the N₂ concentration from 97-100% is also useful. To obtain good control, high temperature and low pH is recommended. At these conditions, the moisture content of grain is low and MA is effective at low grain mc. Temperature is generally maintained above 70°F (> 21°C) and RH is generally maintained below 50%.

In general, insects are killed when oxygen in the intergranular air falls to about 2% by volume, depending upon the species, some being more resistant than others. Most fungi on damp grain continue to develop until oxygen falls to about 0.2%. At higher concentration below 1%, certain microorganisms, particularly yeasts, can grow and impart a moldy appearance to the grain. So, proper dryness is essential and it is worthless to maintain a MA from damp grain.

The MA is generated by burning out the oxygen and removal of resulting water and other organic materials thereby producing air containing basically CO₂ and N₂. Generally, this generated atmosphere consists of 0.1-0.2% oxygen, 10-15% carbon dioxide and rest nitrogen. Generation of such atmosphere is expensive.

3. Controlled Atmosphere Storage (CAS)
Controlled atmosphere storage of cereal grains using carbon dioxide, nitrogen & a combination of atmospheric gases to achieve control of stored grain insects has developed worldwide interest. This follows the increasing worldwide problem of insect resistance to conventional insecticides and also because of the residues associated with the use of these materials.

The technique of CAS involves the alteration of the concentration of normal atmospheric gases present in storage so as to give an artificial atmosphere that is insecticidal & prevents mold growth and quality deterioration of the stored product.

Two classes of externally controlled atmosphere are generated by adding (i) carbon dioxide and (ii) nitrogen. It is carried out by a progressive purge of carbon dioxide or nitrogen. In the case of small bags, it is carried out by fast flushing. Carbon dioxide may also be added in the form of dry ice to the commodities to be disinfested.
Controlled atmosphere storage of grains using carbon dioxide

There are 3 methods of applying carbon dioxide to stored grain. They are:

a. Purging a full silo from the top – involves introduction of gaseous CO₂ into the headspace above the surface of the grain. The CO₂ is forced down into the grain by positive pressure on the headspace of the storage facility. The CO₂ mixes with and displaces a portion of the existing atmosphere and creates a modified atmosphere lethal to any insect present.

b. Lifting the atmosphere out – involves purging with CO₂ gas from the bottom.

c. Applying CO₂ in the grain stream – involves adding CO₂ in a semisolid form called CO₂ snow to the grain stream when loading into silos.

Controlled atmosphere storage of grains using nitrogen

The principles of nitrogen preservation of grains were applied in the experimental facilities to large-scale gas tight bins for barley, wheat and sunflower seed storage, which gave result that long term preservation in nitrogen is advantageous at all temperatures and moisture content. Nitrogen based atmosphere allows prolonged storage without the need of common disinfecting drugs or other protective treatments.

Table: Exposure periods proposed for modified atmosphere disinfestation of grains (<12% mc)

<table>
<thead>
<tr>
<th>Atmosphere source</th>
<th>Initial targets concentrations in storage</th>
<th>Final targets concentrations in storage</th>
<th>Period of exposure within these limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>&gt;70% CO₂ in air</td>
<td>&gt;35% CO₂ in air</td>
<td>&gt;10 days at 20°C</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>&lt;1% O₂ in N₂</td>
<td>&lt;1% O₂ in N₂</td>
<td>&lt;6 weeks at 20°C</td>
</tr>
</tbody>
</table>

Both CO₂ and N₂ have merit in a residue-free insect control programme. Hence, gas-tightness of the storage structures, scope of atmosphere modification, availability of gas and their costs will all influence the choice of the gas and the method of purging or gas mixture creation.

4. Aeration of Grain (cool storage)

It is the technique to cool the grain and to equalize the temperature all over storage bin. Aeration may be accomplished by maintaining the perforated ducts on the floor of storage bins. At the end of each duct, a fan is mounted for exchange of cool air. Initially, cool air circulation is used to cool the center of the bins and thereby prevent the moisture migration from warm grain to cold surface.

Advantages

- Rate of cooling is accelerated by aeration and at a temperature below 15°C, most insect pests become inactive and may eventually die. The activity of insects and mold can be retarded by cooling at or below 18°C.
- Aeration can also be used for the fumigation of the infested grain.
- Aeration with high speed cooling helps to accelerate drying and retain quality during drying.
- It is reliable, labour saving and economical method.
- Temperature is rendered uniform throughout the bulk and prevents moisture migration, activity of fungi and thus reducing the auto deterioration of grain.

Factors that influence the effectiveness of aeration

- Condition of grain mass
- Weather condition
- Air moving or blowing equipment
- Temperature, moisture and RH
During cold air circulation, cooling & small amount of drying occurs. The evaporation of small amount of moisture greatly accelerates the cooling rate. The extent of drying during aeration is lower i.e. 0.25-0.5% reduction in weight or moisture removal. Aeration may be continued till the temperature of cold air is at least 6°C cooler than that of grain. But aeration at humid weather can add moisture to the grain.

The quantity of air used for aeration is from 0.021-0.104 m$^3$/min per ton of grain. The aeration time depends upon grain mass, volume, air flow rates, temperature and RH of air and flow pattern of the grain. Dry grain at mc 12-14% needs only ventilation to cool the grain below 15°C.

![Aeration system for cooling of grain](image)

The arrangement of duct for getting air in and out of the granary also affects the cooling rate as it affects the uniformity of air flow. Aeration should be continued till all parts of the bin is equally cooled. The aeration system comprises of:

- An air moving system
- Grain temperature monitoring system
- Fan operation monitoring system
- Atmosphere condition recording system

In the cold climate, temperature of 5-10°C may also be achieved in aerated grain stores and this temperature is likely to kill many insects. Moreover, if there is some infestation, the activity and heat production by insects can be sufficiently reduced so as to arrest the further infestation. Damp grain should not be stored and if stored, ventilation for 100s to 1000s of hours at the rate of air flow rates more than 0.7 m$^3$/min should be maintained.

Cold damp storage
- Affects the grain fertility
- Favours the development of mustiness and mold growth
- Favours weight loss
- Infestation to mites because they are more resistant in low temperature

5. Refrigeration storage

Use of low (refrigeration) temperature to control stored product insects is an alternative to chemical control method. It can be used alone or in combination with other methods. The time required for refrigeration is determined as the time for equilibrium of temperature of commodity with refrigeration temperature plus the time needed to kill insects.
The effect of low temperature on insects

Insects are poikilotherms² i.e. their body temperatures follow closely to that of environment. In general, if insect body temperature is lowered, its activity level decreases until it comes to rest and show no activity. A further decrease in temperature results in death. The thermal death point varies with species and is dependent on the temperature as well as time of exposure.

6. Insects proof container

The use of plastic sheeting as a means of insects proofing followed by fumigation is practiced satisfactorily. This technique has been taken one stage further in the development of air-ware house, a portable fumigatable and insect proof storage building constructed of PVC-coated nylon or terylene, or neoprene coated nylon. Flexible bulk containers (capacity 1-15 tones) and plastic sacks or plastic liners for natural fiber sacks are also considered suitable for insect proofing. But the limitation of plastic is that they not only restrict the insect’s entrance but also prevent the vapour exit. So, water can’t migrate out, thereby following the mold growth and then damage. It may only be used for the produce that has been adequately dried.

7. Irradiation

Radiation disinfection of grain, whereby infested grain is subjected to ionizing radiations to inhibit insect reproduction and to kill, is a technique of treatment of stored grains which is still under development. This method provides a direct method for insect control in cereal foods. However, special installation and precautions are needed to ensure a protection from exposure to environment.

Ionization radiation kills most living organisms by injuring the nucleus. Thus irradiation is more effective against cells that are forming or dividing such as reproductive cells or insects eggs during embryo development rather than cells that are formed. Damaging of reproductive as well as somatic cells occurs rather than immediate death of insects after exposure to radiation. They make take 2 weeks or even longer for death.

Three types of ionizing radiations have been evaluated to control stored product insects viz. α-radiation, β-radiation and γ-radiation.

Experiments carried out in the US have shown that beetles are more susceptible to gamma radiation than moths. 25 K rads (25000 rads) will kill all stages of beetles *Sitophilus oryzae* and *Tribolium confusum*, but more than 100 K rads are probably necessary to sterilize the moths *Plodia interpunctella* and *Sitotroga cerealelle*.

γ-radiation has been combined with other physical and chemical methods in attempt to reduce effective radiation dose required to achieve control. Exposure of *Sitophilus granarius* (granary weevil) to 300°C before irradiation sensitized the weevil to radiation. γ-radiation combined with IR ray was found to be more effective for controlling grain moth.

The reliability of ionizing radiation, like that of other pest control methods, depends largely on the applied dose, the efficiency of the delivery system and susceptibility of the target species. There is no evidence till date that the insects are resistant to irradiation.

Dose required is 15-100 K rad for wheat and 10-100 K rad for rice disinfection.

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² Organisms having variable body temperature

Compiled by: Sandesh Paudel
Effect on products

Extensive study in the US on the wholesomeness of irradiated food has shown that nutritional quality was not impaired and no toxic or harmful effects were observed (following animal feed tests). In long term storage study of wheat irradiated at 20 K rad, wheat quality was not impaired and milling and baking qualities were also not adversely affected. But germination power was reduced at a dose of 25 K rad. γ-radiation generally reduced the proteolytic activity of wheat flour but baking quality was actually improved. Dose of 50 and 100 K rads increase the gluten absorption soluble proteins and amino acids.

8. Sounds

Experimental studies in the US have shown that the number of progeny from eggs laid during a 4-day exposure of *Plodia interpunctella* to amplified sound waves from two sources was only a quarter of that from eggs of unexposed moths. Moreover, the length of life of adults developing from the eggs of exposed moths was reduced. Ultrasound causes cavitations of cells and thus reduces life span.

The sounds used are:

1. Infra sound (<20 KHz)
2. Ultra sound (>20 KHz)

9. Percussion

It has been found out from experiments that percussion or sharp impact kills insect stages present in foodstuffs, and even the egg stage contained within cereals. A centrifuge type percussion machine, such as Entoleter, provides a convenient method of treating free flowing, particularly powder type of cereals and cereal products, for elimination of the insect pests. The treated food then should be placed in an insect proof sealed container to prevent reinfestation. The finer the product, the more speed of machine and better the killing effects. Cereals and semi-granular products require 1450 rpm speed where as finely divided powder (flour) needs about 2900 rpm.

The Entoleter may be fitted with other machines, such as scourer and aspirator, to improve the appearance of certain produce such as parboiled rice. In modern flour mills, it is a common practice to incorporate Entoleter at grain intake points to ensure that only uninfested grain enters the mill. Entoleters are also used immediately prior to bagging-off the flour to ensure that the flour put into store or sent is uninfested. Material suitable for treatment is that which is sufficiently dry and open in texture so as not to clog or cause bridging inside the machine.

10. Visible or UV light

*Plodia interpunctella* are more attracted to green light than UV light and are then trapped in sticky plates. Very short wavelength <2200 Å are highly toxic to cells. UV is generated by mercury vapour, xenon or hydrogen arc lamp. Egg hatching may also be reduced or completely inhibited by exposure time of 1-5 min. Older eggs are more sensitive than young eggs.

C. Chemical Methods

There are two main types of chemicals used in the control of insect pests or stored products, i.e., contact insecticides and respiratory poisons or fumigants. A contact insecticide is a poison which is able to penetrate the insect cuticle and thereby enter the body tissues. A fumigant is a gas or vapour which is taken into the body of the insect through its respiratory system.
**Contact Insecticides**

A contact insecticide is a substance which kills an insect through its ability to penetrate the outer layer of cuticle and interferes with essential physiological and biochemical functions. Though insects are relatively smaller in weight and volume, they have large surface area (due to the presence of wings, hair, antenna and spines) exposed to cuticle penetrating insecticides. The contact insecticides are developed and designed to penetrate the cuticle rapidly and alter the central nervous system, respiratory system and intestinal system before the development of defense mechanism of insect against insecticides. Contact insecticides are designed on the basis of physical weakness of insects and the effectiveness of the contact insecticides depend on the thickness, hardness and water repellency of the cuticle layer and abundance of hair and spines which may prevent the wetting. The wax covered cuticle may become barrier to the passage of water into and from the insects. To overcome this obstacle, insecticides have been developed which are readily absorbed through the digestive system of insects when consumed along with their normal foods.

Contact insecticides can provide long term protection (by residual effect) but often tend to be somewhat specific in their effect upon insect species and to produce resistance more than fumigants. The contact insecticides have relatively less power to penetrate through sacks and bulk and to become absorbed into individual kernels of grain. There are many contact insecticides which could be effective for controlling insects in and around the stored grain. The insecticides which are used suitably on stored products are limited in number owing to different hazardous problems, like taint or toxic residues.

**Requirements of Insecticides to be used in Stored grain**

1. It must have a wide range of toxicity to insects.
2. It should be less dangerous for personal handling.
3. It must be free of danger from residue problem.
4. It must not develop the resistance in insects.
5. It should not produce taint or loss in germination power as much as possible.
6. It must have a legal limit confined by laws, either governmental or international.
7. It must be acceptable to international trade.
8. It must not affect the quality, flavours, smell and handling property of grain.
9. It must be effective at economic rate of use.
10. It must not be flammable, explosive and corrosive.
11. It must be acceptable to the health authority.
12. Its method of application must be controllable and compatible to the established grain handling procedure.

**Classification of Insecticides**

According to use, insecticides are classified as follows:

a. **Knock down agents**: It is one which is capable of immobilizing or killing an insect easily. Such agents are usually aimed against flying insects on the surface or insects that hide away at crevices and other hard to get at places. E.g. pyrethrum, lindane, BHC(benzene hexachloride), dichlrovos, etc.
b. **Surface sparger:** These are applied to surface of grain bulks and bags. E.g. dichlorvos, malathion, etc.

c. **Structural treatment:** They are applied to the fabric of grain stores, transport vehicles and other structural surface. E.g. lindane, malathion, etc.

d. **Grain protectant:** These are insecticides which when added to grain or seeds prevent infestation becoming established. They are not inter-related to control infestation present in the commodity at the time of treatment. Such infestation should be controlled by fumigation as a separate operation.

Some common contact insecticides group:
   a. Plant poison: nicotine (tobacco), neem, bojho, sisno, etc
   b. Synthetic organic compounds: organochlorines, organophosphorus
   c. Carbamate
   d. Inorganic insecticides

**Common Insecticides in Use**

The insecticides in use are given below:

1. **Pyrethrum**

   This is the best known of the natural insecticides, the most important constituents of which are known as pyrethrins. Their toxicity to insects can be greatly increased through the addition of a synergist, such as piperonyl butoxide; they are unstable when exposed to light. Pyrethrum is non-toxic to man and is therefore very safe to use on food or in situations in which food is likely to pick up some of the insecticide. This is safely used for oil containing products which are otherwise susceptible to taints (spoilage of quality) and odour absorption.

2. **Chlorinated Hydrocarbon Insecticides (Organochlorines)**
   a. **DDT** (dichloro-diphenyl trichloroethane)

   ![DDT](image)

   It is a white to cream coloured powder having melting point 108°C. It is much permanent and durable of all commonly used insecticides. Due to its insolubility in water, it has very low vapour pressure and is resistant to deterioration by light and oxidation. It acts as either contact insecticides or stomach poison to insects affecting the sensory organs and nervous system and causing paralysis and death. It is relatively low acting poison and in some cases, 2 or 3 or more days elapsing before death occur.

   The outstanding feature of DDT is its long residual life and for this reason, it is used mainly for the treatment of the internal structure of the storage buildings. Its toxicity to man prevents its use for admixture with foods or animal feed. Also it should not be applied to the external surfaces of bags containing produce or to the internal surface of containers (e.g. grain bins) which will be bulk loaded with products.
Actual lethal dose for rat (LD_{50}) = 118 mg/kg body weight
Residual tolerance = 3.5-7 ppm

Different formulations of DDT for different purposes are as follows:
- 2-10% dust of DDT with clays or talc powder for control of mosquito’s larvae, mites and varieties of agricultural pests.
- Solution of 0.2-20% DDT in kerosene, mineral oil, xylene, cyclohexane, employed in aerosol for the control of household insects such as mosquitoes, moths, etc.
- 0.1-5% DDT in water from concentrated solution in kerosene plus emulsifier for control of insects.
- Water suspension containing 0.1-5% prepared from wettable powder containing 50-90% DDT formulated with clays.

b. Methoxyl chlorines (Dianisyl trichloroethane)

It is a white powder which gives more rapid knock down of many insects than DDT and is of lower acute and chronic toxicity. It has a melting point of 89°C. It is 20 times soluble as DDT in kerosene and spray oils and has much persistent residual action. It is formulated and used as about the same manners as that of DDT.

c. BHC (Benzene hexachloride)

It is a colourless crystal irritating to eyes and respiratory tract. It is harmful to livestock. BHC and its isomers are slightly soluble in petroleum oil, soluble in aromatic solvents but insoluble in water. It has melting point of 112°C and vapour pressure of 9.4 \times 10^{-6} \text{ mm of Hg} at 20°C. It is very stable under high mc grain but unstable to alkali. It is stable to action of light and oxidation. It is recommended only for seed dressing. It is a high stomach poison as well as contact insecticide. Symptoms of BHC poisoning are nausea and vomiting.
Application rate: 150-300 ppm and Residue tolerance: 2.5-10 ppm

BHC is a name given to the crude benzene hexachloride and consists of the mixed isomers of this chemical. Only one of these isomers, the gamma isomer, is responsible for the greater part of effectiveness of BHC, and only the refined BHC known as lindane (which contains not less than 99% gamma isomer) should be used in the stored product insect control. The use of crude BHC can lead to taints & odours in treated foodstuffs and also increases the potential toxic hazard to man.

Lindane is basically a contact insecticide, which under tropical condition does not persist for very long. Its vapour pressure is such that at tropical temperatures there is also some fumigant action which may be quite important in certain temperatures.
d. **Aldrin**
   It is white crystalline solid having melting point 104°C and vapour pressure of $6 \times 10^{-6}$ mm of Hg at 25°C. It is soluble in alcohol.

e. **Dieldrin**
   It is white crystalline solid having melting point about 175°C and vapour pressure of $1.8 \times 10^{-7}$ mm of Hg at 25°C. It is stable in high alkali and mild acidity.

   Dieldrin is an extremely persistent insecticide and is also more toxic to man than DDT. It is used for the control of termites in the soil or cockroaches particularly in the ducts of certain buildings. But it should not be used for any other pest control operation associated with stored food.

3. **Organophosphorus insecticides (Organophosphates)**

   Although some organophosphorus insecticides (e.g. parathion) are among the most poisonous insecticides in existence, a number are relatively safe and can be used for the control of pests on stored food.

   a. **Parathion** (o-o-diethyl-o-p-nitrophenyl phosphorothionate)

   ![Parathion structure](image)

   This is a dark brown liquid sparingly soluble in water and hydrolyses in alkali. It has melting point of 6°C, boiling point 375°C and vapour pressure is 0.00064 mm of Hg at 26.5°C. It has been proved effective against a wide variety of insects than any other insecticides and generally applied at the concentration of 0.01-0.1%.

   It has relatively short residual action and may be safely used on edible produce, if applied 15-30 days before marketing. It is the most precious organophosphorus insecticide.

   b. **Malathion** (o-o-diethyl-s-1,2-dicarbo ethoxy ethyl phosphorodithionate)

   ![Malathion structure](image)

   It is also known as grain guard or malaprene. It is a brownish liquid having boiling point 150-157°C and vapour pressure of $1.25 \times 10^{-4}$ mm of Hg at 20°C. It is soluble in organic solvent and slightly soluble in mineral oils. LD$_{50}$ for rat is 1.375 gm/kg body weight. It is stable to neutral solution but unstable to both acid and alkali. It has good persistent on dry grain and only short effective on high moisture grain, especially at higher temperature. This is considered as safe insecticide and its direct admixture to foodstuffs to a certain limit is allowed in many countries.

   Sometimes, the dust formation gets broken down and becomes ineffective. This breaking down is favoured by high moisture level, high temperature and enzyme present in the case of grounded foodstuff. Malathion is also unstable when applied to alkaline surfaces, such as cement floor.

   Only premium grade deodorized malathion should be used for insect control in stored product. It is effective against most of the stored product insects but *Rhizopertha dominica* is less susceptible.
c. **Dichlorvos (2,2-dichlorovinyl dimethyl phosphate)**

   It is better known by its trade name DDVP. It is a colourless to amber liquid having boiling point 53°C at 0.2 mm of Hg and vapour pressure of 3 x 10^{-2} mm of Hg at 30°C. It is poorly soluble in water, moderately soluble in kerosene and miscible with organic solvent. It is stable to heat but hydrolyzed by alkali.

   It is much more toxic to mammals than most of the insecticides used in storage practices. It acts equally as contact insecticide and fumigant. It is effective against a wide variety of pests, especially larvae or flies. It appears promising for the control of moths.

d. **Fenitrothion**

   It is brownish yellow liquid partially soluble in water but soluble in most organic solvents. It is a contact insecticide and seems to be promising for beetle control but have not been toxicologically cleared for use in stored foods.

4. **Carbamate Insecticides**

   This group of insecticides is not yet widely used in the storage field. Many of them have a low toxicity to mammals and it is possible that they may be more widely used in future for the protection of stored foods.

   **Carbaryl (1-napthyl-methyl carbamate)**

   ![Carbaryl Structure](image)

   It is better known by its trade name as Sevin. It is a white crystalline powder poorly soluble in water having melting point 95-100°C and vapour pressure of 0.005 mm of Hg at 26°C. It is stable to light & heat and is non corrosive and also it has low volatility. It has a long residual life. It is highly effective against *Rhizopertha dominica*.

**Problems relating to the use of insecticides**

The various problems related to the use of insecticides are mentioned below:

1. **Danger to personnel handling insecticides**
   The danger depends upon:
   - The degree of mammalian toxicity of the insecticide
   - The circumstances under which it is sold
   - The concentration at which it must be used
   - The way it is prepared for use and is employed
   - The local facilities for personnel handling the insecticides to wash immediately afterward.

   Toxicity is expressed in terms of the necessary (or estimated) dosage to kill 50% of a large population of the species of animal under consideration i.e. LD₅₀ figure. It is normally expressed in terms of acute oral toxicity (mg of poison per kg of body weight of the animal). Mammalian toxicity may occur by absorption of the chemical through the skin, through intake of small quantities of the chemical over a period of time, or through the exposure of the human body to a single large dose of the chemical (either inhaled or ingested).
The greatest dangers in this category are caused by absence/delaying of proper washing of any parts of the body which have been in contact with insecticides, sale of insecticides in containers not intended to contain chemicals and improper labeling difficult to understand by the local population. An insecticide container should be properly labeled, with detailed instructions about their method of usage, handling, concentration, toxicity of the chemical and the precaution to be taken in its preparation and use.

Pest control personnel handling contact insecticides should wear protective clothes such as gloves, masks, goggles, cap, etc. in order to minimize the risk of dermal absorption.

2. **Danger from insecticides residues**

This danger varies with:
- Properties (toxicity, vapour pressure) of insecticides
- The absorption properties of the produce
- The handling and processing to which the produce is subjected between treatments and consumption
- The storage period

The danger is increased by non-uniform exposure of the produce to the chemical, by repetition of treatments and by the use of seed stocks, which might be expected to have received heavy dosage of insecticides, as food. On the other hand, the danger is lessened by the loss of chemical before consumption (by volatilization or mechanical means), during storage & cleaning, by processing and cooking methods, and by the consumption of small proportion of treated produce in whole diet.

In cases where the produce is not treated directly with insecticides, there may be insecticides transference to the product through surface of sacks or walls of the bin, etc and this transference may also lead to residual insecticides in foods, if the dose applied to such surfaces is too high. The transference of this kind increases with the dosage rate and with decrease in particle size, increase in oil content of the produce, storage period and temperature.

For commercially available and widely used insecticides, the residue tolerance levels are set and treatments are aimed so as not to exceed these residue levels.

3. **Specific aspect of toxicity of insecticides to insects**

An insecticide has its own specificity of action and effectiveness. The general purpose insecticide which is effective against all pests under all conditions does not exist. Specificity must be carefully considered before deciding on the appropriate insecticide to be used and therefore the most appropriate insecticide for the pest present and the commodity to be treated must be carefully selected.

The susceptibility or resistance of insect towards insecticides not only varies among species but also within a single species. The reaction of insecticides varies with the different stages of egg, larva, pupa and adult. In certain beetles, the larval stage is the most resistant and therefore the dosage required to kill that stage has to be used. The specificity is also dependent on the sets of condition, such as temperature, etc. Thus the effect of physical environment on the efficiency of the insecticides in killing insects has to be remembered in considering specificity.
4. Taints or damage to germination

The use of insecticides, in addition to the presence of chemical residues, may result in an odour or flavour which detracts from its quality and also the ability of the grain or kernel to germinate may be impaired. These aspects of deterioration are affected by

- the inherent characteristics of the produce
- the condition of the storage (moisture content, temperature, etc)
- the properties of the insecticides used

The oil content of the produce is also an important factor responsible for odour absorption. An oilseed such as cocoa beans, and spices such as ginger are more susceptible to the taint problems than cereals and in this case, the use of Pyrethrins is suggested as safe insecticide. Also, the moisture content of the produce can affect susceptibility to taint and to reduced germinative power, particularly in the case of fumigants.

5. Development of resistance in insect species

If an insect shows a high initial susceptibility to an insecticide, a resistant strain will be selected more rapidly than if the initial susceptibility is low. This is unlikely since the rate at which resistance develops depends upon the:

- Incidence of resistance in the genetic makeup of the starting population i.e. hereditary characteristics
- Dosage rate of insecticidal application
- Frequency or uniformity of the treatment
- Life history of the pest in relation to exposure to the insecticidal treatment

Therefore, if insecticidal treatments are applied to all stages of their life cycle, the chance of resistance development is higher than if it has been applied to a single stage only of their life cycle. Also, resistance is more likely to develop if the whole rather than only a proportion of population is exposed to the chemical.

Insecticides Formulation

Insecticides are used in a number of ways and in many forms or formulations. It is important to use the correct formulation of insecticide and the correct equipment for applying it for particular food and particular target pest. The different formulations available for the use in stored products are: dilute dusts, dispersible powder, emulsifiable concentrates, liquid concentrates and pyrotechnic preparations.

1. Dilute dusts

These are ready for direct use and no dilution is required. They may be sold in small containers which are also applicators, or they may be applied through a special dusting machine. Most dilute dusts have a content of 0.1-5% of the active ingredient and the remaining is the base or diluent. There can be a wide variation in the bulk density of the dust. Light dust is generally preferred as it gives a good bulk for mixing. Diluents are flour, starch or other milled products from grain. It is necessary to convert a solid insecticide into a finely divided form so that it may be distributed evenly for a long time. Dilute dusts must be stored in cool and dry place. If they become damp, they lose their insecticidal efficiency and it would be difficult for uniform application.
Dilute dusts are mainly used for the following reasons:

- For admixture with grains
- For dusting the external surfaces of bagged produce to prevent reinfestation
- For applying a band of dust around a stack of produce, to prevent the crawling of insects
- For dusting hides and skins, fish, etc
- For disinfection of railway wagons, although they do not stick well to vertical surfaces.

2. **Dispersible powder**

These are all concentrate powder formulations which are intended for dilution with water before application, i.e. wettable, spray-able, soluble and dispersible powders. They usually contain 20-80% per weight of the active ingredients of the pure insecticide; the exact % should always be labeled in the container. Also, stabilizers, wetters and stickers are included in the formulation. These additives help to prevent sedimentation of the powder in the water before spraying, to stick the insecticide to the target so that it is not easily brushed off, and to spread the spray liquid over the target easily during spraying.

Dispersible powders are generally used for the following reasons:

- For treating store fabrics (walls, roof, floor)
- For treatment of external bag surfaces
- For disinfecting railway trucks, lorries, ship holds, grain or flour bins, etc.

Thorough preparation of the sample is essential. The required amount of powder is mixed with correct volume of water. First, a little water should be added to the powder and stirred to produce a smooth paste, which is then added to the rest of water and thoroughly stirred until an even suspension is obtained. Dispersible powders tend to settle out after mixing and therefore only spraying machines equipped with an agitation system should be used for their application.

3. **Emulsifiable concentrates**

These are liquid concentrates which are intended for dilution in water before they are applied. They usually contain 20-80% per weight of the active ingredients of the pure insecticide. These are sold in containers clearly labeled with the % concentration of insecticides in the formulation as well as the toxicity and the methods of application. Correct amount and type of emulsifier are incorporated in formulation so as to obtain a uniform blend of oil and insecticides in water. These may or may not contain solvent.

These are also used in the same way as the dispersible powders. However, these may also be used for admixture treatments, particularly in relation to bulk grain storage where a flow of grain has to be treated with insecticide. Agitators are not generally required in machines used for applying emulsifiable formulations but the insecticide should be stirred just before refilling the spraying machines.

4. **Liquid concentrates**

These formulations are intended for direct use through the aerosol or fogging machines. These do not contain emulsifiers or other additives and so can’t be diluted with water. They often consist simply of the insecticide dissolved in light mineral oil.
The liquid concentrates are often applied in the liquid form of aerosols (very small liquid droplets of 2-50 microns in diameter). These aerosols remain suspended for an appreciable length of time (more than 30 min) and are capable of penetrating into cracks and crevices and the furthermost corners of a store but do not penetrate through spillage and accumulation of dusts, etc. They are dispersed by wind and air currents and so are usually effective when used in warehouses where there is not too much ventilation.

5. Pyrotechnic preparations

These are smoke bombs, smoke pellets or smoke canisters. The smoke is equivalent to an aerosol. The particles are about the same size as aerosol droplets but they are solid, not liquid. Smokes have the same properties as aerosols with respect to penetration and dispersion by wind. These preparations consist of a mixture of insecticides and pyrotechnic powder made up into a firework-like device complete with taper fuse for lighting. The fuse is lit and a dense column of insecticidal smoke is emitted. Only moderately heat stable insecticides are used in its preparation, such as lindane, DDT or their mixtures, which is widely used.

Different information to be gained before the use of Insecticides

- Trade name
- Active consignment, its common and chemical name
- Claim for use
- Directions for use
- Doses or rate of application
- Necessary storage required for it
- Date of manufacture and expiry
- Name and address of manufacturer

All these information are gained through the label. Therefore the manufacturer or marketer should essentially provide all these information by correct labeling.

Preparations before use

Care must be taken about the concentration to be used, calculation of quantity, accurate measurement of calculated quantity, mixing or dilution, etc. These all should be done according to the directions mentioned on the label.

Safe use of Contact Insecticides

1. Always read the pesticide label and follow the instructions
2. Wear clean and appropriate clothing; gloves are essential; a face mask is advisable but if not available a clean piece of cloth should be tied over the mouth; boots should be worn, trousers should be worn outside the boots; a face shield is useful to protect eyes
3. Always keep insecticides under lock and key & when in use, never leave bottles unattended.
4. Never transfer insecticides to other containers, particularly soft drink bottles
5. Never reuse insecticide containers for other purposes; dispose of empty containers, ensure they cannot be reused.
6. When working with insecticides do not eat or drink, do not rub your eyes, do not smoke and keep food and drink away from insecticides.
7. Have plenty of soap and water available, and a change of clothing. Always wash after handling insecticides.
8. Destroy heavily contaminated clothing; after spraying wash clothing and protective gear.
9. If spills occur wash the area immediately; wash off any dribbles that might have contaminated the outside of the insecticide container and any vessel used for dilution.
10. Nobody except those involved in the insecticide application should be allowed in the store whilst spraying is in progress; nobody should be allowed to handle insecticide containers except authorized personnel.
11. Workers should be made to cover their feet to prevent contamination from the floor.
12. The electricity supply should be turned off before spraying begins.
13. Excess spray solution should be applied to the walls or floor.

**Different methods of using Contact Insecticides**

A number of methods are available for using contact insecticides, such as admixture of insecticides directly with food products, treatment of bag stacks, residual spraying of storage buildings and vehicles, and admixture of insecticides for the protection of seed.

1. **Admixture of insecticides directly with food products**

Due to the potential hazards to health imposed by other insecticides while treating in this way, only three insecticides are recommended for this treatment, which are pyrethrum, malathion and lindane. Admixture treatments can be used for all cereals and grains but not for flours. Malathion, being less toxic, is preferred to lindane as the potential toxic hazard to man is concerned. But malathion has the disadvantage of certain amount of chemical instability and tends to breakdown and so become partially ineffective in certain circumstances. In some cases, insects resistant to lindane are also found. This factor also has to be taken into account.

Admixture is suitable for grains intended for long term storage and is normally carried out at an early stage in the chain of events that occur between harvesting of a food crop and its consumption. It may be used to protect cob maize and other unthreshed cereals stored in granaries. Admixture may be carried out on the farm after drying, at the time of bagging of grain, or at the trader level before acceptance by a central store. Dilute dust formulations are normally used at the rate of 120 gm per 100 kg of grain. Proper mixing of dust with grain is essential and this can be done by the use of shovel mixing on a tarpaulin or in a drum with eccentric axle or by various mixing machines. Failure of admixture treatment is usually due to the inadequate mixing of the insecticides with the grain, provided the grain is properly dried before the application of dust. Recommended insecticides are:

- **a. Malathion – 120 gm of 1.0% dust per 200 kg of grain**
- **b. Lindane - 120 gm of 0.1% dust per 200 kg of grain**
- **c. Pyrethrum - 120 gm of 0.2% pyrethrins + 1.0% piperonyl butoxide dust per 200 kg of grain**

At trader levels, liquid insecticides (emulsifiable concentrates) can be used for direct application to grain. These are usually applied through a mechanized precision spraying apparatus which applies the insecticidal spray to the produce. This can be done when the produce is spread on the floor or while it is moving in a conveyor, etc. there is the added advantage that liquid formulations are more stable than dusts. The insecticides recommended are pyrethrins or malathion.
2. **Treatment of bag stacks**

Two types of treatments commonly used, viz. layer by layer and external stack treatments. These methods are only capable of reducing infestation.

a. **Layer by layer method**

Sprays or dusts are applied to each layer of bags during the construction of bag stack. Such treatments have high efficiency against the more mobile pests than against those that tend to remain within bags. Dilute dust formulations are used. Insecticides recommended are 2% malathion dust or 0.5% lindane dust at a rate of 25 gm per sack or 50 gm/square meter.

b. **External stack treatment method**

It usually consists of a spray application to the four sides and the top surface of a bag stack. Dust treatments may successfully be used on the top surface but side stacks do not get good coverage and is thus inefficient. Wettable powder formulations should be used wherever possible because of the filtration effect, where as emulsified insecticides tend to be absorbed into the fabric of the bags and is thus unavailable for killing insects. The insecticides most commonly used for this purpose are malathion and lindane (at doses mentioned above). Pyrethrum is generally inefficient for this purpose because of its instability to light.

Insecticidal treatments of external bag surfaces are used to prevent reinestation. For e.g. stacks should be sprayed immediately following fumigation or, preferably, immediately prior to sheeting, in order to minimize the risk of cross infestation. Bag stacks will particularly require surface spraying when they are in a store containing other produce which is infested or in an area where infestation from external sources (or from the fabric of the store) is high.

3. **Residual spraying of storage buildings and vehicles**

Before spraying the structures of stores, bins or transportation units, thorough cleaning should be carried out. All internal surfaces, including floor & roof, must be sprayed with malathion or lindane. The dispersible powder formulations are preferable to emulsifiable concentrates for application to cement, brick, stone or whitewashed surfaces. It is because emulsified insecticides are largely absorbed into cement and stonework and are not present on the surface with which the insects are in contact. With dispersible powders, the particles of powder (containing insecticides) are filtered out on the surface of cement, the water being absorbed into the wall (this phenomenon is known as filtration effect). Treatment should be carried out at intervals of 3 week. Insecticides recommended and their rates of application are:

a. Malathion – 400 gm of 25% dispersible powder, 200 ml of 50% emulsifiable concentrate, in 5L of water per 100 sq. meters

b. Lindane - 200 gm of 50% dispersible powder, 500 ml of 20% emulsifiable concentrate, in 5L of water per 100 sq. meters

In some places, DDT is also used to treat store fabric, railway trucks, lorries, etc. But it can’t be used in circumstances where foodstuffs are likely to come into direct contact with the sprayed surfaces. A mixture of lindane and DDT has been successfully used in some areas.

c. Lindane/DDT - 100 gm of lindane 50% dispersible powder plus 200 gm of 50% DDT dispersible powder, or 250 cm³ of lindane 20% emulsifiable concentrate plus 400 cm³ of DDT 25% emulsifiable concentrate, in 5L of water per 100 sq. meters.
4. **Admixture of insecticides for the protection of seed**

Relatively high concentrations of insecticides for admixture can be used for the protection of seeds against insect infestation. In addition to malathion, lindane & pyrethrum, DDT may also be used, if the seed is not intended for human consumption. 3-5 % DDT dust is used at the rate of 100 gm/kg. Malathion, lindane and pyrethrum are used at 2-5 times the rate recommended for food-grain storage.

**Machines/Devices/Provisions for Insecticides Application**

Though there are various designs, the basic operating principle is the same for all equipments.

1. **Knap sacks and hand sprays**

This is a potable equipment consisting of spray container, pump and spray nozzle. Its capacity is up to 2 or more liter. Most equipments are manually operated but in some cases, petrol engine for pumping and blasting the air may be fitted. Another hand spray consists of spray reservoir which is left standing in one place and the operator wonders freely applying sprays at relatively large areas.

Another design consists of pressure cylinder which contains the pressurized spray solution which is released as atomized particles or aerosols through the nozzle operated by hand.

Advantages: cheap, potable and easy to operate.

Disadvantages: high labour required, difficult to carry and operate in small places, and the spray can be projected only short.

2. **Power spray**

These are variable in design, shape and capacity, and the systems are not manual. Beside pump, tank and nozzle, each tank or unit has its own internal combustion engine, series of pipelines and valves, heavy pumps, spray base and nozzles with long projection capacity.

**Advantages**
- Large surfaces and areas are disinfested
- Long projection of spray
- Requires less area for operation
- Different types of insecticides can be used

**Disadvantages**
- Expensive in installation
- Possibility of leakage

**Toxicity of pesticidal chemicals to man and animals**

Various categories of toxic chemicals belonging to the organic chlorinated compounds, organic phosphate compounds and carbamates are being extensively used in agricultural production and public health. These chemicals have spectacular lethal activities towards insects, pests and hence their application is increasing day by day. Unfortunately, these chemicals are basically toxic not only to insect pests but also to higher animals including human beings.

Pesticidal chemicals are residual in nature and thus contaminate food, water and environment. Some are highly persistent (e.g. DDT, Aldrin, Dieldrin, etc) and few are volatile. All these chemicals lead to various kinds of toxicities. Broadly classifying, toxicity are of two types, viz. acute toxicity and chronic toxicity.
The pesticides sprayed on crops, trees, forest, migrants, dwellings, storage, etc eventually reach to some extent up to human beings through water, air and foods. The problems of health hazard of pesticides have become significant during long period due to:

a. Increase in types of chemical employed
b. Increase in quantity of treated materials consumption
c. Increase in number of pests
d. Introduction of newer or more toxic elements
e. Availability of these chemicals for use by unskilled persons

The problems relating to human health and conservation of wildlife arise in general due to the following factors:

- Occupational exposure
- Habitation exposure
- Accidental exposure
- Food contamination

Potential hazards that result from manufacture and use of synthetic pesticides are:

a. Hazards in manufacture or formulation
b. Hazards in mixing or application
c. Hazards to persons not directly associated with pesticides
   - Consumers through contaminated food
   - Children, domestic animals, etc exposed incidentally.

**Mode of action of pesticides in animals/mammals**

The toxicity produced by organophosphorus compounds in mammal is the manifestation of some enzyme system. It is generally believed that mammalian toxicity is associated with inhibition of cholinesterase enzyme whose physiological function is to catalyse the hydrolysis of choline esters. Pyrethrum and malathion exhibit poor enzyme inhibition but in vivo these are metabolized into highly potent cholinesterase inhibitors. These insecticides manifest same mode of action in insects too. Atropine has been found to be antidote for organophosphorus insecticides. The chlorinated insecticides result in chronic toxicity to man and animals. In general, the effect of DDT, BHC, Aldrin, Dieldrin, etc are similar to their manifestation in the central nervous system. Barbioturnates are found to be antidote for these insecticides.

**Fumigants**

A fumigant is a chemical which, at a required temperature and pressure, exists in a gaseous state in sufficient concentration to be lethal to the given pest organism. This definition excludes aerosols which are particulates suspensions of solid or liquid in air and can’t penetrate into materials as fumigants do.

Fumigants are unique groups of insecticides in that they are used as gases and because of this, they have special application. Also they require highly specialized techniques for efficient use. They are used to control insects and organisms in a wide variety of materials, such as grain and grain products.
Fumigation is the process of applying gas i.e. fumigant under appropriate conditions to control the target pests/organisms and this process has served an important role in the pest control application. It is the application of highly volatile chemicals able to penetrate a stack of bagged produce or bulk grain stored in a silo to kill any infestation present including eggs & other immature stages inside the grains. But it doesn’t give lasting protection such as prevention or reinestation or reinvasion by insects. It can be achieved by the use of contact insecticides. In fumigation, gases enter the body of insects via spiracles into tracheal system. The compounds used as fumigants have different characteristic properties which make them useful for insect control. The common properties of fumigants are:

a. Evaporation

Normally fumigants are supplied as solid or liquid phase and these are converted into gases fumes during their use. The evaporation depends on: boiling point, the maximum that can exist in vapour form and latent heat of vapourization.

b. Diffusion and penetration

Fumigants have the ability to diffuse through spaces, penetrate into the materials being fumigated and then to diffuse afterwards. This property allows treatment of large space that is virtually inaccessible to other insecticides. Diffusion and penetration of fumigants can be enhanced by mechanical aids (blowers, fans, and recirculation systems) and by vacuum fumigation.

c. Sorption

This is the phenomenon used to describe the total uptake of gas resulting from attraction and retention by any solid materials in the system known as sorption. Two types of sorption may occur during fumigation.

- Physical sorption: superficial adherence of gas
- Chemical sorption: absorption of gas into the commodity and subsequent reaction with components to release a residue

Following fumigation when gas is removed from the space, desorption of residual vapour from the commodity may occur. During aeration and desorption, it should be taken into consideration as precaution that toxic level of gas must not be build up in areas where human body may expose.

d. Other effects

i. Physiological effects

Effect on living plant: Fumigant may burn the stem or roots of plants. They may kill the plants, may retard the growth in some cases and in some cases, growth may be accelerated or stimulated.

Effect to seed: Germination power may be reduced by fumigation. Seed yield may be altered.

Pest organism: Most of the fumigants have lethal effect to the pest organisms, when used in optimum conditions.

Fruits & vegetables: Surface burning and internal rot may result in some fumigated fruits and vegetables. Flavour may change and keeping quality may be lost. In some cases, storage time can’t be prolonged.
ii. Physical effects

Corrosion: phosphine reacts with copper or brass, ethylene dibromide produces undesirable odour in salts, soap and baking soda, rubber materials, leather & wooden goods, photographic chemicals, materials containing reactive sulphur, etc.

Toxic and other hazards of fumigants

Fumigants enter into the insects’ body mainly through the spiracles and diffuse throughout the tracheal system to poison individual cells throughout their body.

Toxicity of fumigants depend upon

- Species of insects
- Stages of development
- Rate of respiration and metabolism
- Dose of fumigant
- Length of exposure time
- Temperature, etc.

There is a greater variation in susceptibility of different fumigants. Therefore, toxicity of a fumigant for different species of insects is different and it should be determined separately.

On the other hand, as a result of reaction between fumigant and a food product, permanent residues may be formed. For e.g. fumigation with methyl bromide or ethylene dibromide may result in the formation of inorganic bromide bodies. The viability of seeds may be affected by fumigation and also the early growth from fumigated seeds may be impaired. Most fumigants are highly toxic to man and should therefore be handled only by properly trained personnel.

Doses of fumigants and concentration

Dose: amount of fumigant applied (ppm)

Concentration: actual amount of fumigant in air space at any given time

Dose is the predetermined quantity and is always known where as concentration should be determined by taking samples from specified point by analyzing them.

Concentration of fumigant may be expressed as weight by volume (in the same metric system). Concentration of fumes in the space being treated and duration of exposure are important and independent in the action of fumigant.

The product of these two factors i.e. concentration x time (C x T), is often used to express dosage. The expression simply means that the certain concentration of fumigant must be present in the space for given period of time to kill the pest organism. The C x T factor can be manipulated or modified by changing any one factor to get required dosage and thus, to control the fumigation extent. C x T product will vary according to the temperature.

For e.g. Methyl bromide fumigation of dormant

<table>
<thead>
<tr>
<th>Plant temperature</th>
<th>Applied dose (mg/L)</th>
<th>Min. concentration (mg/L)</th>
<th>Exposure period (hr)</th>
<th>Minimum C x T</th>
</tr>
</thead>
</table>
The simple relationship however doesn’t hold good for all fumigants. The more general relationship between concentration and time is

\[ C^n \times T = K \]

Here, \( K \) is constant level of response as LD\(_{99}\) of pests; \( n \) is the toxicity index or specific toxicity index or specific toxicity of pests.

For phosphine, \( n<1 \), this indicates that exposure time is more important than concentration.

For methyl bromide, \( n>1 \), i.e. concentration is more important than exposure time.

Selection and dose of fumigant for particular product is mandatory and use should be in accordance with direction in label and at the level of Environment Protection Agency (EPA).

**Different fumigants used in storage and infestation work**

1. **Carbon disulphide (CS\(_2\))**
   - This is not widely used but is of practical importance in the tropics where vaporization is enhanced by high temperature. Because of its tendency to burn or explode, it is most commonly used in a mixture with the nonflammable carbon tetrachloride for fumigation of small quantities of bulk produce in solid wall containers. Its toxicity to insects is not so high and its use has been replaced by methyl bromide.

2. **Liquid fumigants**
   - They are called so because of their application in liquid form. Several fumigants which are liquid at normal temperature can be vaporized in sufficient concentration to give effective control of stored product insects in many situations. The fumigants should be handled carefully to avoid inhalation of toxic vapours. This group of fumigants includes carbon tetrachloride, ethylene dibromide, ethylene dichloride, mixtures of carbon tetrachloride and ethylene dichloride, and trichloroethylene.
   - They give most satisfactory results when used in small scale bulk storage. They may be used individually or as mixture of various properties. The mixtures are often made to achieve maximum penetrability, toxicity and reduce inflammability. For e.g. carbon disulphide due to its high flammability is often mixed with carbon tetrachloride to reduce fire hazard. For grain in bags, empty bags and for grain not more than 2.5 m deep, a mixture composed of 3 parts ethylene dichloride and 1 part carbon tetrachloride should be used. For grain more than 2.5 m deep, a mixture of these chemicals in equal proportion is more effective.

   a. **Carbon tetrachloride (CCl\(_4\))**
      - It is a colourless liquid and readily vaporizes. It has an advantage that it is seldom absorbed in treated grains. Though it has lower insecticidal property, it is often used when high concentration and long exposure is possible. It is anesthetic to human beings. So, repeated exposure may become dangerous.

   b. **Ethylene dibromide (EDB, C\(_2\)H\(_2\)Br\(_2\))**
      - It is a colourless liquid. It was formerly used in the US for protection against flies in fruits and vegetables and in stored grains too. It is an important soil fumigant but it suffers from surface absorption from many materials and it does not penetrate well. It is used for spot fumigation in flour mills. It is carcinogenic. It causes acute toxicity to rats. LD\(_{50}\) for rat is 148 mg/kg body wt.
c. **Ethylene dichloride (EDC, C₂H₂Cl₂)**

It is a colourless liquid. Absorption by grain can be a problem for its use. It is not widely used. It is formulated as mixture with carbon tetrachloride to get rid of fire hazards.

Liquid fumigants are generally used for the fumigation of small silo bins or small quantities of bagged commodities. In the case of bagged commodities, immediate covering with a gas proof sheet is necessary. They are used successfully to control general insects’ infestation throughout the grain mass and occasionally for treating surface infestation. Liquid can be applied by a sprinkler and hence a good distribution and control can be achieved. The fumigants can be used by gravity distribution technique or air circulation technique. Also, infestations can be treated by injecting liquid through the tubes to various points around the periphery of hot spots and then applying to the spot itself.

3. **Phosphine (Hydrogen phosphide, PH₃)**

It is a colourless and odourless gas with excellent penetration capacity. Mites are quite resistant towards it but it is toxic to all other stored product insects. It has no appreciable effects on stored product insects and leaves no residue. It has become a substituent of fumigant which has no disadvantages.

The tablet or pellet form of this (aluminium phosphide) makes its simple application to bags or to bulk grain during loading into bin. Fumigation results from the liberation of phosphine gas due to the interaction of the temperature and moisture in the grain with the tablet. The residual powder from the tablets consists of aluminium hydroxide.

The fumigant is very toxic to man and, since it requires an exposure period of about 3 days, precautions must be taken during this period to avoid possibility that personnel working nearby may be affected. It is generally used in the fumigation of bulk grain is silos, bagged produce under sheeting, produce in railway trucks and single bags of produce.

4. **Hydrogen cyanide (HCN)**

It has been used extensively in the past for fumigating many foodstuffs which are dried, such as flour, grain, warehouses, etc. It is very toxic to insects & larvae & leaves no appreciable permanent residues in materials. Acute and LD₅₀ for rat is 6.4 mg/kg body weight when used in the form of sodium cyanide salt.

5. **Methyl bromide (Bromoethane/Bromagas/Derofume, CH₃Br)**

It is the most commonly used fumigant. It requires special equipment and specially trained personnel and thus its use is confined to the fumigation of produce stored on a large scale. It has well penetrating power into densely packed material and it is highly toxic to insects and mites. It can be applied commercially under wide variety of condition without producing excessive residue in the grain. It can produce some food smell and odour in some foodstuffs.

6. **Ethylene oxide (EO, C₂H₂O)**

It is used extensively in packaged foodstuffs and for cold sterilization of foods, to prevent microbial spoilage. Being highly inflammable, it is normally mixed with carbon tetrachloride at a rate of 1:9 (EO : CCl₄). Its use is limited due to low penetrating power & only intermediate toxicity to insects. It affects germination power and leaves residues in grain in the form of chlorohydrin.
7. Dichlorvos

It is effective in vapour phase against wide variety of insects either Coleoptera or Lepidoptera. It is effective at low concentration and has some contact effects. It diffuses readily through open spaces but doesn’t penetrate or escape easily through open cracks and crevices. It has potential use for rapid disinfection of open and empty spaces. It should be circulated through grain by forced air circulation devices.

Table: Difference between phosphine and methyl bromide

<table>
<thead>
<tr>
<th></th>
<th>Phosphine</th>
<th>Methyl bromide</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Easy to transport as pellets, tablets, etc</td>
<td>1. Difficult to transport in many cylinder</td>
</tr>
<tr>
<td>2.</td>
<td>Readily available</td>
<td>2. Not so easily available</td>
</tr>
<tr>
<td>3.</td>
<td>Cheap and simple to apply</td>
<td>3. Expensive and difficult to apply</td>
</tr>
<tr>
<td>4.</td>
<td>Leaves almost no residue</td>
<td>4. May leave harmful residues</td>
</tr>
<tr>
<td>6.</td>
<td>Toxic to insects only</td>
<td>6. Highly toxic to insects and mites.</td>
</tr>
</tbody>
</table>

Factors affecting Fumigation
- Environmental factors: wind, temperature variation, atmospheric pressure variation
- Grain packaging
- Dockage
- Grain moisture

Mode of action
All the fumigants are:
1. Respiratory poisons in the sense that they may interfere with insects from obtaining oxygen from the air. In agricultural fumigation, the process of insect control is by biochemical blocking of the passage of oxygen through the interference of toxic fumes (gas) on respiratory enzymes. The process is called anoxia. Thus atmospheric air enters the breathing system of insects but cell to cell transport of oxygen is inhibited.
2. The rate of respiration directly affects the susceptibility of insects to the fumigants. An increased rate of respiration would, therefore, expose the insects to lethal effects of fumigants.
3. Some fumigants such as HCN, H₂S and CO block cellular respiration.
4. Some fumigants such as carbon tetrachloride, ethylene dichloride, and other act as protoplasmic poisons by producing mineral oils in tissues.
5. Nerve poisoning are carbon disulphide, carbon tetrachloride, methyl bromide, etc.

These actions are characterized by delayed effect i.e. the insects often appear normally active soon after fumigation. Based on observed symptoms evolved by the fumigants, the chemicals may be divided into two classes:
- Narcotics: carbon tetrachloride, carbon disulphide and hydrogen cyanide. These cause insects to show symptoms of excitation and paralysis before death.
- Irritant fumigants: chloropicrin, methyl bromide and carbon dioxide. These cause insects to act excited and die without showing paralysis stage.
Fumigant Mixture
The main reasons for fumigant mixing are:
- to reduce the risk of flammability
- to enhance the penetration capacity
- to achieve volatility and diffusion at higher level
- to achieve uniform dispersion of fumes throughout the mass being treated
  E.g. carbon tetrachloride + ethylene dibromide, as carbon tetrachloride has high distribution capacity whereas ethylene dibromide is highly toxic
- to achieve the broad spectrum of specificity to the insects attack and lethality
- mixing of fumigants can help to reduce the chance of development of resistance in insects

Facilities and procedures about the use of fumigant
Fumigants are applied in many different types of enclosure, viz. fumigation chamber, warehouses, transportation facilities, under gas proof sheets, under vacuum, etc. The space to be fumigated should be easy to make gas tight. The dose recommended and the regulatory instructions about fumigants and its toxicity to man and animals should be clearly mentioned in the label of the container. These instructions and recommendations should be followed by the user.

Steps in fumigation to be considered before fumigation
1. Reading the instructions about how to use and how much to use.
2. The bin to be fumigated should not be completely filled with grain. At least 5” head space should be left. Any crust that is present should be removed.
3. Fumigation should not be done at temperature below 60°F (16°C) and above 90°C.
4. For the particular type of bin, the temperature of grain, air tightness, etc should be adjusted.
5. The liquid fumigant may be sprayed as coarse droplets over the surface of grain.
6. When grain temperature of the bin is lower at the periphery and higher at the central part, solid fumigant is applied generally by placing at the bottom of the container.
7. If spillage of fumigant occurs on skin or clothing, immediately remove contaminated clothing and wash the exposed surface immediately with soap and water.
8. Do not feed treated grain or feed to livestock until it has been aired enough to remove all fumigant odour.
9. The safety measures includes the use of mask, goggles, gloves, etc and proper washing of contact organs.

Special techniques used in fumigation
Two basic problems encountered in the use of fumigation to control pests involve:
  a. Contamination of the gas at the site of infection
  b. Penetration and distribution of it through the tight packed mass of infested materials
Various techniques have been developed to cope with these problems. In the grain storage and processing industries, three specialized procedures have been used. These techniques have widened the scope and use of fumigant and improve their physical efficiency. These techniques are:
  i. Recirculation of fumigants throughout the grain mass
  ii. Use of gas proof sheets
  iii. Vacuum fumigation
Types or Methods of fumigation

i. Recirculation

Fumigants can be dispersed and distributed effectively by forced movement and recirculation of the fumigant & air mixtures throughout the grain. Mechanical aeration systems (which have been incorporated into both permanent and temporary storage facilities to cool and dry the grain) have been successfully used to distribute fumigants. Granaries in many diverse structures including oil storage tanks, cargo ships, conventional elevator bins, steel railway trucks, etc have been successfully fumigated using this method.

To obtain uniform distribution, the fumigant is dispersed over the surface of grain or into the duct of aeration system and forced through the grain mass into an air movement of at least 20 m/min per ton of grain. In average silo bins, 15-20 min will be required to replace the air with fumigant air mixture. Fumigation should be continued for up to 45 min. Recirculation is only practicable where the walls of the storage facilities are sufficiently air tight to obtain the fumigants while the system is under positive pressure from the blowers in the aeration ducts.

Methyl bromide has been employed most extensively with this technique although other fumigants such as hydrogen cyanide, chloropicrin, methyl chloride, ethylene oxide, carbon dioxide, methyl bromide, ethylene dibromide, carbon tetrachloride, carbon disulphide, etc can be distributed effectively. During repeated treatments, methyl bromide may leave residue up to 50 ppm as inorganic bromide. So, for repeated treatments, other alternative fumigants should be reached. Phosphine is not recommended for use by recirculation because of possible breakdown of molecule at reduced pressure.

ii. Fumigation under gas proof sheets

This technique is facilitated by the use of fumigants greatly, making it possible to treat infested materials in situ without moving them from storage. It also allows the treatment of large quantities of materials and storage structures that otherwise would impossible or impracticable to fumigate. Large stocks of bagged grain are often fumigated under gas proof sheet, an operation that involves covering and treating large buildings.

Polyethylene/polyethylene and PVC sheets are suitable for covering stacks in protected situation. To protect from large damage, coated fabrics such as nylon, terylene, or neoprene, should be used. The principle fumigants used are methyl bromide and phosphine.

In-bag or in-drum fumigation

When produce is stored in sacks which are gas-proof (e.g. sacks with polyethene liners) it is possible to carry out in-bag fumigations using aluminium phosphide pellets. The pellets may be sealed in paper envelopes at the time of treatment and placed on the top of the produce in the open sack or liner which is then promptly sealed. The stack may be heat sealed or closed by the simple bunch-and-tie method. The sacks should not be opened until they reach the end user who should safely dispose of the paper envelopes containing the toxic residual powder left by the pellets.

The main advantage of this method is that the gas-proof sacks prevent reinfestation of the produce after fumigation and also prevent the loss or gain in moisture.

At the end of fumigation period, there is practice to remove the sheets and allow the stack to air.
iii. Vacuum fumigation

The primary objective of vacuum fumigation is to hasten and improve the penetration and fumigation into the commodity and increase the effectiveness in controlling insects. Vacuum fumigation is used in the fumigation of packaged jute bags. The grain or commodity to be fumigated is placed in a chamber and a large amount of air is sucked out or evacuated by a pump and then replaced by fumigant. By this method, gas penetration can be accelerated and fumigation time can be reduced.

The major limitation is that the equipment is expensive and only small quantity can be treated. It is employed for specialized treatment where gas penetration is difficult in ordinary condition. Generally, fumigants used in this method are methyl bromide and ethylene oxide. Phosphine is unstable at low pressure and should not be used.

An idle fumigant has following properties:
- High insecticidal efficiency against all stage
- Quick action
- No mammalian toxicity
- No flammable
- Inexpensive
- Non-corrosive to metal and paints
- Non-phytotoxic and low sorption

Fumigation of different storage structures

1. Fumigation chamber

Treatments carried out in a properly designed and constructed fumigation chamber can be undertaken with maximum efficiency and minimum hazard. The chamber itself is a gastight room with a gastight door and with an inspection ventilation hatch situated opposite the door. Portable fumigation chambers of plywood or gas-proof fabrics supported on a framework may be used. Permanent chambers are usually built of concrete or brick, well sealed internally. The chamber should be equipped with a fan to exhaust the gas through the doorway or ventilation hatch after fumigation. Care must be taken to ensure that exhausted gas from the chamber at the end of fumigation will not constitute a hazard.

For many types of bagged and packaged foods, fumigation can be achieved conveniently and effectively in specially designed fumigation chambers. Grains are treated in a gas tight room of suitable size and atmospheric pressure. The fumigation chamber is usually situated at or nearby storage or processing facilities where goods can be treated and safely moved to uninfested area.

An effective fumigation chamber must be
- Soundly constructed and air tight
- Provided with system for applying and distributing gases and their removal when necessary
- Loaded in such a way that infested goods can be handled conveniently

The most satisfactory type of chamber which gives minimum trouble from leakage is one with the floor of concrete, walls of brick and a flat roof of reinforced concrete. A fan can be used satisfactorily for circulation of gases into the chamber.
2. **Fumigation in transport facilities (ships, barges and railway trucks)**

Since a transportation carrier moves a variety of goods from many sources, it may become infested with insects and mites. These populations are of great potential hazard for shipments of clean grain and grain products. Usually empty cargos are fumigated after unloading but fumigation with commodity is also possible. Phosphines are widely used for transit fumigation of loaded cargos. Alternatively, methyl bromide can be used.

**Factors affecting fumigation and pesticidal actions**

Many factors can alter the toxicity of pesticide and influence their ability to control insects in grains. Certain environmental conditions affect the stability and toxicity of pesticides. Other factors may prevent the pesticides from reaching its target pest organism and still other will modify the tolerance of the pests to the chemical. The principle factors that influence the use and effectiveness of pesticides in grain are as follows:

1. **Temperature**

   The temperature of grain and environment has profound influence on the successful application and use of insecticides. High temperature in stored grain can greatly increase the rate of metabolism of insecticides. Consequently the effectiveness of many insecticides can be seriously reduced by high temperature, for e.g. malathion. The increased temperature reduces the effectiveness of insecticides. If temperature of grain increases, the metabolism of insecticides also increases.

   The temperature of grain governs the degree of adsorption and absorption of fumigant by the grain and consequently influences the penetration of fumigants into the grain mass. Fumigants are absorbed more rapidly as temperature decreases so that diffusion and penetration of fumigant into the grain mass is reduced and the concentration of fumigant available to kill the insects is also reduced. If the temperature increases, the absorption capacity decreases. Following treatment, desorption of fumigant is correspondingly slow and hence hazardous qualities may be higher in grain for extended period. Chemical reaction of fumigant with component of grain is however increased when the temperature increases and may bring about unwanted residue accumulation.

   The temperature also affects the toxicity of insecticides to insects. The toxicity of fumigants to insects is directly proportional to the temperature. Insects are increasingly not killed if the temperature is lowered. Fumigants are not so generally recommended at temperature lower than 16°C. Extra high temperature i.e. above 90°C results in vapourization of the fumigant too much and also causes the thermal expansion of head space air so the fumigant effectiveness is lowered.

2. **Moisture content of the grain**

   Infestation is generally developed freely as the moisture content of grain rises up to 12% or more. Below this level, insect development is considerably reduced. The moisture content of grain has considerable influence on the toxicity and persistence of insecticides on grain. Higher the moisture content of grain, slower will be the rate of penetration of water insoluble insecticides into seeds and more rapid the penetration of water soluble insecticides. A contact insecticide should remain on the exterior of the seed to be effective. Absorption into seeds removes the compound form the surface and renders it inaccessible to the insects as well as causes the degradation of it by the enzymes present in the seed.
Metabolic activity of seed grain increases slowly as moisture content rises from 11-14% and more rapidly by altering the rate of absorption by grain. When moisture content is high or grain is tough and/or dockage is present, a 25% increase in dosage should be allowed to compensate the poor absorption and penetration.

Moisture content is essential for generation of phosphines or hydrogen cyanide from solid formulation of aluminium phosphide and calcium cyanide and if too little moisture is available, generation of these gases will be unduly prolonged. High moisture content of grain causes hydrolysis of compounds such as dichlorvos to shorten their life.

3. **Formulation of insecticides**
   The formulation of insecticides also plays an important role in the control of pests. The method of use and dosage are important in formulation. It is important to use the correct formulation of insecticide and the correct equipment for applying it for particular food and particular target pest. In some cases, a single insecticide may not work well and there may be necessity to use a mixture of two or more insecticides to fulfill the requirements of each other to work effectively.

4. **Storage structures**
   Storage structures also determine the effectiveness of pesticides used in the control of pests. Closed structures are effective for use of insecticides rather than open structures as the used insecticides may be carried away by wind, or be unstable in sunlight, and may also lead to the contamination of surrounding atmosphere.

5. **Comparative toxicity of substances**
   In some cases, insects might have developed resistance to certain insecticide and in such case alternative insecticide must be used for its control. Also, taking the purpose, target pest, foodstuff to be disinfested and the surrounding condition, appropriate insecticide must be selected.

3. **Space Treatments**
   It is necessary to use space spraying technique to control infestations of flying pests entering from outside and those not controlled by residual treatments. It must be repeated at frequent intervals, preferably every day, to achieve effective control and this also depends upon how well the building is sealed.

   It is very important to carry out space treatment at a time of day when the pests are most active, generally at dusk. After treatment, the door and ventilations must be closed for 1-2 hours. The insecticide usually used is pyrethrum with or without synergist, e.g. piperonyl butoxide at about 5 times the pyrethrin content, although lindane or DDT may be used in the form of smoke.

   For fogging or aerosol spraying with pyrethrum, a liquid concentrate containing 0.4% pyrethrins plus 2.0% piperonyl butoxide is recommended against beetles. The rate of application should be 50 ml per 100 m³. For moth, a liquid concentrate containing 0.5% pyrethrins alone or plus 0.5% piperonyl butoxide should be used at the same rate.

   Lindane or DDT smokes are relatively to use, requiring no special aerosol or fogging machine, but these do not achieve the same level of control as pyrethrum fogging. Dichlorvos is another chemical of probability of use but it is more toxic to man and several precautions should be under taken.
Regular aerosol or fogging treatments are laborious and expensive and therefore are not generally favoured when other treatments such as fumigation or residual treatment are appropriate. However, under certain circumstances (such as when fumigation is not possible and the dominant pests are moth species which are not well controlled with the commonly used residual sprays), space treatments are the only practical means of effectively controlling infestation. The calculation of dosage of such insecticides should be based upon the free space rather than the total volume of the store.

**Estimation, Detection and Analysis of fumigant concentration**

For measuring fumigant concentration of methyl bromide

Detector tubes with sensitivity range of 2-200 ppm are developed for methyl bromide.

The halide leak detector is generally used to detect leakage of methyl bromide and other alkyl halide fumigants. It is only sensitive within threshold limiting values (TLV) of that detector.

For phosphine gas, detector have been used which have sensitivity ranges from 0.1-1000 ppm. Infrared analyzer and gas chromatography are also used for fumigant concentration measurement.

Portable gas chromatography is suitable for analyzing high concentration used for insect control as well as the low concentration around the TLV for safety measurement.

**Pesticide residue**

In tropical countries, incidence of agricultural and stored product pests is chronic and severe. The use of insecticides becomes necessary complement to the production and conservation of foods, pesticides being basically toxic to mammals, their unrestricted uses both on field and warehouse leads to inevitable contamination of foods with these unintentional additives so called pesticidal residues.

The contaminants remain absorbed, adhered or mixed with food and their presence becomes hazardous to the health of consumer. It means any specified substance in food, agricultural commodities or animal feed resulting from the use of insecticides.

For commercially available and widely used insecticides, the residue tolerance levels are set and treatments are aimed so as not to exceed the residue level over the tolerance level.

The residue level at the time of consumption is given in the table below:

<table>
<thead>
<tr>
<th>Insecticides</th>
<th>Residue tolerance (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dieldrin</td>
<td>0</td>
</tr>
<tr>
<td>Dichlorvos</td>
<td>0</td>
</tr>
<tr>
<td>Lindane</td>
<td>1.0-12.5</td>
</tr>
<tr>
<td>Diaziclon</td>
<td>0</td>
</tr>
<tr>
<td>DDT</td>
<td>3.5-20</td>
</tr>
<tr>
<td>Carbonyl</td>
<td>0</td>
</tr>
<tr>
<td>Malathion</td>
<td>8-10</td>
</tr>
<tr>
<td>Pyrethrins</td>
<td>1-25</td>
</tr>
</tbody>
</table>

**Control of pesticide residues**

- Education to the people about proper use
- Legislation control
The controlling considerations may be:

i. Using materials which are not toxic to man
ii. Treatments are aimed so as not to exceed the tolerance level
iii. Using chemicals which are quickly degradable into non-toxic form
iv. Spraying the insecticides before the development of grain or fruit
v. Not spraying within specified time before harvest

### Analysis of pesticide residue

An analysis is of no significance if appropriate sampling is not carried out. If pesticides are applied as dust, residue will be higher in fines than on whole grain. This is also true for pesticides applying as spray because fines with their greater surface area absorb more spray than whole grain.

The analytical procedures involve the following steps:

1. **Sampling**
   - The size of sample depends on the size of lot and the type of content of insecticide. Sample should be representative.

2. **Extraction**
   - Preliminary separation of toxicant is done by stripping with an organic solvent. Generally, soxhlet extraction of grain sample with appropriate solvent is done. Commonly used solvents are petroleum ether, n-hexane, isopropyl alcohol, etc.
   - Pesticides and their residues are analyzed for three main reasons, which are:
     - a. To find out whether enough insecticide is present to kill insects
     - b. To find out whether insecticide is present in excess of level of internal tolerances
     - c. To find out if the concentration is up to specified strength

3. **Clean up**
   - The extract contains non-insecticidal materials such as fat, waxes, colouring materials, etc. These are removed from extract by a process called clean up. Some cleaning up methods are as follows:
     - a. To 100 ml of extract, add 10 gm mixture containing 10 parts anhydrous sodium sulphate, 5 parts diatomaceous earth, 5 parts supercel and 2 parts activated carbon. Shake the mixture in a stoppered flask filter.
     - b. Pass the extract through a column of absorbent such as silica acid, aluminium or magnesium oxide, charcoal in various combinations.
4. Detection and estimation

The clean up solution i.e. isolated extract then can be subjected to several analytical procedures such as:

a. Bio-assay

The test insects may be *Tribolium castaneum* or *Oryzaephilus surinamensis*.

Residues more than 20 ppm can be detected by releasing the insecticides directly from foodstuffs. Lower levels of residues require extraction and concentration prior to subjecting them in bio-assay, useful in determining aldrin residue. This technique cannot give quantitative data accurately but gives qualitative results.

b. Spot test

It is the qualitative technique for detecting chlorinated insecticides. The insecticide extract is spotted on filter paper and dried. The paper is sprayed with mono ethanol amine or alcoholic KOH (1N) and heated on oven (100°C, 40-60 min). The paper is then passed through trough containing 0.1N AgNO₃ in 2N HNO₃, 30% H₂O₂ and distilled water. The filter paper is then exposed to sunlight and the spot developed by photochemical reaction is studied. This technique is applicable to BHC, DDT, lindane, etc.

c. Micro crystallization on micro-slide

This method consists of sublimation of cleaned up extract on micro-slides and examination of pesticide and studied and compared with the crystal structure of individual insecticides prepared as reference. This is also a qualitative technique.

d. Total chlorine method

The total chlorine of chlorinated insecticides is determined whose concentration can be related with the concentration of respective insecticides. Chlorinated insecticides include BHC, DDT, Aldrin, Dieldrin, Endrin, etc

Aldrin, Dieldrin, Endrin, etc can be reacted with phenyl azide and coupled with diazotized 2, 4-dinitronilise. The concentration of insecticide can be determined by comparing with standard solution.

BHC is dechlorinated to benzene which is titrated in a special apparatus. The resulting meta-dinitrobenzene gives violet colour with methyl ethyl ketone in the presence of strong alkali. The intensity of colour is compared with that of standard solution for quantifying the results. DDT is nitrated to tetra nitro-derivative which gives colour with alkylated sodium methylate. The concentration of DDT is proportional to the intensity of the colour.

e. Hydrolysable chlorine detection method

This method is the modification of the method based on the total organic chlorine estimation. The hydrolysable chlorine of organochlorines insecticides is determined and the ratio of total chlorine and hydrolysable chlorine is obtained which is constant for a particular insecticide. So, this method can be used to estimate and identify the insecticide concentration in food.

The ratio of total and hydrolysable chlorine for certain insecticide, obtained by using sodium and isopropyl alcohol and with mono ethanol amine (hydrolyzing agent) are as follows:
### Insecticides

<table>
<thead>
<tr>
<th>Insecticide</th>
<th>Total chlorine : hydrolysable chlorine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lindane</td>
<td>2</td>
</tr>
<tr>
<td>DDT</td>
<td>5</td>
</tr>
<tr>
<td>Aldrin</td>
<td>3</td>
</tr>
<tr>
<td>Dieldrin</td>
<td>3</td>
</tr>
<tr>
<td>Endrin</td>
<td>3</td>
</tr>
</tbody>
</table>

**f. Chromatography**

This method gives both qualitative and quantitative results.

**Thin Liquid Chromatography:**

- Plate is washed and rinsed with distilled water and the absorbent layer Al₂O₃ is coated over the plate appropriately. These plates are dried at 80°C for 30 min and then cooled. The cleaned up and concentrated sample extract is spotted with spotting pipette and chromatograph is developed in developing solvent, which consists of
  - Methyl cyclohexane for organophosphorus and
  - N-heptane for organochlorines

  The development is stopped when solvent phase reaches 10-12 cm above spotting line, and the plates are removed and dried. These dried plates are sprayed with chromogenic agent of respective insecticides (see AOAC). These plates after final spraying with specific chemicals are exposed to UV light for observation of presence of visible spots. Similarly, paper chromatography and gas liquid chromatography may be used.

**Methods of estimation of fumigant concentration**

There are three methods for the estimation of fumigant concentration in treated goods. They are:

1. **Bio-assay Method (Developed by CFTRI)**

   The test insect is *Tribolium castaneum*. 32-33 week old *T. castaneum* are taken in a stoppered glass tube of U-shape. The fumigant from fumigation chamber is aspirated into the U-shaped tightly stoppered tube for considerable time. The time between death of insect and the time of aspiration is noted. The C x T product of the fumigant already shown is divided by death time in hours to determine the concentration in mg/L. this method holds good over 2 ppm concentration.

2. **Chemical Methods** (Discussed earlier)

3. **Instrumental Methods**

   It involves Thermal conductivity analyser and Interference refractometer.
   a. **Thermal conductivity analyser**

   The analyser consists of 4 filaments out of which 2 are used for reference i.e. air and remaining 2 for fume (gas) stream. Initially the 4 filaments are brought to equilibrium with air and then the gas-air (to be analyzed) stream is passed over analysis side. If the current and temperature of ambient are constant, the filament resistance is the function of thermal conductivity of surrounding gas. The difference between resistances of two side filament is indicated by galvanometer. The galvanometer deflection is calibrated on scale for direct reading of concentration of gas in ppm or any suitable unit.
b. **Interference refractometer.**

This works according to the difference between refractive index of air and that of fumigant gas. In this type of instrument, parallel light from the cellimeter is divided into two beams by slits and passed through three chambers which are initially flushed with clean air for which the instrument is calibrated to zero. Among the three, two of the chamber are for clean air and are interconnected.

On emerging from the chamber, the two beams are brought together by a lens and thus provide fine vertical fringes (due to path difference) on the focal plane of the lens which can be viewed through eye-piece.

First, the zero setting is adjusted by flushing the clean air through two air chambers. Then gas mixture is flushed and difference in refraction of gas on tube shown by shift in fringes in scale is measured. This shift is calibrated to give the concentration of gas directly.

Other methods available are: Detector tubes (staining method), Detector lamps (staining method), and test paper and tapes (colour changes).

**Knowing Pesticides**

Pesticides are chemicals used to prevent, destroy, repel or migrate insects, plants, disease, weeds, rodents or other organisms perceived to be troublesome to human beings. These chemicals are very effective tools available for use in pest control in crops husbandry. But their misuse is equally deleterious to crops and human beings.

To use them efficiently and safely, one must first acquire a basic knowledge of pesticides.

**Types of Pesticides used in agriculture**

<table>
<thead>
<tr>
<th>Pesticides</th>
<th>Target pest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insecticides</td>
<td>insects</td>
</tr>
<tr>
<td>Fungicides</td>
<td>Fungi</td>
</tr>
<tr>
<td>Herbicides</td>
<td>Weeds</td>
</tr>
<tr>
<td>Rodenticides</td>
<td>Rats and mice</td>
</tr>
<tr>
<td>Acaricides</td>
<td>Mites</td>
</tr>
<tr>
<td>Nematicides</td>
<td>Nematods</td>
</tr>
<tr>
<td>Molluscicides</td>
<td>Mollusca and snails</td>
</tr>
</tbody>
</table>

**Mode of action of various pesticides**

Pesticides affect the target pest organisms according to their innate chemical nature (present from birth). They enter in pests in several ways and their life process, causing difficulty in surviving. The result may be illness, reproduction inability or death. To use them efficiently and safely, it is important to know their mode of action on pests. The following are the general mode of action of major pesticides:

1. **Insecticides**

On the basis of mode of action, insecticides are grouped into:

a. **Stomach poison**

These poisons produce an effect on the insect only after entering into the body through mouth and being absorbed in the digestive tract. These insecticides are used for controlling the insects having chewing mouth. Pests include caterpillars, grubs, beetles, etc. The commonly used
insecticides are borax, paris green, aldrin, BHC, chlorodane, endosulfan, dichlorvos, fenitrothian, diazoiner, etc.

b. Contact poison

Contact poison enters the insect’s body when its body surface comes in contact with treated surface. The nerve and respiratory centers of pests are vulnerable sites where these poison effect. The insecticides are used for controlling any sort of insects except the thick body wall beetles, hairy caterpillars and those which remain concealed inside the plant parts like bores, miners, leaf folders and leaf rollers. Hairless caterpillars and aphids (insects that feed on plants) are much affected by these insecticides. Some common insecticides are aldrin, BHC, chlordane, DDT, diazoiner, malathion, methyl parathion, sumithion, nicotine, pyrethrum, etc.

c. Systemic poison

Systemic insecticides, when treated onto plant parts, are absorbed and move through the vascular system to the entire body of plant. Because of this action, cell saps remain filled with poison and feeding insects get killed. These insecticides are effective against piercing and sucking mouth parts such as aphids, leaf hoppers, scale insects, thrips (tiny sucking insects), wall flies and small bugs. Some common insecticides are phorate, dimethoate, carbofuran, etc.

d. Fumigants

These insecticides when exposed to air turn into gas and enter the insect’s body through the respiratory system. Fumigants can control stored grain insect pests effectively provided that the treated space is air tight. Some common fumigants are aluminium phosphide (phosphine), ethylene dibromide, methyl bromide, dichlorvos, etc.

e. Physical poison

Suffocating the insects, clogging its breathing pores and desiccating it to death due to cuticle desorption are the main action of physical poison on the insects. These are effective against scales, meaty bug and thrips. For e.g. petroleum oils, etc.

2. Fungicides

On the basis of mode of action, fungicides are divided into three groups, viz. Eradicants, Protectants and therapeutants, and systemic fumigants.

3. Herbicides

On the basis of their mode of action, herbicides are divided into two groups, viz. contact herbicides and systemic herbicides.

4. Rodenticides

On the basis of their mode of action, rodenticides are divided into two groups, viz. acute poison and chronic poison.

a. Acute poison: these rodenticides are highly poisonous and are capable of killing rodents in single dose within a period of usually half an hour. For e.g. zinc phosphide, arsenous oxide, sodium fluoroacetate, etc.

b. Chronic poison: A small dose of these chemicals is usually mixed with food and fed to rodents for 3-10 days. Rodents are finally killed because of internal bleeding. These type of rodenticides are formed as anticoagulants. For e.g. Warfarin, racumin, fumarin, etc.
Formulation

All fumigants must enter the vapour phase to be effective. There are two methods of formulation depending upon the insecticide used.

**Liquid formulation:** Liquid formulations are made for specific or general purpose by discriminating selection of different chemical. Vapours of some chemical such as carbon disulphide and carbon tetrachloride will penetrate readily and reach the distant parts of bin while others such as ethylene dichloride are surfaced and hold on grain surface.

**Solid formulation:** Calcium cyanide and phosphine producing compounds are suited for application to moving grain stream. Chemicals such as methyl bromide and hydrogen cyanide, which are gases at ordinary temperature and pressure, are well developed to convenient forced distribution method of application.

All fumigants are toxic but some are much more toxic than others. Those of relatively low toxicity may be considered as diluents or carriers. Chloropicrin, which has a sharp penetrating odour, is cased as warming agent in the solution with methyl bromide, which is practically odourless. Some combination of fumigant chemicals are synergists. E.g. ethylene dibromide and other halogenated hydrocarbon.

**Primary necessities in fumigation**

1. Selection of proper fumigant considering the conditions under which fumigation is to be carried out (selected fumigant must have no residual effect, taintative effect, and must not cause impairment of germination of seed)
2. Dosage requirement is to be calculated prior to fumigation. The successful fumigation is dependent upon the attainment of the critical value which will kill at least 99% of insect population. So, it is necessary to know the volume of space to be fumigated and the exposure period for calculating dosage.
3. Precautionary measure: Fumigants are in most cases toxic to all animals including man. So, caution notice will have to be properly displayed. The operators should put on protective overalls to avoid contact of fumigants with the body.
4. Sealing of the fumigation space: The space to be fumigated should be air-tight enclosed chamber to avoid leakage of fumigant which will bring down the concentration of fumigant in space being applied.
5. Cleaning operation: Effectiveness of fumigant is increased if fumigation is done in a clean space for free passage, better distribution and dispersion and also minimizes the loss due to unnecessary sorption.
6. Application of fumigants: There are variations in behavior of different fumigants, e.g. some may be heavier than air and some may be lighter. Fumigants may be gaseous higher temperature, but may be solid or liquid at ordinary temperature. In spite of these varied properties of fumigants, the primary need is to obtain the lethal effect in as short time as possible. The different methods of application of fumigants are:
- Sprinkling – fumigants can be sprinkled at the top of the stack
- Open space method
- Pot method
- Spraying of fumigant
- Dry method – pellets, powder and tablet of few fumigants are directly applied at required place and at required intervals.

**Inspection and reports**

The purpose of inspection is to gather information about the store and its contents so that decisions can be made regarding procedures needed for quality maintenance. Quality inspection must be efficient and quicker to operate so as to minimize the delay in transportation.

When the produce has been taken into store, it is essential that an accurate assessment of its condition is obtained. It is the poor warehousing practice to keep stacks of produce in store without knowledge of any changes taking place within the bulk or stack. Inspection allows the storekeeper to decide if and when to carry out pest control. It also makes the manager aware of the progress of the commodity whilst in the store, and its shelf life. Inspection must be accompanied by effective record keeping so that the history of the commodity can be followed. Record keeping also informs the storekeeper of when the commodity was received and what pest management practices have been carried out. Inspection must be done regularly and not less than once a week, irrespective of the size of the store or of its content. It should include both interior and exterior of the store, including food and non-food items.

The inspector must look carefully for:
- Signs of pest infestation, including live insects, rodent droppings, rodent urine trails
- Dampness
- Mould damage
- Spillage
- Contamination of sacks by foreign matter such as oil, fertilizer, pesticides, roof leaks and other structural faults
- Theft or other security problems

In addition, when insecticidal treatments have been carried out, it is necessary to inspect all stocks within the premises at regular intervals. Records of temperature changes and special attention to possible sources of residual infestation such as bags of accumulated grading samples, sweepings or privately owned stacks should be made and the necessary steps taken. This may include fumigation.

It is an essential part of good warehousing to keep accurate records of stock intake, inspections carried out, spray treatments and fumigations, together with details of the quantities of pesticides used and in stock. Whenever applicable, the records should be checked by a person in authority.
TRANSPORTATION OF FOOD MATERIALS

Introduction

The food produced by the farmer has a long journey to travel on its way to the consumer’s plate or the animal’s feed trough. There may be a long chain through which the crop will be transported, stored and processed, with accompanying losses in quality, quantity, nutrient content and monetary value. These losses can be substantial, and if they are allowed to occur and build up, will result in a significant loss in revenue for the farmer and the end user.

Losses arising during transportation

Losses that arise during transportation occur mainly due to damage to the packaging, such as tears or rips in woven polypropylene sacking, resulting in spillage. For longer haul carriage, for e.g. by rail or lorry to distant markets, other problems may occur such as water penetration or wetting and subsequent mold damage and mycotoxin contamination; insect or rodent pest infestation; changes due to the micro-climate as a result of moving grain from cool, high altitude to lowland, humid altitude; and accidental contamination.

Care of grain must be of paramount importance no matter what type of transport system is used. Even the largest and most sophisticated means of transport require human intervention to make sure that grain quality does not suffer during the voyage or journey.

The most basic method of transport from farm to market is the head load in rural areas. People usually carry water, fuel, and grain on their heads. Although grain may be well exposed to the elements during carriage, the short duration of journey means that little of any change in quality is experienced. However, if this head load is interspersed (break continuity) with travel on a bus or train, then problems may occur particularly due to spillage. Less difficult methods of delivering grain from the farm use animal or motor driven carts or more. Oxen are used in many parts of the world to pull carts, which may contain 2 tons or more of grain in sacks. Replacing the oxen with motor driven vehicles such as a tractor will enable the load to be increased. However, both types of transport are relatively slow and allow only short journeys to take place.

The short journeys made in the transport do not allow time for biological deterioration to take place. However, if trucks are used to transport grains, journeys can be much longer and the effects of pests and diseases may become evident when the commodity is inspected on arrival. Trucks transporting any grain or other food commodities must be clean. They must be swept free of dust and fragments. Insects must be eliminated to ensure that the new consignment is not subjected to infestation from residual populations.

Loading of truck must be done with enough care to avoid damaging sacks. Woven polypropylene and paper sacks should not be handled with hooks as these easily damage the fabric resulting in spillage. Loading should be done manually or using a small conveyer. Trucks must be loaded only to their stated capacity as overloading will make the truck unstable & likely to tip over.

All commodities should be accompanied by documentation, which records the origin of the consignment and any pest management treatment that has been applied. This documentation will be needed where a consignment is to cross an international border. This certification may also be
required for internal grain movements, particularly when grain has to be moved into or out of areas of quarantine. If any commodity is attacked by certain pest, than the movement of such commodity into or out of these areas must be restricted. However, other crops that are not affected by this pest have to be treated with insecticide or fumigated.

Open rail wagons should be treated in the same way as road trucks. Freight wagons that can be closed off can be fumigated if they can be made air tight. When empty, freight wagons must be thoroughly cleaned. Once the commodity has been loaded, preferably on pallets, tablets of aluminium phosphide, which release phosphine gas on exposure to air, should be placed under the pallets and the container than sealed. Fumigation will take 7 days or longer depending on the temperature, during which time access to the commodity will not be possible. Fumigation can also be undertaken when the container is empty to disinfest the fabric, although this is generally not necessary. It is however useful to disinfest bales of empty, used sacks placed in the unloaded container.

Grain carried in freight containers can also be fumigated whether transported by road, rail or sea. This is a practice that is becoming increasingly common, although the treatment frequently fails. Failures are due to the leakage of gas out of the containers so that the concentration inside is insufficient to kill insect pests. Most containers may have ventilated openings, and for successful fumigation, these ventilators have to be sealed to prevent gas leakage. This may be difficult to achieve, especially if the ventilators are difficult to access, either because the container is full or because their position under the floor makes them inaccessible. If the container can’t be adequately sealed, fumigation should not be attempted as to do so would be dangerous (personnel would be at risk from escaping gas) and ineffective because insects would not receive a fatal dose.
GOOD STORAGE PRACTICES

Post harvest storage and problem
Everything undergoes a changing process, which may be physical, chemical, biological or all of them. Nothing remains permanent. The changes may be beneficial (e.g.: fermentation and curing) and destructive, which causes loss. Various variables that affect grain & their quality are temperature, moisture, and geographical location, physical, chemical & biological properties of grain bulk, moisture, mites, rodents & birds.
Storage not only means building, it is an art and technology of keeping things safely for a period of time.

Functions of Storage
Mainly storage is aimed to reduce and control the rate of deterioration. Storage is repeated phase in the complex e.g. transporting grain from producer to producer and grain product from producer to consumer.
Good storage thus involves controlling the following characteristics:
- Temperature
- Moisture
- Light
- Insecticides
- Hygiene

Quality in a grain storage & handling associated with laboratory equipments and techniques
It is associated with the following:
- Technical and managerial personnel should be aware of process of receiving, drying and storing.
- Storage is an integral part of food processing chain such as production, transportation, storage, marketing and consumption. As soon as the grain is put into storage, its quality can’t be improved but quality can be maintained.
- Quality control serves as an alarm that will indicate the procedure.

Following functions are carried out here
1. Periodically controlling the temperature of stored grain using temperature probe.
2. Executing defined procedures to be followed in case of different insects infestations including the doses of insecticides, exposure time and safety measures, etc.
3. Establishing when and under which type of environmental conditions and situations the equipment should be used.
4. Keeping the storage facilities under the best sanitary condition possible to prevent the presence of pests, such as rodents and birds, etc.
5. Keeping an excellent stock control of the stored grain with clear identification of the product in each storage unit.
6. Defining when and under which conditions the transfer of grain from one store to another to take place.
7. Establishing segregation techniques by quality factors.
8. Maintaining storage units and handling equipments in optimum conditions through a preventive maintenance programme.
9. Setting procedures, safety measures and time for cleaning and handling equipment that is not self cleaning, such as screw conveyor.

**Warehouse Management**

Warehouse management plays an important role in stack piling of grain stocks. Traditional forms of storage and the latest implementation serve the same function as a store. However, we should recognize that for long term storage of grain, the store must be managed in a systematic manner. The grain should be protected from certain elements. So, proper warehouse practices are necessary.

Firstly, we should observe that prior to storage of grain; we should provide pretreatment of the area to be stacked with some chemicals, pellets, etc and the surrounding areas must be similarly treated. A common practice is the stacking of grain bags close to the wall probably to utilize maximum space. This should be discouraged as it hampers proper application of fumigation and pest control measures as well as sanitation practices.

A clean store inhibits the breeding of insects. Though it is tedious to clean the store frequently, its importance can’t be over emphasized. Some planning should be given to layout of stacks for storage, for stock movement such as issue and receipts, for inventory control and pest control measures. It is unlikely for a warehouse, even if it were properly administrated, to be free of insects and rodents. Pest control and fumigation methods must be hand in hand with good storage practices.

The first consideration would be to train the operator to recognize the sign and need to implement pest control measures. Timing for receiving and issuing the stacks should be cared. Rodent control is another problem to be considered as there is no specially tailored method to control pests.

Most stores observe the principle of first in first out (FIFO) for the rotation of stocks. The problems encountered with these rules are the proper identification of the stocks during the time of receipt and storage, its quality assessment and follow up action. For decision on stocks inventory by management, information must be readily available and accurate. The staff involved in warehouse operation must be trained. Management must provide training and motivation to their staffs to perform better. Formulation of pest control measures and fumigation procedures for warehouse operators as a guide for the application of control procedure is necessary.
SUMMARY OF ACTIONS NEEDED

**Hygiene and Store Management**
- Clean all areas where stock may be kept in stores, mills, around machinery; sweep at least once a week
- Remove from store and dispose of sweepings and other rubbish
- Remove from store all empty sacks and pesticides where other space is available; otherwise keep non-food items separated from grain and other food stock
- Keep store well maintained and in good repair; repair cracks and crevices, make good where the floor has broken up, fill in holes in structure; make sure ventilators can be open & closed
- Fit wire mesh to openings to stop rodent and bird entry; fill in holes in doors, floor and walls
- Spray the fabric of the building, freight container or truck with contact insecticide solution to kill off insect pests in the empty store
- Make sure that any sacks that are reused are free of pests.

**Stock Management**
- Build stacks using an appropriate stacking pattern so that they are stable but easy to dismantle (break down into parts)
- Leave a gap of 1 m between stacks, from the walls and beneath the roof eaves; ensure that it is possible to gain access easily to all exposed surfaces, including the top
- Build the stack on dunnage of pallets or poles, or on a polythene sheet if floor is level
- Inspect the stock and the store itself at least once a week; check for the presence of pests and to confirm the effectiveness of pest control procedures that had been carried out
- Use cards attached to stacks to record the history and performance of the commodity; use record cards/sheets to record pest control procedures and inspections.

**Transport**
- Make sure truck or cart is clean and well swept
- Spray the fabric of the transport with contact insecticide
- Ensure that all paperwork related to the load is in order
- Do not use hooks to load and unload sacks, rather use man handling or a conveyor
- Do not overload the vehicle
- If transport can be made airtight, fumigate if pests are present.

**Pest Management**
- Fumigation should only be undertaken by trained personnel
- Only fumigate in airtight enclosures or where it can be made airtight
- Fumigation should last at least 7 days, before aeration begins. Aerate thoroughly
- Dispose of spent fumigation tablets by tipping residue in water
- Spray store with contact insecticide to kill off insects present before fumigation takes place; do not use insecticides to provide residual protection
- Only trained personnel should handle and apply contact insecticides; never work alone. Ensure a supply of clean water is to hand; Wash off spillages from the body or from other surfaces immediately
STORAGE STRUCTURES

Introduction
At the beginning of human civilization commenced the storage of cereal grains collected from wild plants. Gradually the human race learnt how to cultivate and grow crops. Farmers throughout the world, in hot countries or cold, in more developed or less developed countries, store grain. They may store in earthen pots, in pits or in granary, either in bulk or in a reasonably sophisticated elevator. They store some or most of the grain.

Principles of Storage
The main or primary aim of storage is to prevent the quality of grain from deterioration. This may not be achieved directly, but indirectly through the control of moisture content and air movements and by preventing attack of micro-organisms, insects and rodents.

The major objective during the storage period is to reduce metabolic activity to such a low level that the grain mass is sufficiently stable with minimal deterioration. The 2 alternative methods are:

i. Reduction of moisture content to a safe level and cooling of grain
ii. Modification of atmospheric condition of the storage system

If moist grain is stored without first being cooled, it will heat spontaneously. Such heating is known as damp grain heating. It is not necessary for the whole batch of grain to be at risk condition for the deterioration to become widespread. Warm areas cause formation of convection currents, which in turn, cause redistribution of moisture. This results in the development of hot spots in which molds develop, which are tolerant of high temperatures. This mold associated with damp grain heating produce toxins which are harmful if consumed and the spores may cause allergies and respiratory disorders in man.

Since the grain in storage constantly interacts with environment, exchanging heat and moisture, both temperature and moisture content change with both time and position because of weather changes. In warmer areas, the moisture content is to be lower for safe storage whereas in colder areas the moisture content can be higher. The relationship of storage temperature and grain moisture content due to insect respiration and damp grain heating is important and can be used as the criteria for safe storage of grain.

Types of storage
Grain storage is carried out for three main purposes: to retain a supply of food; to serve a trading system; and to retain seed for planting the following season. Storage is therefore carried out by the producer, the trader, the processor, and the exporter, and at all these levels the methods adopted affect the problem of deterioration of foodstuffs. Most of the methods of storage used at different levels are similar.

Two methods of storage are used, viz. in sacks, or loose in bulk in a variety of containers. The methods are chosen depending upon the local factors:

i. Type of produce
ii. Duration of storage
iii. Value of produce
iv. Climate
v. Transport system
vi. Cost and availability of labour
vii. Cost and availability of sacks
viii. Incidence of rodents and certain type of insects infestation

In general the advantages and disadvantages of sack and bulk storage respectively are:

<table>
<thead>
<tr>
<th>Sacks</th>
<th>Bulk</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Flexibility of storage</td>
<td>1. Inflexible storage</td>
</tr>
<tr>
<td>2. Partly mechanizable</td>
<td>2. Mechanizable</td>
</tr>
<tr>
<td>3. Slow handling</td>
<td>3. Rapid handling</td>
</tr>
<tr>
<td>4. Considerable spillage</td>
<td>4. Little spillage</td>
</tr>
<tr>
<td>5. Low capital cost</td>
<td>5. High capital cost</td>
</tr>
<tr>
<td>6. High operation costs</td>
<td>6. Low operation costs</td>
</tr>
<tr>
<td>7. High rodent loss potential</td>
<td>7. Low rodent loss potential</td>
</tr>
<tr>
<td>8. Reinfestation occurs</td>
<td>8. Little protection against reinfestation</td>
</tr>
</tbody>
</table>

With both methods, it is essential to ensure that the container (sack, warehouse or silo) is kept free from dust, spillage and old grain residues, and that the food grains put in the container are of good quality, and that the grain is dry and free of dust and other unwholesome particles. The aim should be to put dry, clean, uninfested produce in a sound, clean, uninfested storage container.

**Design of grain storages**

Proper design of storage is not only to restrain and properly hold the material, but also to prevent or minimize the damage to the grain which might occur due to moisture condensation or excess temperature. The storage unit must be designed as to withstand the change in pressures on the grain during filling and emptying. The several aspects to be considered in grain storage design are grain types and quantities; location, size and number of bins, handling equipment and methods; structural requirements; conditioning methods and requirements and plans for future use and expansion.

**Structural requirements**

Grain storage bins and structures should be designed primarily to maintain quality. The performance of this task requires that the structures can withstand the loads imposed by the grain during grain movement and its storage. In addition, these structures should withstand wind loads whether the bins are empty or full.

In general, the grain storage bins should:

a. Hold the grain without loss from leaks or spill.
b. Protect the grain from rain, snow, moisture, soil, etc.
c. Protect grain form rodents, birds, insects, off-odours, theft, etc.
d. Permit effective treatments to prevent or control insect infestation.
e. Protect from fire and wind damage.
f. Provide head room over the binned grain to allow for sampling, inspecting and ventilating.
g. Be easy to clean and inspect.
h. Facilitate the loading and unloading at the store.
Construction Materials

Steel is perhaps the most common building material for grain storage structure. It must be galvanized or otherwise coated to minimize deterioration from moisture and oxidation. The major problem with steel is the low resistance to heat transfer, which can be overcome by the use of various foamed-in-place insulations. Also, steel is impervious to moisture penetration. In some cases, grain storage structures are made from glass coated steel panels, which have high resistance to deterioration from acids and other chemicals and are used primarily for the storage of high moisture grain for the animal feed industry.

Wood is also used for the construction of rectangular bins and large capacity storage structures. Its advantages are low thermal expansion, good heat transfer characteristics and its ease of working. Wood must be treated or coated to prevent deterioration from repeated wetting and drying cycles.

Concrete is also widely used in the construction of high capacity elevators for country or terminal storage. It is not so widely used in smaller farm storages. Walls constructed with concrete must be watertight and joints must be adequately sealed. Recent studies indicate that smaller ferrocement bins can be used as small scale storage structure at farm level. Moisture proofing of these types are difficult. Use of aluminium, plastic and other materials for farm storage structures is limited.

Storage systems
- Traditional storage systems
- Modern storage systems

Traditional storage systems

Storage of food grains by the indigenous people of tropics and subtropics is mostly traditional. The methods employed today have been used for many years with little or no modification. These methods achieve various degrees of success in applying the basic principles involved in the safe storage of food grains. The variations observed are related to climate and local natural resources.

Different regions of Asia and Africa have different climatic conditions, local construction materials and traditional storage systems. The design and capacity of these facilities are determined by the type of foodstuff and the size of crop. Farmers store their crops either outside, suspended and on platforms or in granaries or even inside their dwellings.

The most frequently used grain storage systems in rural areas are the different types of traditional bins made of plant materials or/with mud or clay. Rural storage of food grains accounts for 70-80% to the total produce. That is why improved design and management of traditional systems are of vital importance.

Modern storage systems

Basically, modern methods of grain storage are elaborations of traditional methods, but constructed with the use of modern materials. There are two main types: storage in bags (e.g. in sisal, kenaf and jute) in warehouses; and bulk storage in various types of silo bins. Such methods are commonly used by traders, cooperatives, etc. and at large-scale central storage depots. They are also adopted by farmers in a number of countries.
Modern storage systems may be classified into the following based on the type of storage structures or container, facilities for loading and unloading, and methods of controlling the storage atmosphere:

- Bagged storage system
- Silo storage system
- Airtight storage system
- Aerated storage system
- Low temperature storage system
- Controlled atmosphere storage system
- Damp grain storage system with chemicals.

**Bagged storage system**

Bagged grains are stored in flat warehouses which are known as ‘conventional godown’. Public bagged food grain storage includes local supply depots (at the rural and urban district areas) and central storage depots (at regional levels). The local and central depots are essentially for short-term storage of food grains. These food grains are either produced from the farmers during harvesting season or received from other local and central storage depots, silos and imports for distribution to other local and central storage depots.

The grains contained in bags are stacked on one above the other, such that the bags do not remain in contact with the floor. The dunnages (packaging materials for ship cargo) are placed away from walls to allow movement of personnel engaged in inspecting and facilitating pest control. The vertical stacks should not be close together.

Bag storage is advantageous because:

a. Each bag constitutes a definite unit and facilitates loading
b. The bags can be neatly arranged in stacks of different sizes
c. The individual bags detected to have infestation can be easily segregated and
d. The bulk of grain being small, there is little chance of having considerable variations of temperature and moisture at different depth

The major disadvantage of the bagged storage system is that the readsoption of moisture takes place during humid wet season, especially in the outer layers of bags, and this accelerates biological activity in the food grain and results in deterioration and loss of the product. In hot dry season, when the roof and wall surface temperature is extremely high, the food grains stacked within one meter of roof or close to walls become hot. This causes relocation of moisture which results in deterioration of grain during storage.

**Buildings for bag storage**

Warehouses should be a simple structure and must be suitable for fumigation procedure. This is achieved by fumigation stacks under gas-proof sheet.

First of all, the building for the storage of produce in bags must be watertight:

- the roof, walls, doors, windows and floor must be leak proof
- the floor must not transmit water vapour from the soil with which it is in contact
- windows, etc should be sealable in order to permit control of ventilation
Secondly, the building must be proof against the entry of rats and mice
- gaps between roof and walls should be sealed
- pipes, shafts, ducts, etc should be fitted with wide metal guards outside and netting inside

Thirdly, it must be designed in such a way as to assist the control of insect pests
- walls should have a smooth, uncracked finish with the floor to wall angle curved to eliminate areas from which spillage is difficult to remove
- the floor should be finished in such a way that spillage can readily be swept up, and it should be free of roof-supporting pillars
- the whole construction should be capable of being sealed so as to allow fumigation of the entire contents & should be built in such a way that areas of high temperature are eliminated

There is an urgent for new storage building designs providing the essential criteria for safe storage of products. Structures built according to these criteria should be:

a. entirely weather proof
b. gas tight to enable fumigation of entire components
c. fitted with controllable ventilation
d. proofed against the entry of rodents and birds
e. free of ledges (narrow shelf against wall) and corners where dust and produce residues may lodge
f. free form light transmitting areas in the roof in order to avoid high temperature areas on top of stored produce
g. designed to permit incorporation of a few fans in the walls and ducting on the floor for special bulk storage requirements

The following may be important considerations while designing for bag storage:

a. **Siting and foundation**
   It is very important to select a good site in which the soil movement is not excessive. A well drained site should be selected where the ground slopes away from the store and prevents water from accumulating around it. This can be of great benefit where sudden storms occur with rainfall of high intensity. Low lying areas where water is close to the surface should be avoided.
   - Termite infested sites should be avoided or should be thoroughly treated with insecticides.
   - Filled or made-up ground is not good base for foundation.
   - The position of the sun should be considered as it is needed to keep the building as cool as possible.
   - Should be close to outlets such as processing plants, transport, electricity, water & labour.
   - Too many trees around the site should be avoided as there may be birds’ problem.

b. **Damp proof materials**
   The use of damp proof courses and vapour barriers to prevent the entry of water and water vapour is essential. The type of damp proof course material used is important since many only resist liquid water under certain conditions. Materials used as damp-proof courses include lead, copper, bitumen felt and mastic asphalt. Some plastics, notably polythene and polyisobutylene, are also used as damp-proof materials.
c. **Floors**

The floor of storage buildings, in general, consists of a concrete screed laid over a concrete base. Concrete must be well cured. Premature drying, resulting in a lack of hydration of the cement, is a common cause of much poor concrete seen in the tropics. Waterproof barrier should be incorporated in concrete and made continuous with DPC in the wall; otherwise the moisture will rise through the floor and be absorbed by any commodities that are in contact with the floor. Floor level must be above ground level and with sufficient elevation to ensure drainage away from the building.

d. **Walls**

- Best materials for wall construction are clay, bricks or concrete blocks. These have greater thermal capacity and less temperature fluctuation.
- A vapour proof barrier i.e. damp proof coarse (DPC) is essential to prevent dampness rising in the wall from ground.
- The inside surface of masonry walls must be rendered with a cement sand mortar, essential for internal cleaning and pest control.

e. **Roof**

The pitched roof of stores is usually of galvanized steel, aluminium or asbestos sheet. Flat roofs of stores are commonly of concrete treated with bituminous covering; the main problem is to prevent the deterioration of the covering.
- Great care should be taken to provide sufficient overlaps to prevent entry of rain.
- The pitch of roof i.e. angle of slope must be between 17-22°. If less than 17°, it will not shade rain efficiently and if greater than 22°, it will be costly.

f. **Doors**

It must be large enough to permit easy handling of large commodities but should be good enough to prevent the entry of rodents when closed. Steel shading doors are generally the best selection.

g. **Ventilations**

Eaves (part of roof) level ventilation is usually necessary in which effective shuttering that can be operated from the ground level is desirable.

h. **Rodents and birds proofing**

Doors, ventilations or eaves and baffles should be well maintained to prevent the entry of rodents and birds. All high level opening into the store should be screened with mesh. The store and surrounding area should be kept clean of spillage and attractive food for birds.

**Bulk storage**

It is a common practice in countries storage system and is done on large scale. Piling up of grains on base floors of godowns may dampen the grain by accumulation of moisture through sweating of floors. But, if piling is done on moisture proof floor or on impervious sheets, the bulk storage is good. The exposed surface in bulk storage is small as compared to bag storage for identical quantity of grain. So, the infestable surface or treatment area is smaller than that in bag
storage. The interior of bulk storage is somewhat less exposed to infestation of pest as the infestation detected on superficial layer of bulk store enables immediate protection measures to be taken to eradicate the pest readily before reaching the interior.

Storage of produce in bulk is carried out in various types of containers and buildings, the design of which affects the stability of produce. It is possible to adapt buildings which were originally designed for bag storage to bulk storage.

- The storage of produce in bulk in large heaps on extensive floor areas is not possible because the control of insects by fumigation or other chemical methods is extremely difficult.
- Bulk stores vary from simple flits to a very elaborate structure of ferroconcrete or still lavishly equipped with conveying, cleaning and weighing equipments and incorporating automatic means of pests control.

Certain basic principles needed to be followed are:

1. **Siting**
   - All bulk storage structure must be constructed on solid earth and never on an area which has been filled with loose earth.
   - The area of minimum of $3m^2$ immediately surrounding the base structure must slope away from straight in all dimensions, so that rain water will drain away from base structure.

2. **Dimension**
   - To obtain the maximum storage capacity for a given quantity of structure material, the nearer the shape of cube or sphere the better.
   - For optimum capacity, the height may be approximately equal to the diameter.
   - It is more economical in practice to increase the height, well above the theoretical optimum as the material and labour requirement for walls are less than for base and roofs.

3. **Foundation and base**
   When storage bins are constructed above ground level, the design may be either a flat bottom to the container, in which case complete emptying and cleaning is often not carried out, or a conical or sloped bottom (about $32^\circ$) which makes the container self emptying. A flat base may be made out of a sheet metal or timber whereas conical base implies concrete construction.

   The stability of a building is dependent on properly designed foundations. The plinth (flat base) should be capable of supporting the load of produce which will be placed on it. Plinths for silos should be constructed with a vapour barrier by means of which liquid water and water vapour are prevented from entering the silos and being absorbed by the produce in contact with the plinth.

4. **Walls**
   - Walls can be constructed of much timber sheets, metal, concrete or local bricks.
   - The efficiency of these bins depends upon the effectiveness with which insect infestation and water damage can be controlled in them, and the ease with which they can be erected under local conditions.
   - In a good design and construction, the bin is automatically rodent and weather proof and insect pest are readily controlled.
Metal grain storage bins

Bulk grain storage bins are made of
- Galvanized iron sheet
- Mid steel black sheet

However, bins made from sheet are commonly used in Nepal. These are simple, portable and not very expensive. The bins are barrier against moisture, insects and rodents.

Advantages
- The bin is made of metal sheet and is wall covered. So, insects and rodents can’t get free entry.
- Fumigation can be done if necessary.
- It is economical and requires little or no maintenance.
- It is portable and can be handled conveniently by one person.
- The fabrication work is not very complicated.

Silo storage system

A silo is a storage facility in bins with provision for mechanical loading and unloading of the grains. A silo installation is known as ‘Elevator’ because it is equipped with elevator to take the grain up and down. This is made either of steel, aluminium or concrete. Modern silo facilities are constructed of steel or reinforced concrete and usually consist of a battery of adjoining bins with different configurations.

Hygiene and Organization

Irrespective of the types of storage building or container used, unless storage hygiene is practiced, losses of stored produce will occur. It is essential that there should be an organized approach to the problem at each point where food grains are handled and stored. Teaching storage hygiene and organization to the farmer, trader and warehouse foreman is the first step in raising storage standards and reducing losses.

The following procedures summarize the techniques to be considered in a routine approach to storage.

1. Ensure that the storage container is of sound construction.
   - The roof is sound and free from leaks.
   - The walls are free from cracks (e.g. by re-treating with mud or concrete)
   - The floor is free from cracks (and, where appropriate, that it will not allow the passage of moisture into the produce)

2. Ensure that the storage container is clean.
   - Brush out old crop residue and clean walls, roof and floor.
   - If a building, treat the walls with whitewash.
   - Treat the empty container with insecticidal dust, spray or smoke.

3. In the chain between farmer and consumer, at each point where produce changes hands, a thorough examination should be carried out so that only produce which is dry, clean and free from discoloured and low quality grains, is accepted for storage. Where necessary and appropriate, dry, clean and hand-pick small quantities of produce before intake.
4. At intake, record the moisture content and other quality characteristics and weigh every bag of produce and record quantity taken into storage.
   - Record day’s intake in a stock book.
   - Prepare an account of description of goods, marks, condition, shortages (if any) and remarks on damage.
   - In these cases where produce is being held in store for another party, a certificate or warrant should be prepared for the owner of the produce giving description of goods, situation of warehouse, etc.
   - Issue a delivery order to record: goods to be delivered; name and address of firm receiving goods; warehouse address; special identity marks; dates required.
   - Check test the weighing machines in use (platform scales).

5. Where appropriate, treat the produce during intake or loading of the container with an insecticide (in one of the following ways),
   - Admix an insecticidal dust with the produce.
   - Inject an insecticidal dust into bags or produce & attempt even distribution by tumbling.
   - Spread the produce in a thin layer on a tarpaulin and spray with a liquid contact insecticide; mix the produce thoroughly by shoveling before bagging.
   - Spray the grain stream with a liquid contact insecticide.
   - Spray the grain stream with a liquid fumigant.
   - Add granules of fumigant to the produce during the filling of the container.

6. If bag storage, build the produce into a stack on water proof floor or on wooden dunnage (pallet form) which keeps it entirely off the floor. Where appropriate, treat the produce by one of the following methods.
   - Dust each layer of bags as a stack is being built.
   - Spray the outside of a complete stack with a water-dispersible powder.
   - Fumigate the stack under gas proof sheets, if the stack to be treated is small and is contained in a gas tight chamber.
   - Effectively seal the entire building (if necessary by covering with gas proof sheets) and fumigate.
   - Completely enclose the stack in an air tight envelope.

7. If silo storage, disinfestation measures which can be adopted, vary with the circumstances.
   - Small bulks can be fumigated by laying sacks on the surface of the produce and sprinkling with liquid fumigant; very small bulks up to about 1 ton can be fumigated in a gas tight container by exposing the fumigant in a wide mouthed vessel on the surface of the grain.
   - Large bulks of grain can be fumigated.

8. With both bag and silo storage, ensure that the first parcel of grain to be put into store is the first parcel to be taken out of the store and that each parcel of produce which has been treated with an insecticide should be clearly labeled with a “treatment card” on which every treatment is recorded.
RURAL GRAIN STORAGE SYSTEM

Introduction

Storage of food grains by the indigenous people of tropics and subtropics is mostly traditional. The methods employed today have been used for many years with little or no modification. These methods achieve various degrees of success in applying the basic principles involved in the safe storage of food grains. The variations observed are related to climate and local natural resources.

Cereals are staple foods. 80% of the daily calorie uptake is provided by cereals. The most frequently used grain storage systems in rural areas are the different types of traditional bins made of plant materials or/with mud or clay. Rural storage of food grains accounts for 70-80% to the total produce. That is why improved design and management of traditional systems are of vital importance.

Post harvest losses and grain availability

Traditionally, increased production was considered to be enough to increase the food availability and very little attention was paid to the food loss during post harvest operations like harvesting, threshing, cleaning, sorting, processing, packaging, transportation and distribution to the consumer.

Rural storage structure

An ideal storage facility should satisfy the following requirements:
1. It should be provided the maximum possible protection from ground moisture, rain, pests, molds, rodents, insects, birds, fire, etc.
2. It should provide the necessary facility for inspection, disinfection, loading, unloading, cleaning and reconditioning.
3. It should protect grain from excessive moisture and temperature favourable to both insects and mold development.
4. It should be economical and suitable for particular situation.

The storage structures are made by locally available materials which are generally not fit for long term storage of grains.

The produce is stored in heaps on the ground for periods ranging from few days to months or even more. The traditional storage structures found in Nepal are classified into 6 broad categories, which are Bhakaris, Thekas, Kothis, Mud bins and Peachers.

i. Split bamboo structures – Bhakaris
ii. Bamboo cum timber structure – Thangro, Kathe, Bhakari
iii. Earthen structures – Peachers, mud bins
iv. Kothis
v. Masonry structures
vi. Metal bins
Improvement of rural grain storage structures

The existing storage structures in rural Nepal are not ideal from the scientific point of view as substantial losses occur during the storage of grain.

Improved and management of traditional systems are of vital importance. Improvement in storage practice can be brought about by:

1. Replacing the existing structure by new ones involving huge expenditure & organizational setup
2. Incorporating simple feature into the existing structure which the farmer can make use of under the present condition. The second alternative is preferable.

The improved mud bin is a storage structure with polyethene sheets placed between the walls of unburnt bricks to give protection and support to polyethene, whereas the unburnt bricks make the structure well insulated against the fluctuations in ambient temperature. The polyethene films prevent the entry of moisture and air.

Broadly speaking, the improvement of rural grain storage structures can be achieved by:

1. Improvement of “Bhakari” by providing 50 mm metal base and cover on the top to protect against rodents.
2. A layer of polyethene sandwiched between bamboo mats to make it air tight.
3. Use of moisture proof plants on mud bins structure to make it air tight.
4. Outdoor structure raised 1 m above the ground and metal cones provided in each pole to prevent rat from climbing.
5. The roof of outdoor structure made airtight by providing mud plasters over the thatched roof and painted with water proof paint on the roof covered with polyethylene sheets.
6. Clay pots covered and painted with moisture proof paint.
7. Chemical pesticides such as malathion, are used in the empty storage structure.
8. Use of clean stores and better sanitation to prevent the infestation by rodents and insects.
9. Use of insect repellant plants in stores to prevent pest attack.
10. Use of metal structure and “Pukka Kothi” for storage.

Factors affecting grain quality

The maintenance of quality of food or feed commodities depends upon the same principles and practices whether the quantities are small, perhaps a few tones, or whether national food reserves are to be considered. The following factors will influence actions that might be necessary to take:

- The type of material being stored, whether it is cereal, pulse or oilseed; entire grain or milled products.
- The end use of the commodity; whether it is for animal feed or food for human consumption; commodities for local or national consumption or for export.
- The duration of storage, i.e. transit, medium or long term storage.
- The climatic conditions to which the commodity was exposed before receipt; what conditions are likely to occur whilst commodities are held in storage.
- What pest management practices have been put into place before receipt; the cost benefit of pest control; what pest control materials and equipment are available; what training in pest management have staff received; what pest control services are locally available and their cost.
Inspecting Grain during Storage

The probability of grain becoming infested by insects or spoiled because of moisture damage and mold growth is increased when it is stored and left undisturbed in the same location for several months. Therefore, regular inspection routine should be maintained throughout the storage period to determine general condition of grain and to detect early infestation and dampness or grain heating. Inspections are particularly important during summer when the grain temperature is optimum for rapid insects development. So, it must be inspected twice in this season.

To inspect the grain properly, a grain probe is needed, a section of canvas through a strip of canvas for receiving the grain from probe, screening pans for shifting insects from grain sample and a means of measuring temperature of grain.

Grain temperature is a good indicator of grain condition. It serves to identify areas of grain bulk in which conditions are favourable for insects development and to locate areas in grains that are heated.

Stored grain contains moisture that can be shifted from one location to another primarily as a result of temperature difference that develops within the grain bulk. Moisture from warm grain is transferred to cooler regions of grain bulk and is condensed there resulting in damp areas that favour insect activity and mold development. These in turn cause rapid deterioration and heating of grain.

During warm weather, infestation generally begins near the grain surface particular in areas directly below the point of entry, where foreign materials have accumulated during binning. Samples are taken by inserting probe on grain and pushing it one inch or two beneath the grain to collect the sample.

During cold weather, use grain temperature as a location guide and sample areas where temperature is above 18°C. Sieve the sample with 10-12 mesh screen, and examine screenings for insects.

To complete the inspection, look for insects on the outside and inside of the bin surface, especially around the base, doors, ducts and joints or seams in walls. Check for water leaks through roof or walls and look for evident of rodents or birds entry into the bin.