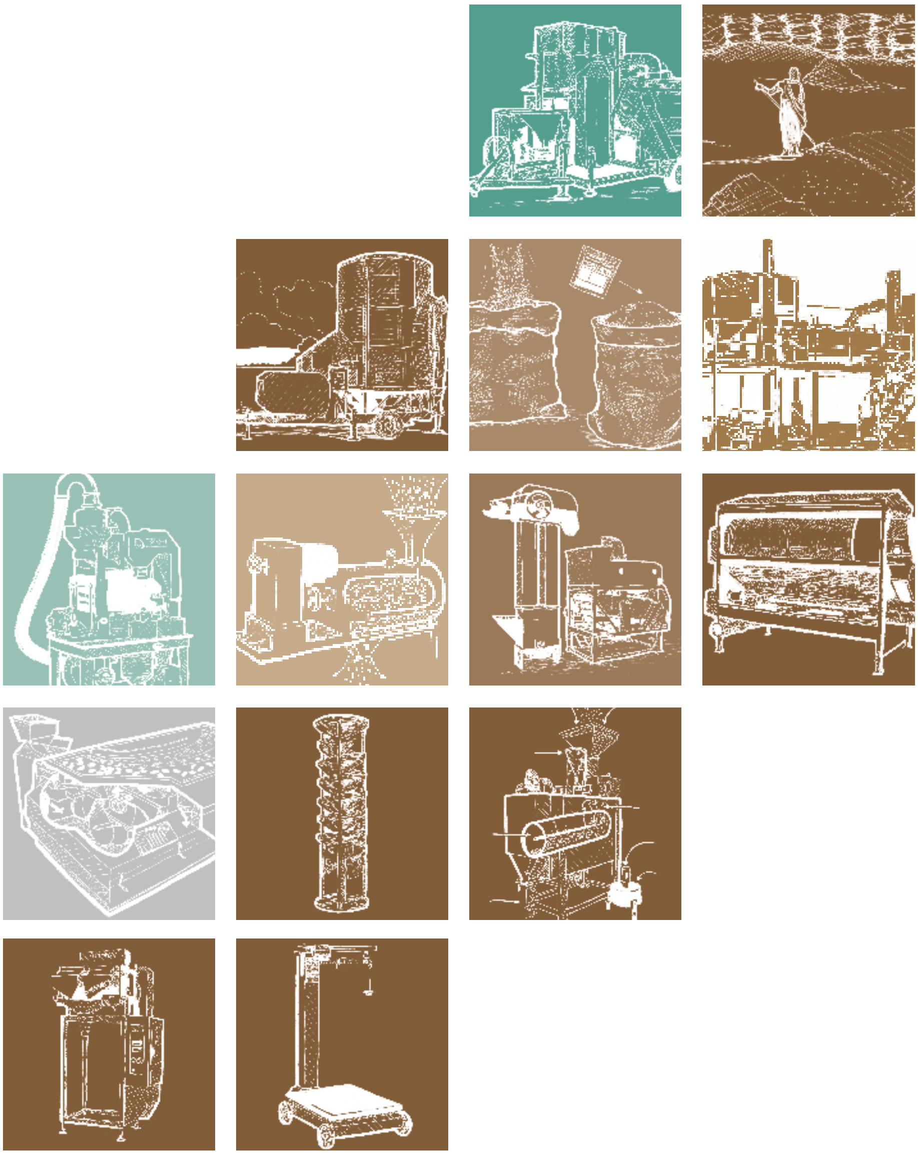
Food and Agriculture
Organization of the
United Nations

SEEDS TOOLKIT

Module 6: Seed storage



SEEDS TOOLKIT

Module 6: Seed storage

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Contents

TABLES

Foreword

The global community, through the Sustainable Development Goals, has committed to achieving a world free of hunger by 2030. This will require the sustained production of about 60 percent more food than at present, food that is both nutritious and safe, and produced in ways that do not damage the environment. Under most scenarios, there are no surplus land or water resources to deploy to increase agricultural production. In fact, the most sustainable path to this goal is through enhanced productivity in a sustainable way. That means producing more yield with fewer external inputs. To support this, farmers need to use well-adapted crop varieties.

FAO and partners work with countries to increase farmers' use of quality seed and planting material of well-adapted varieties, particularly for the rural dwelling resource poor small-scale and family farmers who produce most of the food consumed in vulnerable communities of developing countries.

A country's seed delivery system is best conceived as a value chain composed of interrelated components – from the development of well-adapted and nutritious crop varieties and their adoption by farmers, through the production and distribution, including sales, of quality seeds and planting materials, to on-farm utilization of these inputs by farmers. The effective functioning of the value chain, enabled by the applicable national seed laws, policies, strategies, action plans and regulations, depends largely on the extent to which the stakeholders are able to put into practical use the relevant knowledge and skills required for producing quality seeds and planting materials.

This Seeds Toolkit has been developed to support practitioners along the entire seed value chain to acquire the knowledge and skills they need in order to deliver quality seeds and planting materials of well-adapted crop varieties to farmers. The Toolkit is designed primarily for capacity building activities, especially for small-scale farmers and small and medium-scale entrepreneurs, and contains six interrelated modules. These modules address: the setting up of small-scale seed enterprises; the processing of seeds; quality control; and the storage and marketing of seeds. There is also a module on seed regulatory matters. These easy-to read modules of the Toolkit should also be useful for policy-makers and other practitioners interested in better understanding the workings of effective seed delivery systems.

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Director Plant Protection and Production Division

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TECHNICAL REVIEWERS

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Hamza Bahri and Diana Gutiérrez Méndez coordinated the language editing, illustrations and layout. Ruth Duffy edited the document, Shalis Stevens produced the illustrations and Art&Design undertook the overall design and layout of the publication.

Abbreviations and acronyms

AI	Active ingredient
CP	Crude product
db	Dry basis
FIFO	First in–first out
MC	Moisture content
PVC	Polyvinylchloride
RH	Relative humidity
ROI	Return on investment
UV	Ultraviolet
wb	Wet basis

Introduction

It is estimated that 25–33% of the world grain crop including seeds is lost each year during storage, and this has a significant effect on **global food security**. The impact is even greater in food-deficit developing countries, where every year farmers struggle to preserve their seeds as basic input needed for food crop production.

Seed storage is the **preservation of seeds under controlled environmental conditions to maintain seed viability** (germination and vigour) for long periods from harvesting through to planting of the processed seed by the farmer. However, storage is often thought to mean simply keeping the seed in a physical "storage" structure. This misconception can lead to the unnecessary building of complex and costly buildings. It is important to take into account other factors contributing to the maintenance of seed viability. The guiding principle is to understand **how the seed and its internal biological–physiological–biochemical processes function and interact with its surrounding environment**, and hence determine when seed storage really begins and ends.

Seed storage actually starts in the field when the seed reaches physiological maturity, i.e. when the seed ceases to receive the full protection of the mother plant and is exposed to the external environment in terms of moisture, temperature, biotic pressures etc. For this reason, the environmental conditions during seed maturation through physiological maturity to planting all have a high impact on the seed's viability and storage potential.
The **storage period** can thus be effectively divided into stages:
- pre-harvest;
- harvesting–warehouse;
- warehouse; and
- warehouse–planting.

Following this logical sequence is essential from the outset to ensure that seed of the highest possible initial quality and safe moisture content is placed in warehouse storage. Therefore, when deciding the location and timing of seed production, the choice of location and timing must be determined not only by high yields, but also – as far as possible – by prevailing conditions during harvest. The ideal conditions at harvest are low temperatures and low relative humidity.
Investment in sophisticated warehouse conditions may only be justified when all other conditions are ideal:
- Harvesting takes place when the seed is of optimum quality.
- Proper handling is ensured during relevant post-harvest operations (drying, threshing, processing and interim transportation).
- High-quality seed is available for placing in the warehouse.

Warehouse storage serves, not to improve, but to maintain the quality of the seed. The management practices provided during the warehouse storage phase can do no more than **preserve the initial seed quality**. If the seed is of high quality at harvest (due to optimum pre-harvest factors), this state can be maintained by the adoption of appropriate practices during storage. On the other hand, if the seed originates from poor field conditions (field weathering, high moisture at harvest, extreme temperatures, low germination, low vigour, poor seed health etc.), even the best storage practices cannot offset the shortcomings.

This module is organized in five chapters to cover **best practices throughout seed storage.** Each chapter includes exercises designed to provoke group discussion and brainstorming during training sessions.

Chapter 1 introduces and explains basic principles, issues and concepts in seed storage: pre-harvest physiological maturity, post-harvest handling and storage, warehouse storage and storage by the farmer until the seed is planted.

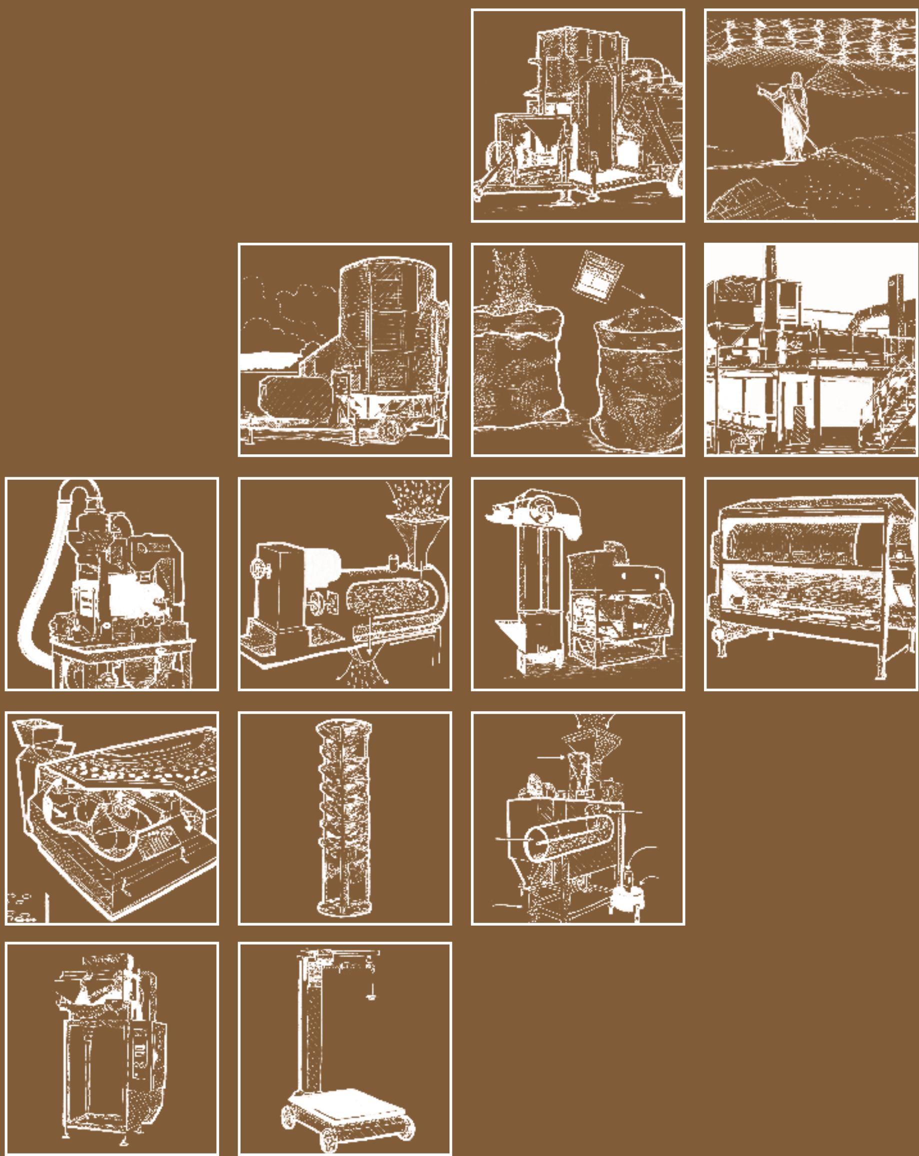
Chapter 2 considers the environmental factors affecting seed storage, including the basic principles of managing the warehouse storage environment to reduce the risk of a decline in viability, especially when seeds are stored for over a year. The three primary environmental factors determining successful seed storage are discussed: initial seed viability; initial seed moisture content; and storage temperature in combination with relative humidity.

Chapter 3 describes storage pests and explains how to control them, in consideration of the significant annual losses in world grain crops and seeds due to pest damage during storage. The principles of controlling the main storage pests of crop seeds (insects, pathogens, mites, rodents and birds) are discussed.

Chapter 4 presents a wide range of storage structures, both indigenous and improved, suitable for keeping seeds from harvest until the next planting season. Particular attention is given to how structures at local small-farmer level can be improved for better storage of agricultural seeds.

Chapter 5 examines the economics of seed storage: how to make warehouse operations cost effective and efficient by selecting appropriate structures for particular situations, taking steps to avoid economic waste and ensuring that correct routine management practices are adopted.

1 Principles of seed storage



Principles of seed storage

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Once a seed crop is harvested and cleaned, it may be necessary to keep it for a period before it can be marketed or used by the farmer. The period the seed can be safely kept depends on the conditions during harvesting and cleaning, and the type of storage facility used. Essential principles govern the storage of seeds, in particular practices relating to the control of **temperature and relative humidity** (RH) in the storage facility itself. Seed with a lower moisture content (MC) kept at lower temperatures can be stored for longer before the quality deteriorates. The presence and buildup of insects, mites, moulds and fungi – all influenced by temperature and moisture content of the seed – affects both the quality of the seed and the duration of its storage. The incidence of other conditioning factors (e.g. rodents and birds) depend on the structure used and its condition.

WHAT IS SEED STORAGE?

Seed storage is the preservation of seeds under controlled environmental conditions to maintain seed viability (germination and vigour) for long periods from harvest until the seed is finally required for sowing by the farmer. The entire storage period comprises several processes and sites. In the broadest sense, storage begins at physiological maturity and ends with germination in the field. The storage period can be divided into five stages:

1. Harvest maturity
2. Drying and threshing
3. Processing
4. Distribution and marketing
5. On-farm storage

1. The period **from physiological maturity** to harvestable maturity is the first segment of the storage period. Seeds are physiologically mature when they reach maximum dry weight on the plant. At physiological maturity, dehydration of the seed has begun, but is not yet complete; it continues until the moisture content of the seed and fruit decreases to a level that permits effective and efficient harvest and threshing, i.e. harvest maturity. Any delay in harvesting after the seed reaches harvest maturity prolongs the first segment of the storage period, and often results in deterioration of quality. The moisture content is the amount of water in the seed and is usually expressed as a percentage on a "wet basis" (wb), calculated as follows:

$$\frac{\text{Weight of moisture}}{\text{Weight of wet sample}} \times 100$$

Occasionally, "dry basis" (db) moisture content is given and it is important to know which has been used. For example, if 100 kg of moist grain is dried and loses 20 kg of water, the moisture content is:

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$$\frac{20 \times 100}{100} = 20\% \ (wb) \quad \text{or} \quad \frac{20 \times 100}{80} = 25\% \ (db)$$

Grain is normally harvested at MC 18–25% (wb). However, a range of factors – stage of crop maturity, season, weather pattern and drying facilities – influence the moisture content, which can therefore be substantially higher or lower.

Hand-held electric moisture meters are used at field level to obtain a rapid reading of grain moisture content. They measure the grain's electrical properties, which are closely related to moisture content and give quite accurate results within the range of MC 13–16%.

2. The second segment of the storage period is **from harvest to the beginning of seed processing**. When seed is in the combine, the grain wagon, in bulk storage or the drying bins, it is in storage; its quality is affected by the same factors conditioning seed quality during the later stages of storage (packaged seed or distribution and marketing).

3. The third segment of the storage period is **from the onset of seed processing through to packaging**.

4. Once the seed is in its packaged form, the storage period covers **distribution and marketing**, including storage in warehouses and at retail points.

5. Finally, seed is stored on the user's farm **before and during planting**.

The seed quality – mainly germination and vigour (see Module 2) – can be significantly affected during any of these five stages. It is therefore essential to follow sound principles of seed storage and to handle seeds properly; best practices apply also to seed held at transit points during transportation by cart, lorry, rail, air or any other means.

Harvesting and air-drying rice seed

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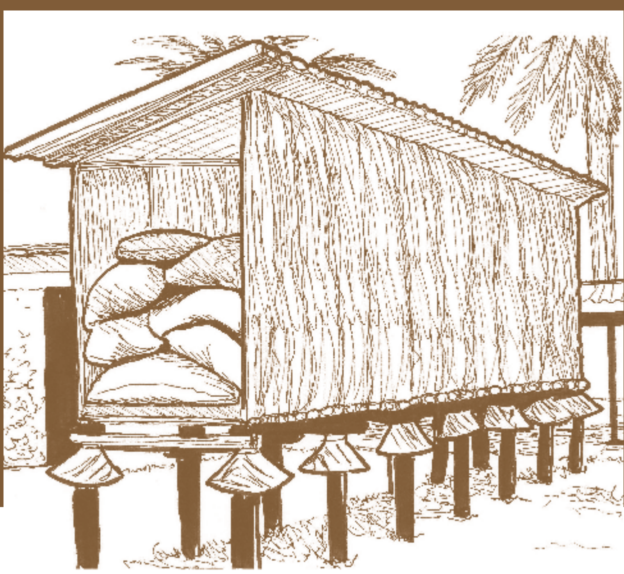
Drying rice and transporting harvested rice seed

Seed processing operation

Handling processed seed in store

On-farm seed storage in open crib



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WHAT IS THE PURPOSE OF SEED STORAGE?

The purpose of seed storage is to **maintain the seed in good physical and physiological condition** from harvesting through to planting by the farmer. For most crops, time passes between harvesting and planting; the seed has to be kept somewhere during this period, and storage is therefore necessary. For some crops, seed can be sown almost immediately after harvesting, and little or no storage is required. For example, in some countries seed of a particular crop may be harvested in the highlands and then almost immediately planted in the lowlands, or a crop such as rice may be produced two or three times a year, thus reducing the seed storage period.

Traditionally, the primary purpose of storing seeds at farm level is to preserve seed stocks for sowing or planting in the following season. However, extended storage – i.e. keeping seed for ≥ 2 years to meet future demand – may be necessary for various reasons:

- Desire to preserve material of well-adapted and preferred varieties – especially at the level of farmers in local communities.
- Perceived risk of crop failure in difficult conditions. Part of the production from a good harvest is kept as buffer stock to cover seed needs in less productive years. Seed yield and quality (particularly germination and vigour) can be unpredictable due to growing conditions.
- Variations in market demand for certain crops and seeds. When seed suppliers do not manage to market all their seed during the immediate planting season, the unsold seed is carried over to the second planting season. However, not all seeds naturally store well for carryover purposes; for example, groundnut, soybean and onion seeds have a naturally short storage life.
- Elimination of need to produce seeds every season. This is a potentially efficient and economical strategy for foundation seed enterprises producing seed of varieties with limited demand during any given season. In fact, many kinds of seed lots – mostly vegetable, flower and forage seeds – in international trade are not used the first year after production.
- Provision of sufficient time for breaking dormancy, thus improving the percentage of germination.
- Conservation of genetic resources, which requires long-term seed storage.

Regardless of the specific reasons for storage of seed, the purpose remains the same – to **maintain a satisfactory capacity of the seed for germination and field emergence.** The facilities used and procedures adopted in storage must focus on this purpose. During storage, seed must be regularly tested, particularly for germination capacity.
Seed is **routinely stored for > 1 year**, and is it is important to understand how operations during the different segments of storage – harvesting, drying and threshing, processing, storage, and transportation – affect the longevity and vigour of the seed. Seeds are fragile living organisms, and their shelf-life is affected from the beginning of the plant life cycle by soil nutrition, plant health and other factors. Provision of optimum conditions for crop growth and health

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is fundamental; nevertheless, the greatest impact on seed viability and vigour is made by harvesting, threshing/extraction, drying, cleaning, transportation and storage. Indeed, damage occurs easily at any of these stages. Care must be taken to **minimize seed damage and maximize seed viability and vigour from pre-harvest through to post-harvest handling**.

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TYPES OF SEED STORAGE REQUIREMENTS

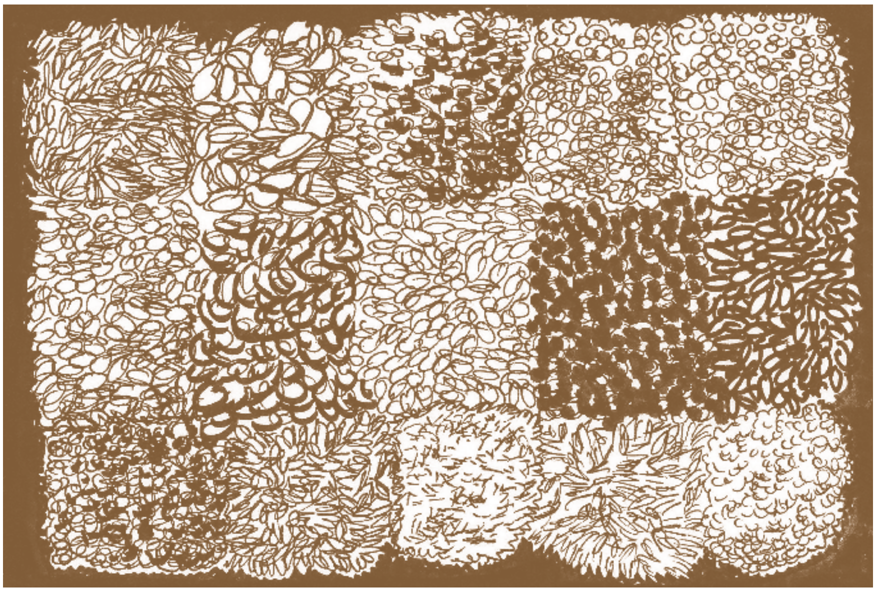
In general, the cost of storage facility per unit of seed stored increases in line with storage requirements. The type of storage required depends mainly on the **expected duration** of storage, classified into **five categories**:

- Short-term storage of farm-saved seed or community seed banks
- Short-term storage of early-generation seed stocks (breeder and foundation seed)
- Short-term storage of commercial seed stocks (certified seed)
- Storage of carryover seeds (both early-generation and commercial seed)
- Long-term storage of germplasm seeds (genetic resources)

SENSITIVITY OF SEEDS TO DRYING AND TEMPERATURE

Seeds differ in terms of sensitivity to drying and temperature; some seeds lose their viability once they reach a certain level of moisture content. Seed moisture is a critical factor determining the viability and longevity of all seed types. For this reason, it is fundamental to **identify the seed type** before considering the method of storage. In terms of seed longevity and the effects of drying and storage on germination, there are different seed categories:

- **Orthodox seeds** – long-lived, can be dried to moisture content of 5% (i.e. lower than they would normally achieve in nature) without damage, can be packaged and tolerate freezing. The longevity of orthodox seeds increases with reduction in both moisture content and temperature in a wide range of



Orthodox seeds

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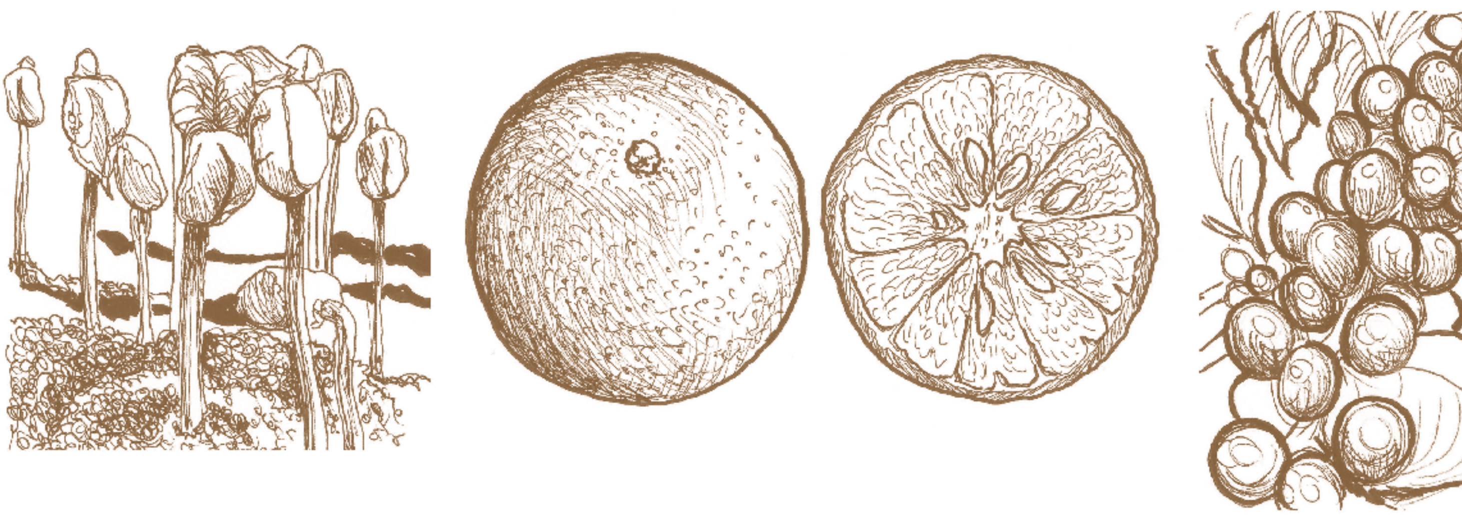
storage environments. Ex situ conservation of orthodox seeds is, therefore, not problematic. Examples of orthodox seeds that can exist in the dry state for extended periods, include most annual and biennial crops (most cereals and legumes) and many vegetable seeds, for example, lettuce, cabbage and rapeseed (canola).

- **Recalcitrant or unorthodox seeds** – short-lived, cannot be dried to MC < 20–30% without injury, do not tolerate freezing and, therefore, are not amenable to long-term storage. Ex situ conservation of unorthodox seeds is problematic and, for this reason, plants producing recalcitrant seeds are conserved in the growing form rather than as seeds. Recalcitrant species belong mostly to trees and shrubs; common examples of plants that produce recalcitrant seeds include avocado, cacao, coconut, mango, papaya and walnut. Recalcitrant seeds are generally larger than orthodox seeds; indeed, large seeds often have a high moisture or oil content and are generally recalcitrant in their storage behaviour.
- **Intermediate seeds** – not conforming fully to either the orthodox or the recalcitrant category, have limited tolerance to drying but are sensitive to freezing temperatures. Examples of intermediate seeds include relatively small-seeded agroforestry species, such as citrus, coffee, guava and cashew.

Recalcitrant seeds

Intermediate seeds



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PLANTING MATERIALS

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Plants are not only raised from sexually produced seeds (orthodox/recalcitrant); they can be raised **asexually** from parts of roots, tubers, bulbs or stems. Plant parts used for vegetative propagation are known as planting materials. Crops planted using planting materials include cassava, sweet potato and yam.

The farmer must ensure that planting materials are available when required. Vegetative planting materials should be kept in fresh condition, viable and without disease; storage can, therefore, be a problem, especially for seasonal crops. The **availability of healthy planting material** is the most important limiting factor in the production of root and tuber crops such as Irish/white potato, sweet potato and cassava.
Besides conventional vegetative propagation, plants are also produced through **micropropagation**, using tissue culture techniques to produce disease-free, high-quality plants, tubers and bulbs for high-value commercial agriculture. Certain fruits (e.g. banana and plantain, citrus, pineapple and strawberry) and crops (e.g. sugar cane, potato, sweet potato and cassava) multiply through micropropagation. High-value early-generation materials require specialized storage conditions. For example, minitubers of potato produced through tissue culture require air-conditioned storage until they are needed for the production of disease-free certified seed potato stocks.

Planting materials of cassava (left) and sweet potato (right)

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SEED HANDLING DURING DIFFERENT STAGES OF STORAGE

Harvest maturity (storage on the plant)

Seed quality is greatly influenced by prevailing **environmental conditions** from the time the seeds reach physiological maturity until harvest, and damage due to weather is often a serious factor at this stage. For example, seeds of certain crops (e.g. soybean and groundnut) can lose their viability and vigour, resulting in reduced germination capacity before harvesting.
Other factors (e.g. soil conditions, mineral nutrient deficiencies during plant growth, water stress, high or low temperatures, disease and insect damage) may also lead to deterioration in seed quality, with reduced viability and vigour at physiological maturity.
It is, therefore, essential to **maintain initial seed** quality at the highest attainable level, minimizing damage arising from weather and other factors and adopting good practices:

- raising a healthy seed crop;
- harvesting early; and
- making adequate and timely arrangements for seed drying and threshing.

Harvest to processing (storage from harvesting to processing)

Since seeds have high moisture content at harvest, seed deterioration can be rapid following harvesting. If the cereal seed moisture content is > 13% at the time of harvest, **rapid and serious deterioration** can occur during the periods of storage involving:

- transport from the field to drying and the threshing floor;
- transport from the threshing floor to the processing plant; and
- storage at the processing plant.

At MC ≥ 13%, mould can grow and heating may occur. The utmost care is required when handling material with a high moisture content after harvest. If seed is harvested at MC > 13%, take steps to preserve seed quality. Note that freshly harvested seed may seem dry overall, but individual seeds with high moisture content can initiate mould growth in spots. **Aerate** freshly harvested seed – even when the seed appears dry. **Prevent mechanical admixture and maintain seed lot identity.**

Distribution and marketing (storage in warehouse)

After processing, the seed is placed in different forms of storage to await distribution or marketing. Although the ageing of seeds and the reduction in germination cannot be stopped entirely during storage, they can be controlled by providing good storage conditions.

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Storage in transit, at retail and on farm

Construction of excellent warehouses serves no purpose if the seeds lose their viability as a result of improper storage during transit, at the retail store or on the user's farm. Adequate **storage precautions are necessary** at all these points.

FACTORS AFFECTING SEED LONGEVITY IN STORAGE

The maintenance of seed quality and seed longevity in storage warehouses depends on a range of factors (explained below). In general, low moisture content and low temperature reduce the loss of seed viability, and different combinations of **moisture content and temperature** can be used to prolong seed viability during storage.

Seed type

The nature or kind of seed – orthodox, recalcitrant or intermediate – affects seed longevity, as sensitivity to drying and temperature influences the natural storability. While seeds of some crops (e.g. onion, soybean and groundnut) are naturally short-lived, others (e.g. most cereals and grain legumes) last longer in storage.

Initial seed quality

The quality of a seed lot cannot be enhanced by putting it into storage (with the exception of sometimes breaking dormancy in hard seeds that would not have germinated otherwise), since the function of good storage is only to maintain the quality status of the seed lot by preventing a rapid deterioration in quality. The storability of seed depends on its **quality at the beginning of storage** because seed of high initial quality (germination and vigour) is much more resistant to unfavourable conditions in the storage environment than low quality seed. A seed lot with highly vigorous and undeteriorated seeds stores longer than deteriorated seed lots, because once deterioration begins, the process is rapid. Even a seed lot that has good germination at the beginning of storage can decline rapidly, depending on the severity of damage to its seeds. It is, therefore, important to carry over only high-quality seed for future planting seasons and to reject low quality seed.

Seed moisture content

It is essential to dry seeds to a safe moisture content, because the moisture level is probably the most important factor influencing seed viability during storage.

In general, if moisture content increases, storage life decreases. High moisture content can lead to mould growth and rapid losses; very low moisture content (MC < 4%) can result in extreme desiccation, causing damage to seeds or hard-

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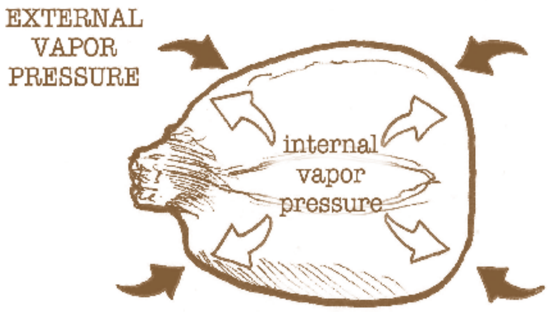
seededness. The **safe moisture content** depends on:
- desired length of storage;
- type of storage structure;
- seed type; and
- nature of packaging material used.

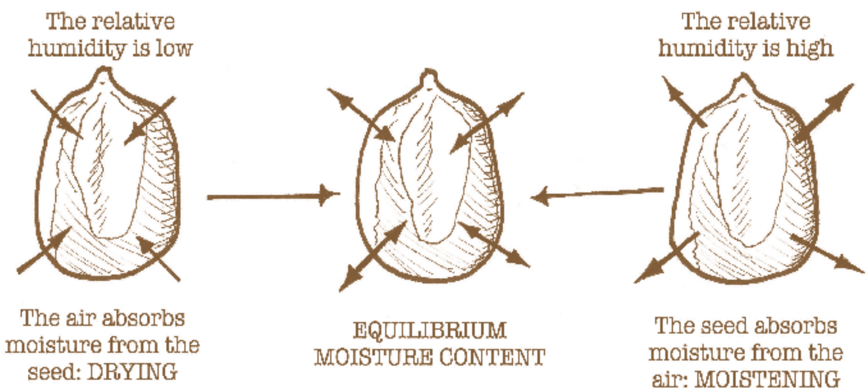
For example, under ordinary storage conditions for 12–18 months, drying to MC 10% is sufficient for cereals, while for storage in sealed containers, drying to MC 5–8% may be necessary.

Relative humidity and temperature

Relative humidity is the amount of water present in the air at a given temperature in proportion to its maximum water-holding capacity. Seed moisture content changes constantly in relation to the temperature and relative humidity of the air surrounding the seed. Seeds are hygroscopic, readily absorbing and releasing water based on the amount of water surrounding them. Seeds absorb or lose moisture until the vapour pressure of seed moisture and atmospheric moisture reach an equilibrium; at this point the seeds attain a specific and characteristic moisture content: the **equilibrium moisture content**. At equilibrium moisture content, there is no net gain or loss in seed moisture content.



Internal and external vapour pressure in maize seed



Equilibrium moisture content in maize seed

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When seed is placed in a new environment, if the relative humidity is higher or lower than the level at which its moisture content is in equilibrium, the seed will gain or lose moisture until an equilibrium is re-established with the new environment. In sealed storage, seed moisture content determines the relative humidity of the environment in the containers.
Establishment of moisture equilibrium in seeds takes time, it is not instantaneous. The **time required to establish moisture equilibrium** depends on:

- seed kind;
- initial moisture content;
- average relative humidity; and
- temperature.

Under open storage conditions, seed moisture content fluctuates with changes in relative humidity. However, normal daily fluctuation in relative humidity has little effect on moisture content.
In general, for a particular kind of seed at a given relative humidity, **equilibrium moisture content increases as temperature decreases**. Therefore, maintenance of seed moisture content during storage is a function of relative humidity and, to a lesser extent, of temperature.

Although temperature is not the controlling factor in the maintenance of seed moisture content during storage, it plays an important role in the life of the seed because **infestation by insects and development of mould increase as temperature increases.**
The higher the moisture content of the seeds, the more the seeds are adversely affected by temperature: **to maintain seed quality in storage, decrease temperature and reduce seed moisture**. Low temperatures are very effective in maintaining seed quality even when relative humidity is high. Good cold storage for seed should not exceed 60% RH.
To assess the effect of moisture and temperature on seed storage, follow the **guidelines of Harrington**:

- For every decrease of 1% in seed moisture content the life of the seed doubles. (applicable at MC 5-14%)
- For every decrease of 5 °C in storage temperature the life of the seed doubles. (applicable at temperatures of 0–50 °C)
- For good seed storage the sum of the RH % in the storage environment and the storage temperature (in °F) is 100. (applicable at temperatures ≤ 50 °F)

FACTORS CONTRIBUTING TO SEED DETERIORATION

Seed deterioration is the natural process of **decline in seed quality over time** due to exposure to challenging external factors. Multiple factors contribute to the rate of seed deterioration leading to **physical, physiological and biochemical changes** in the seeds. These changes reduce the viability of the seed and ultimately cause its death.

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Seed deterioration can start as soon as the seed reaches physiological maturity: the seed ceases to receive the full protection of the mother plant and it is exposed to the external environment in terms of moisture, temperature, biotic pressures etc. From physiological maturity through to planting, **seed deterioration is affected by a range of factors during different phases**:

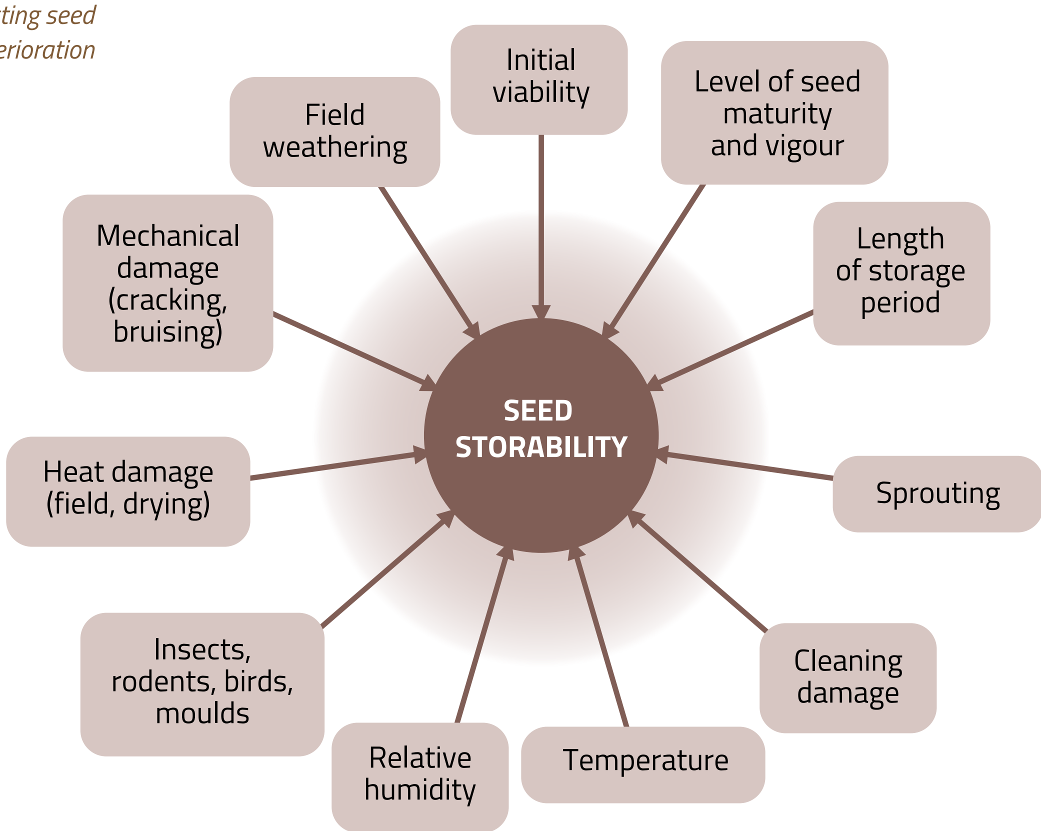
- Pre-harvest
- Harvest and post-harvest
- Warehouse storage
- Transport and transit

Pre-harvest

Seed storage starts in the field and high-quality seed requires optimum pre-harvest factors. Seed quality (germination capacity, viability, vigour and health) is affected by **field location** and by **field weathering** (exposure to adverse conditions, resulting in high relative humidity and high temperature), more specifically:

- **Rainfall** after ripening and physiological maturity, exposes the seed to hot and humid pre-harvest conditions, leading to loss in seed quality. Heavy

Factors affecting seed deterioration



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and prolonged rainfall results in increased moisture content, hastened seed respiration and possible fungal activity, causing rapid deterioration of quality.

- **Adverse environmental conditions** at seed filling and maturation can result in forced seed maturation, leading to low yields and poor quality.
- **Delayed harvest** beyond optimum maturity extends field exposure and intensifies seed deterioration.
- **Location** of seed production has a high impact not only on yield, but also on seed moisture management and overall quality (viability, germination capacity, seed vigour and health).

Weathering does not only lower seed germination, but also increases susceptibility to mechanical damage and disease infection. To avoid weathering, ensure timely harvesting to avoid prolonged exposure of the seed to moisture. Rain-free regions with low relative humidity and cool temperatures during seed maturation and harvest are most suited for seed production; regions with high rainfall, high humidity and excessively high temperatures present problems.

Harvest and post-harvest

Seed quality depends on the handling methods adopted during harvesting and post-harvest. Deterioration can occur during drying, threshing, processing, collecting, handling and transporting. Indeed, mechanical damage is a major cause of seed deterioration during harvest and post-harvest stages. Very dry seeds are prone to mechanical damage and injury (cracking and bruising), resulting in physical damage or fracturing of essential seed parts. **Broken seed-coats** permit early entry and easy access for microflora, making the seed vulnerable to fungal attack and reducing its storage potential.

Warehouse storage

Maintenance of seed quality and seed longevity in storage warehouses depends on the initial seed viability, initial moisture content and the combination of temperature and relative humidity during storage. Management practices adopted during warehouse storage (e.g. regulation of temperature and relative humidity) can only build on the initial seed quality. Deterioration of seed during storage is inevitable, but the **rate of decline depends on the seed's initial quality**:

- Seeds with high initial viability maintain their quality in storage longer than seeds with low initial viability.
- Vigorous and undamaged seeds can store longer than damaged seeds.
- Seeds developed under environmental stress conditions (e.g. drought, nutrient deficiency and high temperatures) are more susceptible to rapid deterioration.
- Seeds that are broken, cracked or bruised due to handling deteriorate more rapidly in storage than undamaged seeds (e.g. cracks create an entrance for pathogens).

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Seed heat production accelerates deterioration. Respiration occurs in all living cells (including seeds) and can lead to heat production. Aerobic respiration, occurring in the presence of oxygen, is essentially responsible for the breakdown of carbohydrates, fats and proteins to carbon dioxide, water and energy. The energy liberated during aerobic respiration is used by the cells to fuel metabolic processes and is then released as heat.

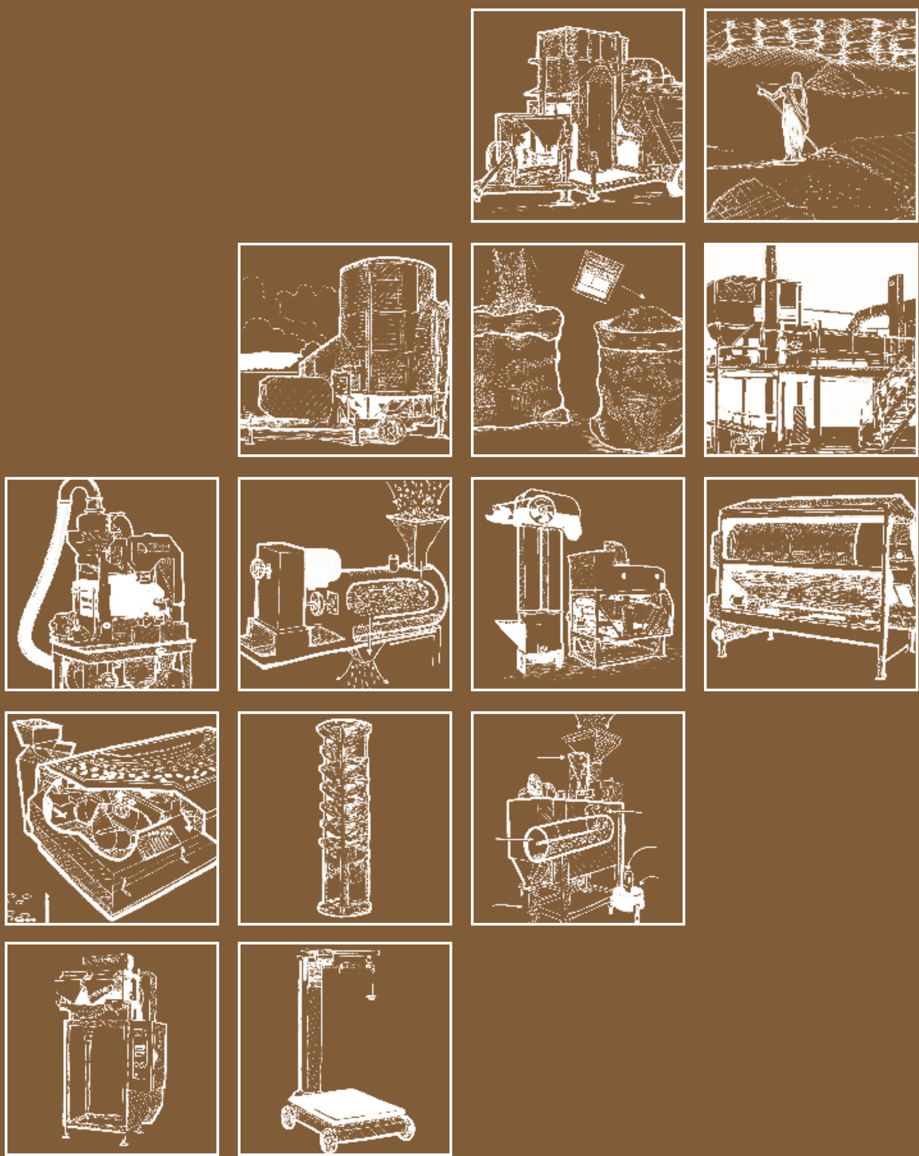
Transport and transit

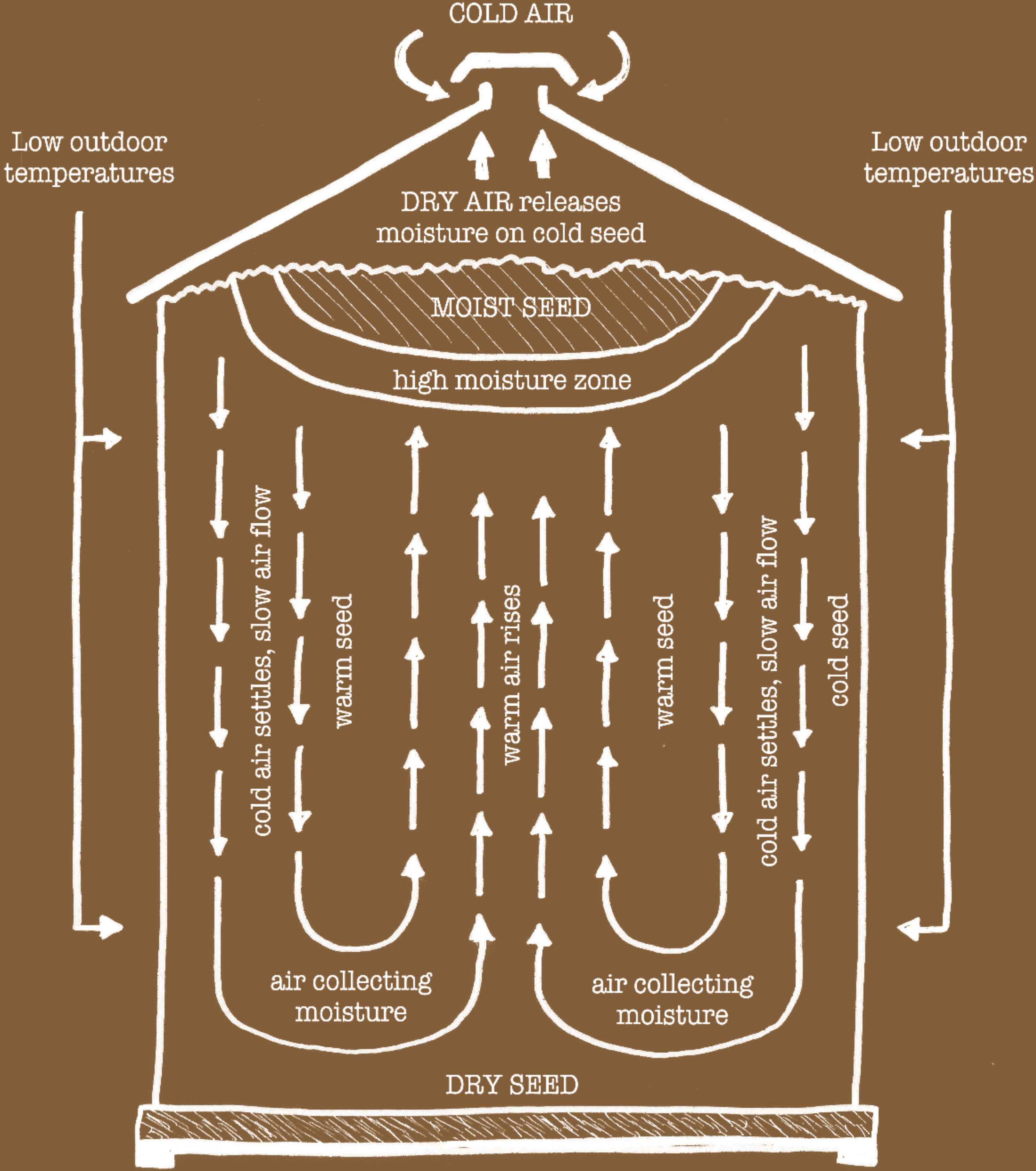
Seed is "in storage" during transport and transit, while on the premises of the trader or agro-dealer and also when with the farmer before planting. All measures should be taken to maintain the quality status of the seed at all times through to planting under good soil conditions to support germination and seedling growth. The principles of seed storage regarding handling and management of the storage environment remain the same, whether the seed is in the warehouse or in the premises of the agro-dealer or farmer.

EXERCISES AND DISCUSSION POINTS

1. When does seed storage actually begin and end? Which stage in the seed storage process do you consider most critical and why?
2. Explain why excellent storage conditions cannot improve the quality of stored seeds.
3. Why do enterprises choose to keep seed in storage for more than 1 year or season, given that seed storage is expensive and seeds eventually deteriorate regardless of the storage conditions?
4. Explain why seeds at MC 13% placed in sealed storage will deteriorate more rapidly than seeds in open storage.

② Warehouse Environmental factors affecting seed storage




COLD AIR
Low outdoor temperatures
Low outdoor temperatures
DRY AIR releases moisture on cold seed
MOIST SEED
high moisture zone
cold air settles, slow air flow
warm seed
warm air rises
warm seed
cold air settles, slow air flow
cold seed
air collecting moisture
air collecting moisture
DRY SEED

Warehouse Environmental factors affecting seed storage

2

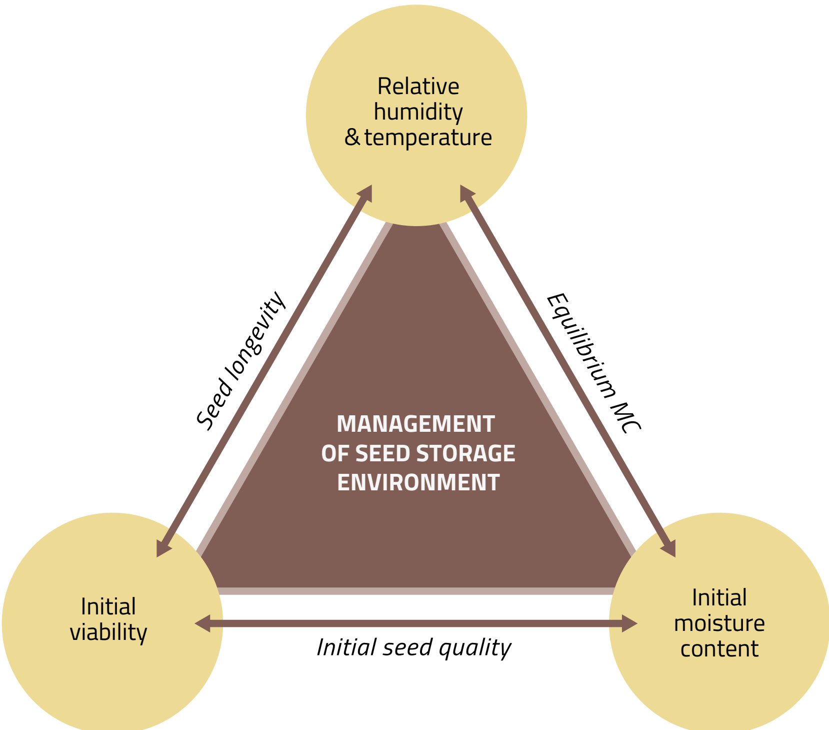
notes

The main purpose of keeping seed in storage is for planting the following season, but seed enterprises and dealers may also carry over seed lots from one year to the next for other reasons. In long-term storage, seed management aims to maintain a high viability status throughout the storage period. This chapter reviews in detail the basic principles and practices that must be observed in the storage environment to reduce the risk of a decline in viability during storage, especially when storage exceeds 1 year. While a wide range of factors potentially contribute to the rate of seed deterioration, successful seed storage depends on three primary environmental factors, known as the seed storage triangle:

- Initial seed viability
- Initial seed moisture content
- Storage temperature combined with relative humidity.

In order to evaluate seed deterioration, it is necessary to **establish initial seed quality** by testing viability (germination and vigour) and measuring initial seed moisture content.

Environmental factors affecting seed storage



notes

CRITICAL FACTORS DURING STORAGE IN THE WAREHOUSE

Most crop seed is stored before being used by the farmer; but during the storage period, it can deteriorate considerably. While good storage conditions can slow the rate of deterioration, seed germination and vigour cannot be improved, regardless of the storage facilities. Indeed, ageing, and loss of germination and vigour cannot be stopped, but they can be reduced by providing good storage conditions.

Many costly storage problems begin during field exposure, harvesting and conditioning of the seed. For example, excessive harvesting delays, mechanical damage and injuries, and improper drying techniques, which are then followed by poor storage conditions, can lead to rapid deterioration of seed germination and vigour. **Seed longevity in storage warehouses depends upon a number of factors** (described below).

Nature or kind of seed

In general, orthodox seeds are amenable to warehouse storage or *ex situ* conservation, since they can be successfully dried to low moisture content levels without damage and then packaged. Orthodox seeds, of some crops (e.g. onion) and some legumes (e.g. soybean and groundnut) are naturally short-lived and are not normally carried over from one planting season to the next. Other legumes (e.g. clover and alfalfa), cereals (e.g. corn and wheat) and cotton have a medium storage life and can be carried over from one planting season to the next if stored in the proper environment. Other seeds, including most cereals and grain legumes (e.g. rice and beans), last longer in storage. Starchy seeds have a hygroscopic nature (ability to retain moisture content) and can generally be stored for longer than seeds with a high oil or protein content.

Moisture content

The amount of moisture in the seed is probably the most important factor influencing its viability during storage. Moisture content is at the root of many problems in storage – increased metabolic activity, high respiration, fungal attack, heating and weakening – leading ultimately to death of the seed.

If the moisture content of the seed increases, it may encourage fungal growth and attack by insect pests; in general, seeds of MC > 14% deteriorate quickly. On the other hand, very low moisture content is also detrimental to seed quality, as the seed becomes susceptible to mechanical damage, resulting in physical breakage or fracturing of essential seed parts, making the seed vulnerable to fungal attack, and reducing storage potential.

Moisture content is the basis of one of Harrington's rules of thumb: "For every decrease of 1% seed moisture content, the life of the seed doubles." However, this rule is applicable within the range of MC 5–14%, because MC < 5% causes physiochemical changes in the seeds, and MC > 14% exposes the seed to insect and fungal attack.

2

notes

It is important to **harvest mature, relatively dry seeds** or – when seeds have a high moisture content – to reduce the moisture content as soon as possible after harvest. Moisture management after harvest depends on the climatic conditions during seed maturation and harvest. If the natural field environment dries the seed, most storage problems are minimized. If it does not, drying must be done artificially – a potentially complex and expensive operation.

If **wet seed** is carried over after harvest, further damage may occur during threshing and processing. It is essential to reduce seed moisture content to a safe level for storage; however, it is also important to be aware of the possible adverse effects of low moisture content. The fundamental requirement at harvest is to **ensure the moisture content is at a safe level**.

The **safe moisture content** depends on the storage period, type of storage structure, kind of seed and type of packaging material used. For example, MC 10% may be acceptable for cereal seed in open storage, but it should be reduced to 4–8% if the seed is kept in sealed containers. For safe moisture levels, see Table 1.

Maintaining low moisture content is the best prevention for all moisture-based problems. For practical purposes, MC < 13% is generally regarded as safe for storage of most seeds. The lower the moisture content, the longer seeds can be stored – provided the moisture level can be controlled throughout storage. The more this can be achieved in the natural storage environment, the better.

Seeds stored at MC > 13% can exhibit increased respiration, heating and fungal invasion, resulting in poor seed viability and vigour. The higher the moisture content, the worse the problem if the seed is not dried immediately. Seed moisture content of about 6% is optimum for storing most crop species and attaining maximum longevity.

Table 1. Safe moisture content of selected seeds

Crop	Maximum moisture content %
Millet	12
Rice (paddy)	13
Cowpea	9
Pulses	9
Maize	12
Sorghum	12

notes

Initial viability of seed

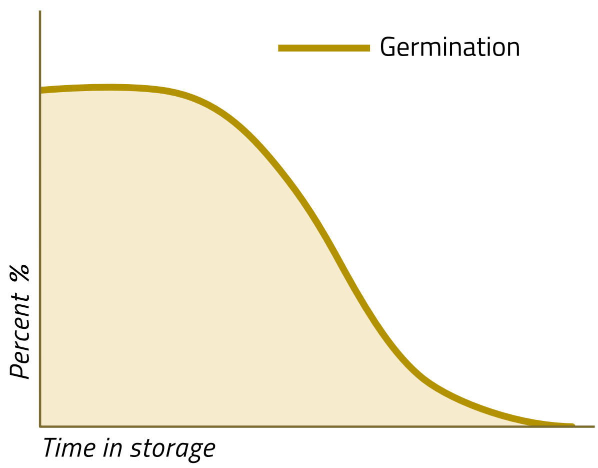
Seeds with high initial viability maintain their quality for longer than seeds with low viability. The dry and cool conditions prevailing in certain locations during seed maturation and harvest mean that freshly harvested seeds reaching very high viability and germination capacity levels. This **high initial viability** can be key for the **successful and sustainable supply of high-quality seed**. Test for germination right after harvest to determine which seed lots have high viability (good candidates for storing) and which have low viability (higher risk in storage).

The quality of any seed decreases with time and **deterioration is inevitable**. The sigmoid survival curve in Figure 14 illustrates the general pattern of seed deterioration. The survival curve for dry seeds stored under favourable environmental conditions is divided into three distinct parts:

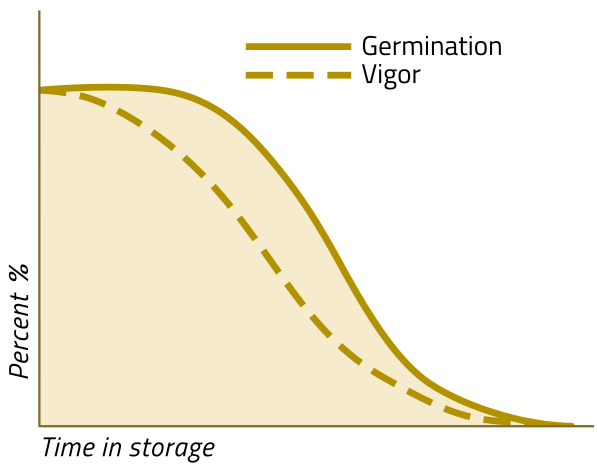
1. The seed is vigorous and the decline in life functions proceeds slowly. Germination (viability) remains unchanged for a period during storage until this stage ends at a survival level of 90–75%.
2. Deterioration and decline in germination proceed very rapidly to a survival level of 25–10%.
3. Deterioration slows again and continues gradually until all seeds are dead.

Figure 15 shows the fundamental relationship between seed vigour and seed germination. As seeds age, both germination and vigour decline, first slowly and then more rapidly as the end of the seed's useful life is reached. The curves for vigour and viability are very similar, except that vigour declines faster than germination.

Survival curve (germination) of seed in storage



Survival curve (vigour) of seed in storage



Temperature and relative humidity during storage

notes

Regardless of the method used, successful seed storage depends primarily on the percentage of relative humidity and temperature in the storage facility. Since deterioration slows when seeds are stored under cool and dry conditions, temperature and relative humidity should be considered together when planning for safe storage. This combined effect is the basis of Harrington's rule of thumb: "For good seed storage the sum of the % relative humidity in the storage environment and the storage temperature (in °F) is 100 (applicable at temperatures ≤ 50 °F)." The effects and interactions of temperature, relative humidity and moisture content on stored seed and its associated pests and diseases are complex. Temperature and relative humidity affect the amount of moisture in the air and influence the equilibrium moisture content of seed. The **initial condition of the seed** (moisture content and temperature) is usually the overriding factor affecting storage; it **influences and even directs events during storage** and may sometimes lead to spoilage and self-heating.

Effects of temperature and moisture content on storage duration

There is an intricate relationship between storage temperature and seed moisture content. The ideal condition for seed storage is usually the combination of **low seed moisture content** and **low storage temperature**.

Both factors affect the risk of spoilage of stored seed: high moisture content produces humidity, encouraging enzyme activity and the growth of storage fungi; moderate-to-high temperatures promote fungal growth and insect development, and enhance enzyme activity. Therefore, the rate of enzyme activity and of micro-organism (fungal) and insect growth and development are a function of both moisture content and temperature.

Dry mature seeds in storage have a very low rate of respiration, as they are largely dormant. In contrast, freshly harvested, immature seeds or seeds with a high moisture content have a much higher rate of respiration, because the seeds are still metabolically active and moulds on the surface and within the seed-coat are actively respiring. **Seed and mould respiration produce heat, manifested as an increase in grain temperature.**

Continuing growth of these organisms in seeds results in spoilage. According to Harrington, for each 1% rise in moisture content and for each 5 °C rise in temperature, the storage life of seed is halved. This makes seed moisture by far the most important factor affecting seed longevity due to its interrelationship with or influence on both humidity and temperature and the final impact on storability.

Figure 16 illustrates the effect of temperature (°C) and moisture content (% water, wb) on the safe storage time of cereal seeds. Moisture content and temperature influence enzyme activity and micro-organism and insect growth, with the following consequences:

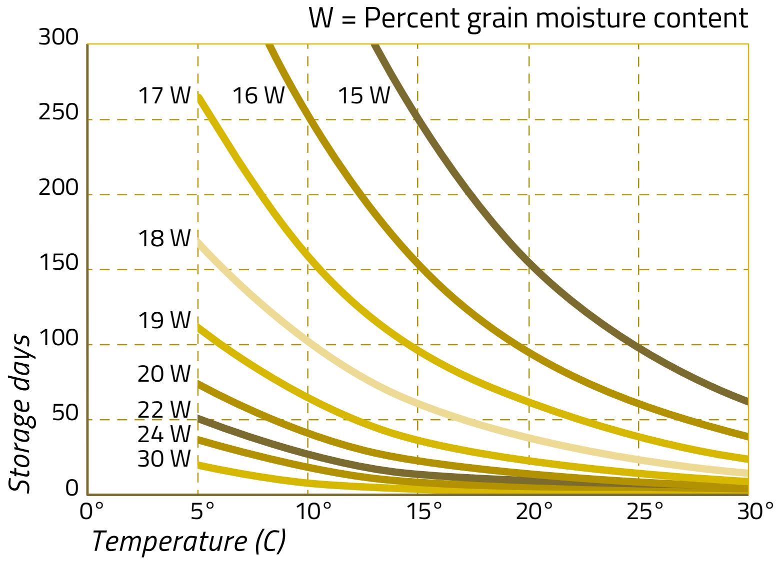
- Damp seed stored at warm temperatures spoils rapidly.
- Dry seed stored at cool temperatures can be safely stored for a long period.
- Cereal seed harvested and stored at high moisture content, especially in a warm environment, deteriorates.

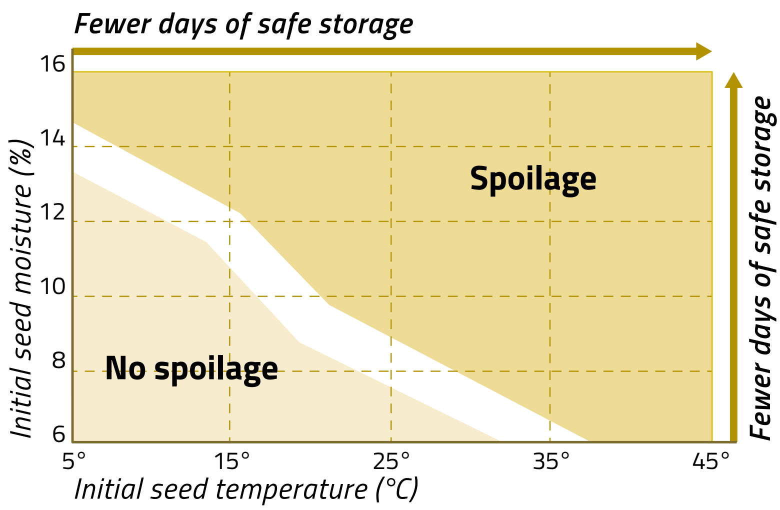
notes

Effects of temperature and moisture content combinations on seed spoilage

Each crop seed has its own particular storage characteristics and the safe storage of seeds depends largely on moisture content, temperature and the length and duration of storage. The seed storage time chart in Figure 17 illustrates how initial seed moisture content and initial seed temperature impact safe storage of seed (particularly for bulk seed stored in bins). Based on the initial moisture content and temperature of a crop seed at binning, it is possible to predict its future keeping quality or storability over a certain length of time under varying temperatures and moistures. Moisture–temperature combina-

Effect of temperature and moisture content on seed storage





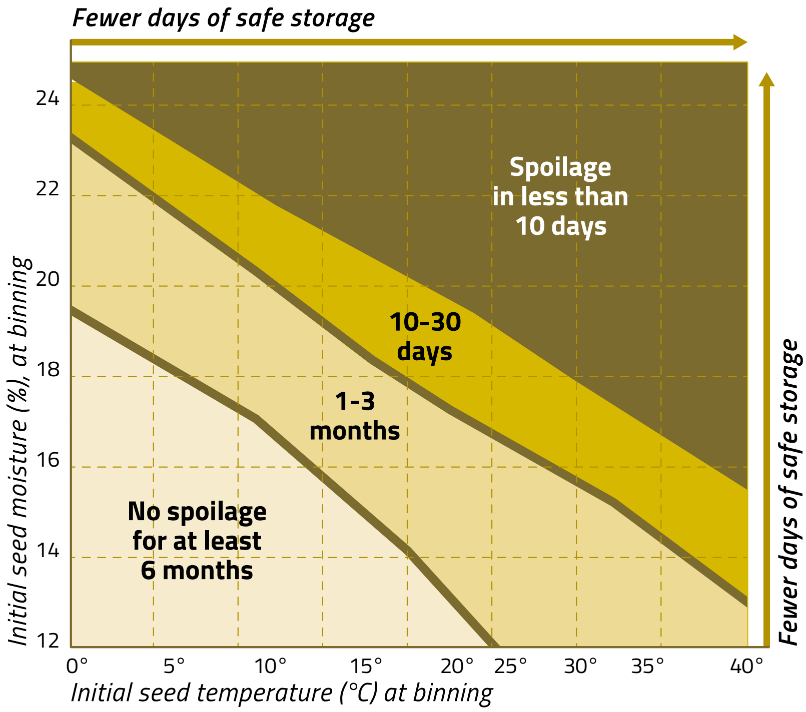
2

tions are shown for storage of seed, resulting in either spoilage or no spoilage over 6 months.

- If the seed is binned at > 25 °C, or if pockets of immature seeds or green weed seeds are present, MC 9% is too high for long-term, safe storage.
- If the seed is binned at MC ≤ 8% and cool temperature, storage may exceed 6 months.
- If the seed is carried over during the summer months in bulk or bin storage and exposed to extremely high temperatures, it must be low in moisture (MC 8–10%) when placed in storage; it also requires protection from insect attack.

Note that there is no absolute line between "no spoilage" and "spoilage" of seed in storage. If the temperature or moisture content of a given seed falls within the spoilage area of the chart, take steps to reduce one factor or both. To move seed from "spoilage" to "no spoilage", either dry the seed (reduce moisture content) or cool it by aeration (reduce seed temperature). It is also possible to reduce moisture content by delaying harvesting (to allow further drying on the plant in the field) or by artificially drying the seed.
Depending on the moisture–temperature combination, the spoilage area can be subdivided into different subspoilage areas with varying periods required for seed spoilage.

notes



Effect of moisture content and temperature on safe seed storage in bins

notes

Effect of temperature on moisture migration in stored seed

Even when the initial moisture content and the temperature of seed are low, rapid deterioration can occur depending on the storage method and the temperature of the **external environment** (much hotter or cooler). High moisture spots can develop because of moisture migration during storage, regardless of the moisture content at which the seed was binned. Temperature differences within a seed bin cause moisture migration from warmer to colder areas and, if air movement is insufficient to remove the moist warm air from the storage bin, conditions may become favourable for rapid grain spoilage.

Moisture migration in cold weather

Even when seeds are stored dry, moist spots may develop as a result of moisture migration within the bulk or when rain or cold air enter through roof vents and other openings. High moisture spots usually develop when there is a sharp fall in outside temperature, typically during late autumn to early winter in temperate countries, triggering the following process:

- Seed near the inner perimeter and roof of the bin cools as the outside air temperature decreases.
- Warm seed in the centre of large, non-aerated bins remains close to the harvest temperature.
- Air moves up through the warm bulk at the centre because of this temperature difference.
- Moist, warm air comes into contact with cold surfaces or objects, resulting in condensation.
- Warm moist air moves upwards and the cooler grain at the top of the bulk absorbs moisture from the air, or the moisture may condense or freeze on the underside of cold roofs.

Moist spots coupled with mould growth result in heating within the seed bulk, leading in turn to spoilage. Damp seed rapidly heats and spoils unless the seed temperature is controlled. Therefore, **cooling is imperative** when dealing with high moisture seed in storage. Aeration may be adopted to cool damp seed and maintain uniform temperatures throughout the bin in order to **delay or prevent the formation of high moisture areas and hot spots.**

Moisture migration in warm weather

Temperature differences between seed and the outside air can create high moisture areas within the bin in warm weather. If the seed in the bin is colder than the outside air, moisture migrates to the bottom centre of the bin; when it is warmer than the outside air, moisture migrates to the top centre.

Effects of relative humidity in determining storage life of seeds

Relative humidity describes how close the air is to saturation; it is measured as a percentage. At RH 100%, the air is saturated. At RH 50%, the air contains half the water vapour required to reach saturation. If the amount of water vapour in the air increases, the relative humidity increases, and if the amount of water

2

vapour in the air decreases, the relative humidity decreases. The formula for estimating relative humidity is as follows:

$$\text{Relative humidity} = \frac{\text{Vapour pressure}}{\text{Saturation vapour pressure}} \times 100\%$$

notes

In other words, relative humidity is a **relative measure of the amount of water vapour in the atmosphere**. It depends on both the amount of water vapour in the air (vapour pressure) and the amount of water vapour the air can hold (saturation vapour pressure) at a given temperature.

Relative humidity is dependent on air temperature:

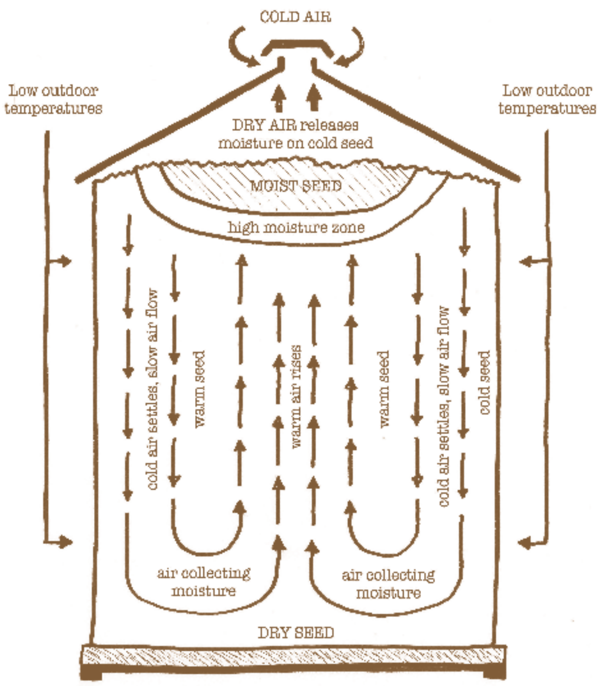
- If the water vapour content remains constant and the temperature drops, relative humidity increases (as cold air requires less moisture to become saturated than warm air).
- If the water vapour content remains constant and the temperature rises, relative humidity decreases (as warm air can hold more moisture than cold air).

Relative humidity is higher during daytime than at night. It is normally not advisable to ventilate seed at night, when the air may reach saturation and dew point, resulting in increased seed moisture content during aeration.

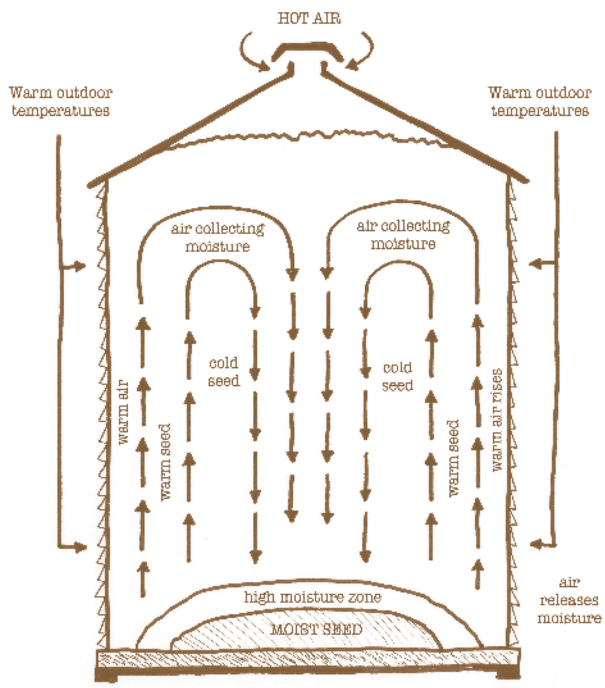
Relative humidity varies according to season and climate zone:

- In temperate regions, relative humidity is higher in winter than in summer, because cold air holds substantially less moisture than warm air and it is easier to saturate a parcel of cold air.

Moisture migration in storage bin in cold weather



Moisture migration in storage bin in hot weather



notes

- In non-temperate regions, relative humidity is higher in the rainy season than in the dry season, because the amount of water vapour in the air increases during the rainy season. Note that periods of high relative humidity in the rainy season are often accompanied by periods of low temperature, decreasing the negative effect of high relative humidity.
- In coastal areas, high relative humidity is a permanent feature.

Seed for commercial purposes is usually packaged and placed in short- or long-term storage under conditions of ambient humidity. As sacks are porous and allow air to circulate readily through the crop, it is generally acceptable to allow the grain to be stored at MC 1–2% higher than the moisture content in bins or containers with non-porous walls. Regardless of the storage conditions, the seed moisture content fluctuates with the changes in relative humidity until it eventually reaches an equilibrium with the moisture or humidity in the surrounding air. Given the low relative humidity in the dry season, it is possible that the seed moisture content is < 13% and in some cases < 10%. It probably increases somewhat during rainy months due to high relative humidity. The magnitude of the fluctuations varies depending on:
- storage method;
- type of bag used; and
- kind of seed.

The above factors all influence the migration of moisture from the air to the seed and vice versa.
Monitor the moisture of seeds in storage:
- **directly** – measuring the moisture content of the seed; or
- **indirectly** – measuring the RH or water vapour inside the store using a hygrometer.

Tables 2–4 show the equilibrium moisture content of several crop species at different relative humidity levels. The **values are indicative** and should not be regarded as exact equilibrium moisture content values.

Table 2. Equilibrium moisture content of vegetable seeds at various relative humidity levels and approximately 25 °C (wb)

	Moisture content at indicated relative humidity (%)						
Vegetable	10	20	30	45	60	75	80
Broad bean	4.2	5.8	7.2	9.3	11.1	14.5	17.2
Cabbage	3.2	4.6	5.4	6.4	7.6	9.6	10.0
Carrot	4.5	5.9	6.8	7.9	9.2	11.6	12.5
Eggplant	3.1	4.9	6.3	8.0	9.8	11.9	-
Lettuce	2.8	4.2	5.1	5.9	7.1	9.6	10.0
Okra	3.8	7.2	8.3	10.0	11.2	13.1	14.5
Onion	4.6	6.8	8.0	9.5	11.2	13.4	13.6
Pepper	2.8	4.5	6.0	7.8	9.2	11.0	12.0
Radish	2.6	3.8	5.1	6.8	8.3	10.2	-
Spinach	4.6	5.0	7.8	9.5	11.1	13.2	14.5
Tomato	3.2	5.0	6.3	7.8	9.2	11.1	12.0
Watermelon	3.0	4.8	7.6	7.6	8.8	10.4	11.0

Table 3. Equilibrium moisture content of cereal seeds at various relative humidity levels and approximately 25 °C (wb)

	Moisture content at indicated relative humidity (%)						
Cereal	15	30	45	60	75	90	100
Barley	6.0	8.4	10.0	12.1	14.4	19.5	26.8
Maize	6.6	8.4	10.4	12.9	14.7	18.9	24.6
Oats	5.7	8.0	9.6	11.8	13.8	18.5	24.1
Rice	5.9	8.6	10.7	12.8	14.6	18.4	-
Rye	7.0	8.7	10.5	12.2	14.8	20.6	26.7
Sorghum	6.4	8.6	10.5	12.0	15.2	18.8	21.9
Wheat	6.6	8.5	10.0	11.5	14.1	19.3	26.6

Table 4. Equilibrium moisture content of other crop seeds at various relative humidity levels and approximately 25 °C (wb)

	Moisture content at indicated relative humidity (%)									
Crop	10	20	30	40	50	60	70	80	90	100
Cotton	3.7	5.2	6.3	6.9	7.8	10.1	10.1	12.9	19.6	-
Flax	3.3	4.9	5.6	6.1	6.8	7.9	9.3	11.4	15.2	21.4
Pea	5.3	7.0	8.6	10.3	11.9	13.5	15.0	17.1	22.0	26.0
Groundnut	3.0	3.9	4.2	5.1	5.9	7.0	8.5	11.1	17.2	-
Rape	3.1	3.9	4.5	6.0	6.0	6.9	8.0	9.3	12.1	15.5
Soybean	-	5.5	6.5	7.1	8.0	9.3	11.5	14.8	18.8	-
Sugar beet	4.4	6.3	8.0	9.4	10.7	12.0	13.3	16.6	20.5	22.5

notes

Each crop seed has a characteristic sigmoid-shaped equilibrium curve obtained by plotting moisture content against relative humidity at a specific air temperature. Figure 21 shows the relationship between atmospheric relative humidity and moisture content of vegetable seed. Once the **isotherm** (RH/MC relationship at a given temperature) is known for a commodity, it is sufficient to measure the relative humidity of the air in equilibrium with the commodity in order to estimate the moisture content of the stored seed. The chart enables the estimation of the moisture content of stored seed at given levels of ambient relative humidity in the store.

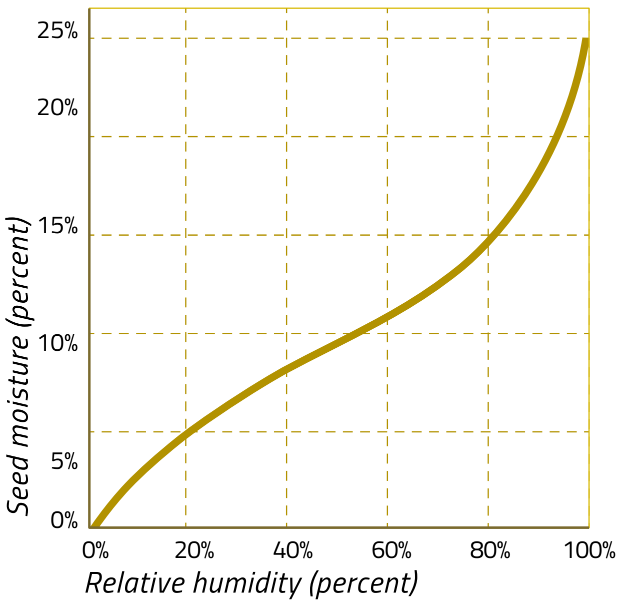
At RH 75% and MC 13%, there is increased respiration and fungi become a significant problem. At RH > 75%, the moisture content rises dramatically and seed storage is not safe. The **maximum acceptable level for storage** of any sample is with the equilibrium moisture value at RH 75% and 25 °C.

At the same humidity, cereal seeds with a relatively high content of carbohydrate have higher equilibrium moisture content than seeds rich in oils. For example:

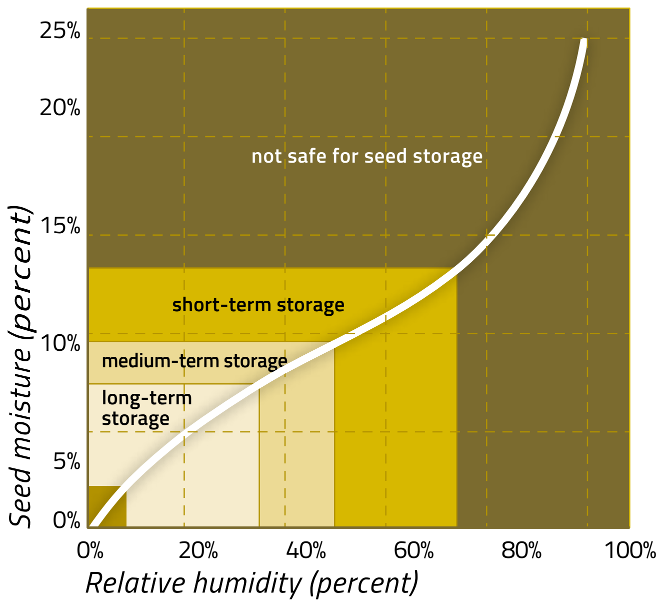
- at 25 °C and RH 45%, the equilibrium moisture content of maize is 10%, and of peanut it is 5%;
- at 25 °C and RH 90%, the equilibrium moisture content of maize is 19%, and of peanut it is 11.

The difference in moisture content is due to variation in the chemical composition of the seed (carbohydrate versus oil content).

Isotherm showing relationship between seed moisture content and relative humidity



Isotherm showing duration of seed storage



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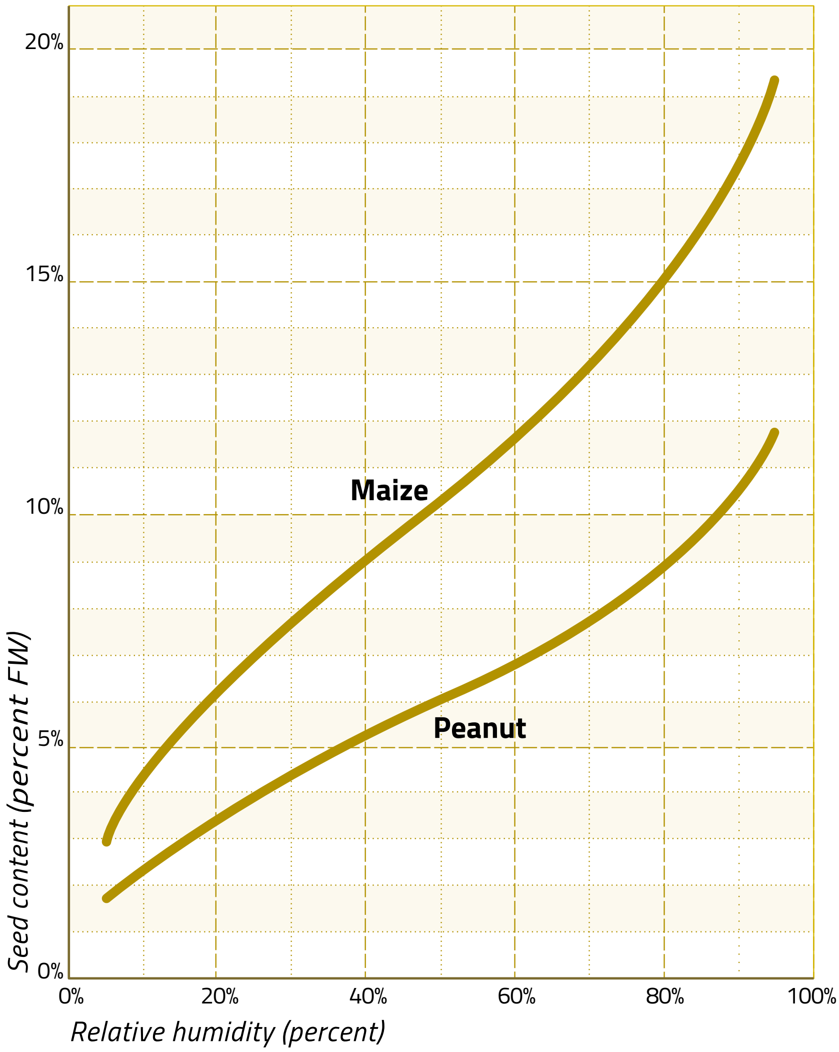
FACTORS AFTER SEED LEAVES THE WAREHOUSE

notes

Biologically, seed storage does not end when the seed leaves the warehouse. Problems can begin the moment the seed is taken outside the door of the storage facility, even if the pre-storage phase and storage phase were managed perfectly. Potential problems:

- Poor handling during transit leading to deterioration of seed.
- Non-ideal conditions on farmer's premises for keeping seed until planting.
- Soil moisture insufficient for germination but sufficient for seed deterioration.

Relationship between moisture content and relative humidity for maize and peanut seeds

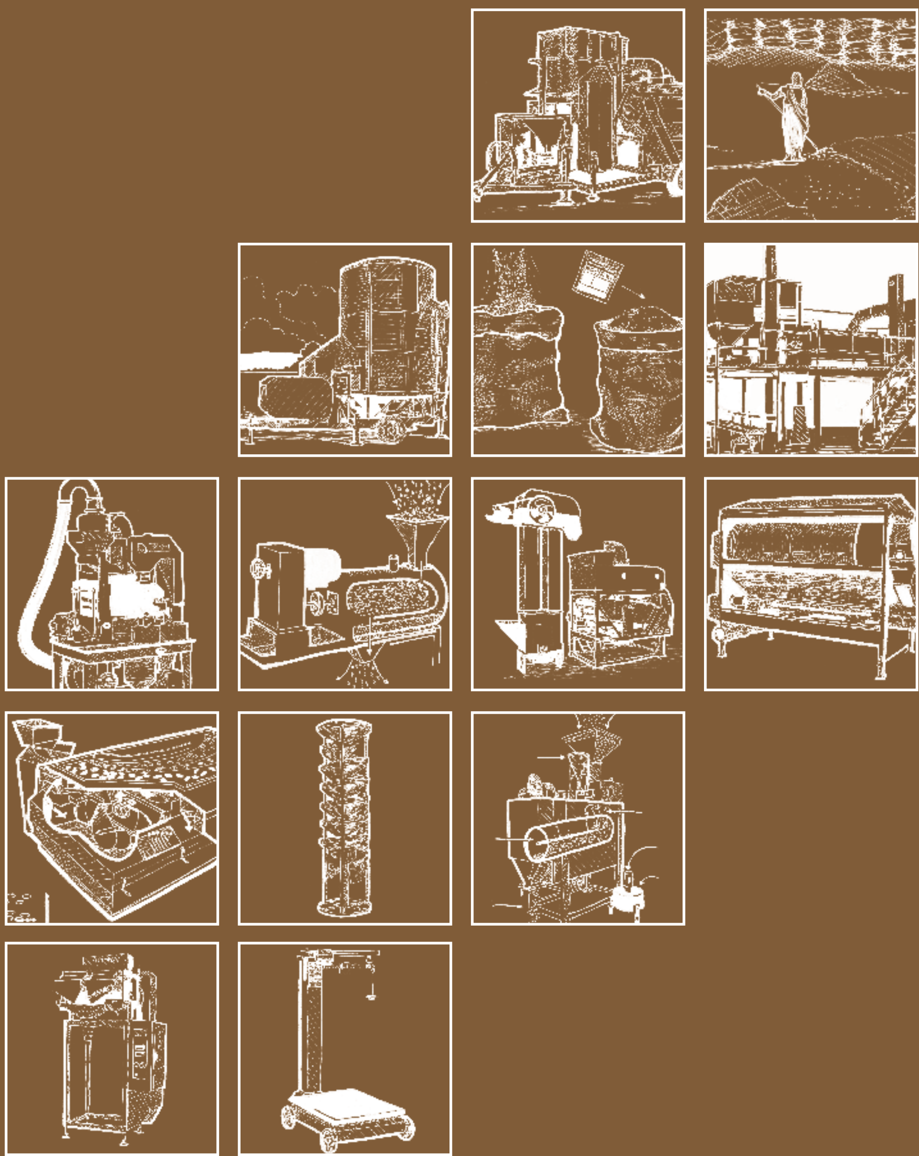


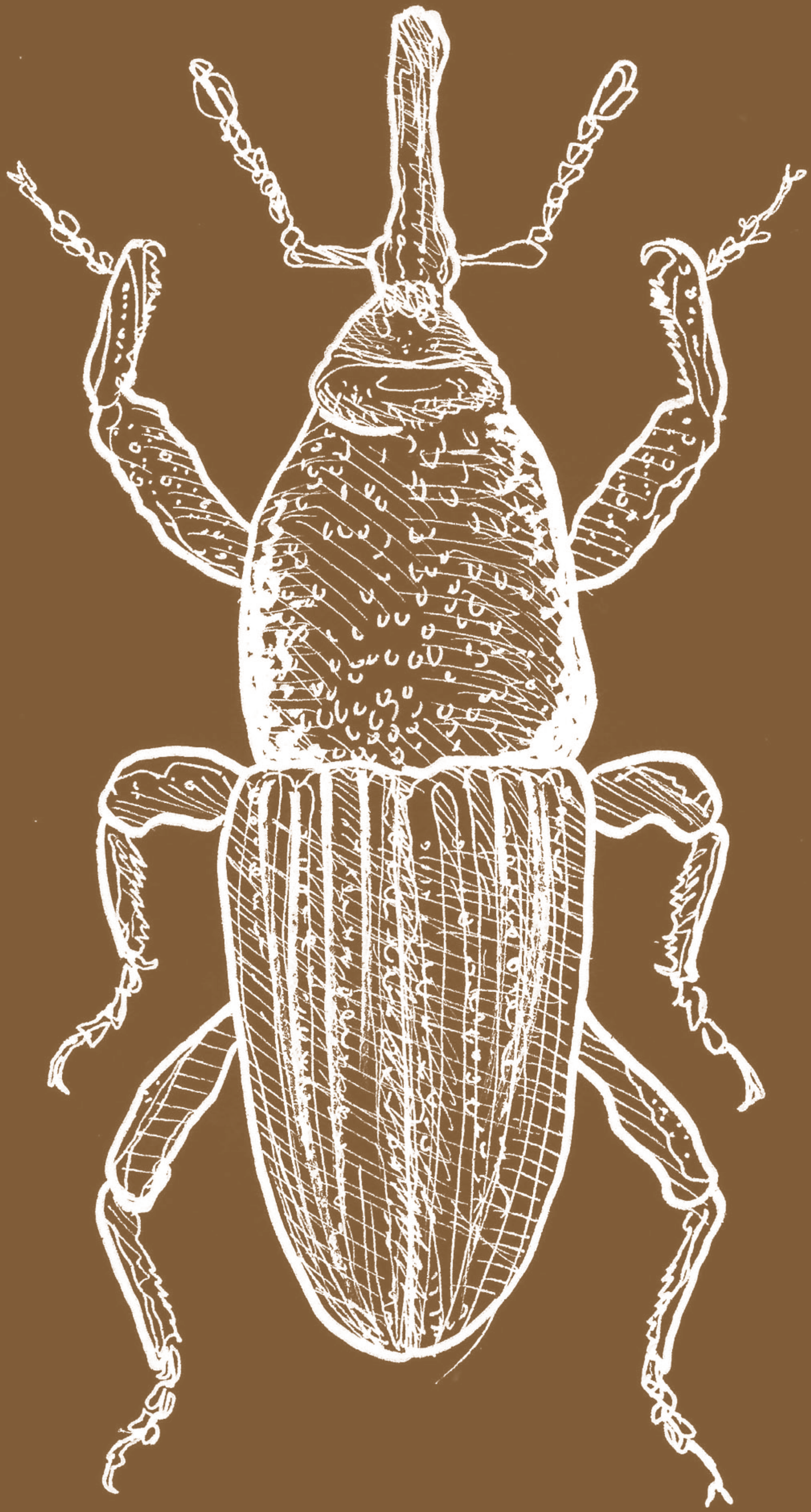
notes

EXERCISES AND DISCUSSION POINTS

1. Explain the relationship between storage temperature and seed moisture content. Why is seed moisture a far more important factor affecting seed longevity in storage?
2. Discuss the relationship between germination and vigour for seeds kept in storage. Why is it important that both parameters are as high as possible when seeds are put into storage?
3. Illustrate the relationship between atmospheric relative humidity and moisture content of a particular seed crop. Discuss the different segments of the plot obtained.
4. Explain how high moisture areas and hot spots develop within bulk seed stored in metal bins under hot and cold atmospheric conditions. What are the negative effects of these spots and how could they be controlled?

3 Storage pests and their control





Storage pests and their control

3

notes

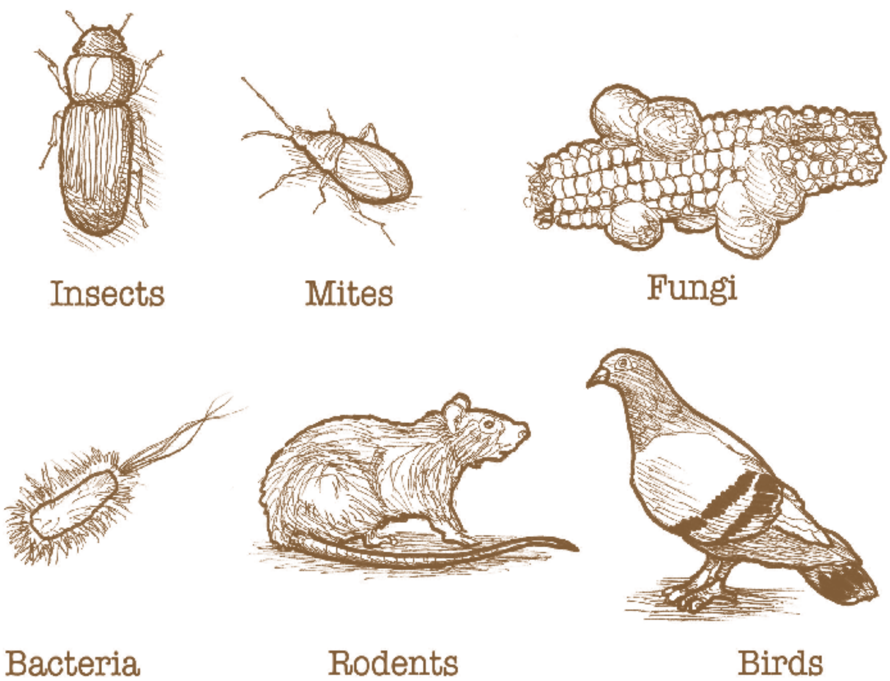
It is estimated that 25–33% of the world grain crop is lost each year during storage due to pests. The main storage pests of crop seeds are insects, pathogens (bacteria and fungi), mites, rodents and birds. They **feed on, spoil or contaminate stored seed**, resulting in significant **economic loss** and **reduction in seed quality** (even complete loss). It is important to recognize and control storage pests to prevent them from causing serious damage to seeds in storage.

INSECT PESTS OF STORED GRAIN

A significant part of the grain losses (whether economic or quality) in grain during storage is due to insect attack. The majority of insect pests are either **beetles (Coleoptera)** – by far the largest group – or **moths (Lepidoptera)**. Many storage insects feed on grain embryos, resulting in reduced protein content of the grain or a lower percentage of seeds that can germinate.

Insects that attack cereal grains and pulses are usually divided into **primary pests** and **secondary pests**. Primary grain insects attack whole, unbroken grains; secondary pests attack only damaged grain, grain dust and milled products.

It is fundamental to **identify insects** in stored seed or grain to determine whether control is needed and which methods are most economical.



Types of seed storage pests

notes

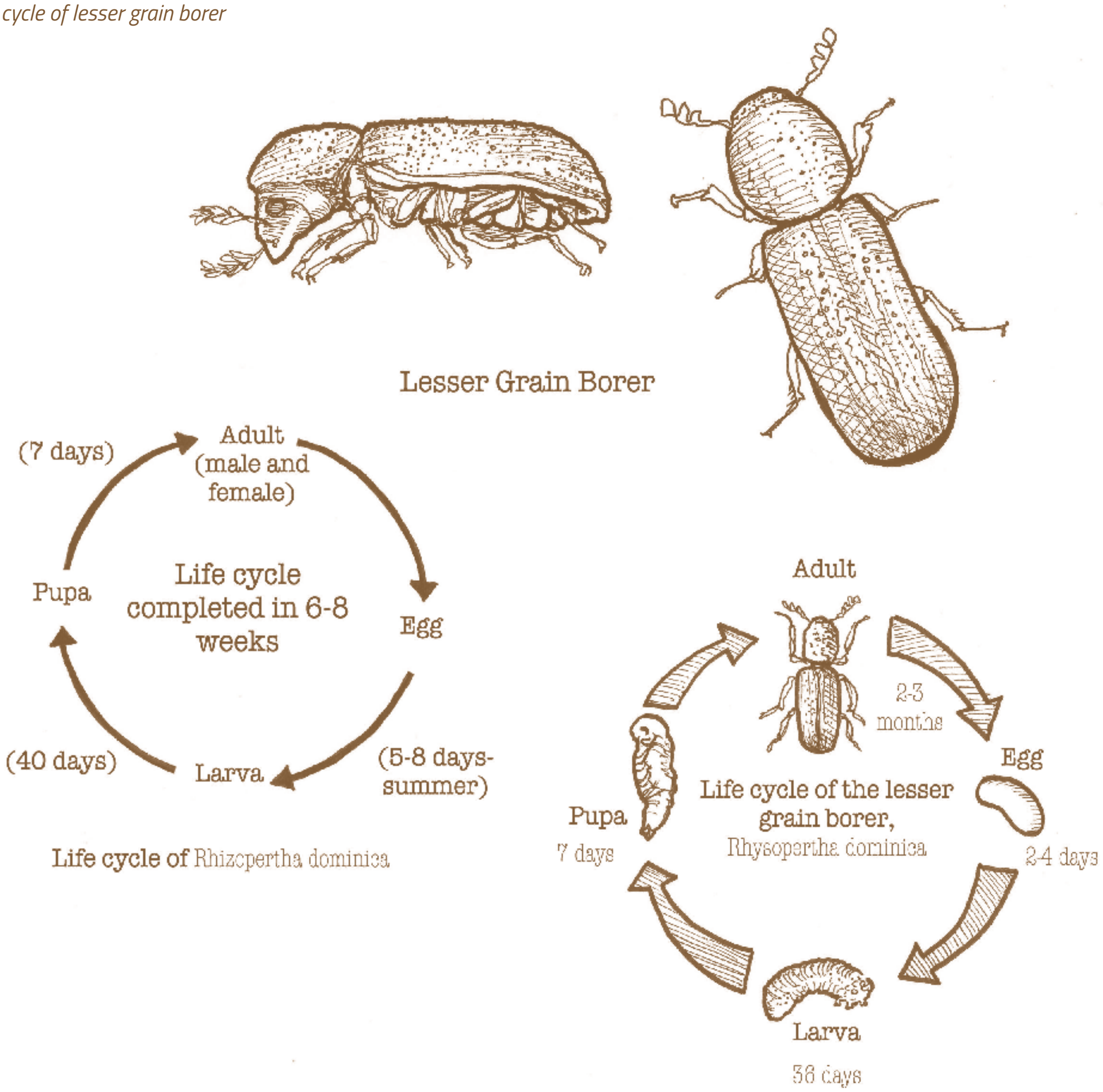
Primary insect pests

Primary pests **attack and breed in undamaged cereal grains and pulses**, but rarely feed on milled or ground foodstuffs. Primary pests are usually more destructive than secondary pests, especially in **short-term storage**. Major primary storage insect pests are described below.

Lesser grain borer (Rhyzopertha dominica)

A member of the Coleoptera order, the beetle species, *Rhyzopertha dominica,* is known as the lesser grain borer or stored grain borer. It is found almost worldwide and is the most serious pest of stored cereal grain in many countries and a major pest of groundnuts. Dark brown, cylindrical and about 3 mm long, its head is hidden by the thorax when viewed from above.

Life cycle of lesser grain borer



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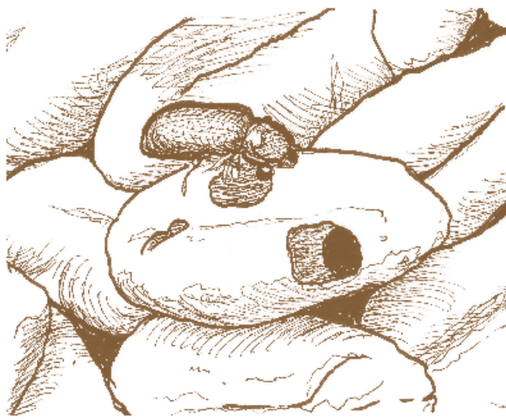
notes

Life cycle: Females lay ≤ 500 eggs scattered loosely through the grain. The eggs hatch to produce curved white larvae with brown heads and three pairs of legs. The larvae burrow into slightly damaged grains and eat out the starchy interior. After pupating, the adults emerge from the grain. The life cycle is 3–6 weeks depending on the temperature. Adults may live ≤ 2 months.

Damage:
- Adult chews grain voraciously causing damage, facilitating infestation by secondary pests.
- Emerging adults make large irregular holes in the grain when exiting.
- A strong flyer, it can rapidly migrate to begin new infestations

Seed damaged by lesser grain borer



Grain weevil

A member of the Coleoptera order, distribution varies depending on the type (granary/rice/maize). It undergoes complete metamorphosis with egg, larval, pupal and adult stages. The grain weevil has the following features:
- cylindrical body and pronounced rostrum (snout) equipped with biting mouthparts (used by females as a boring tool);
- hard and leathery forewings meeting along the midline of the dorsal surface;
- membranous hindwings (sometimes lacking);
- elbowed, clubbed antennae set on the rostrum;
- 4-segmented tarsi; and
- well-developed thorax.

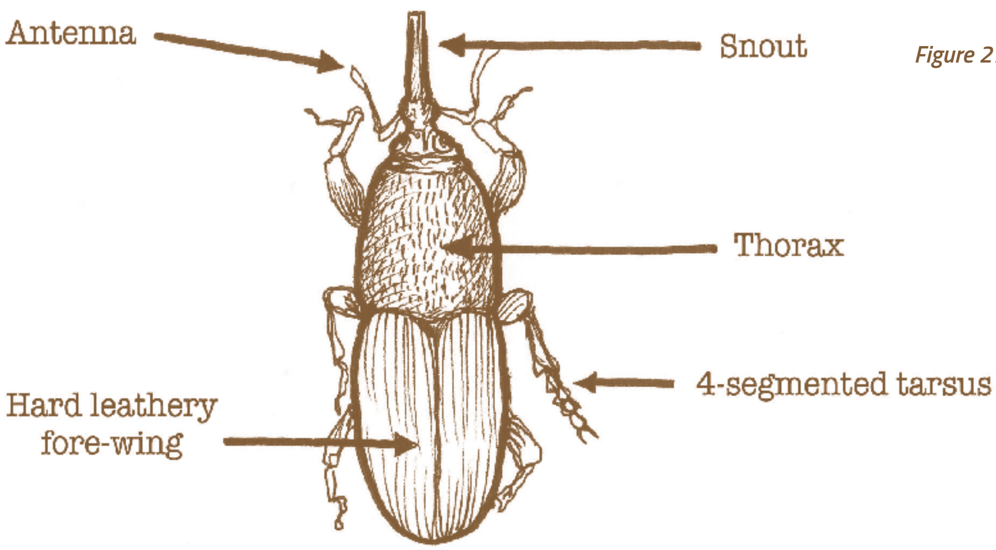


Figure 27. Grain weevil

notes

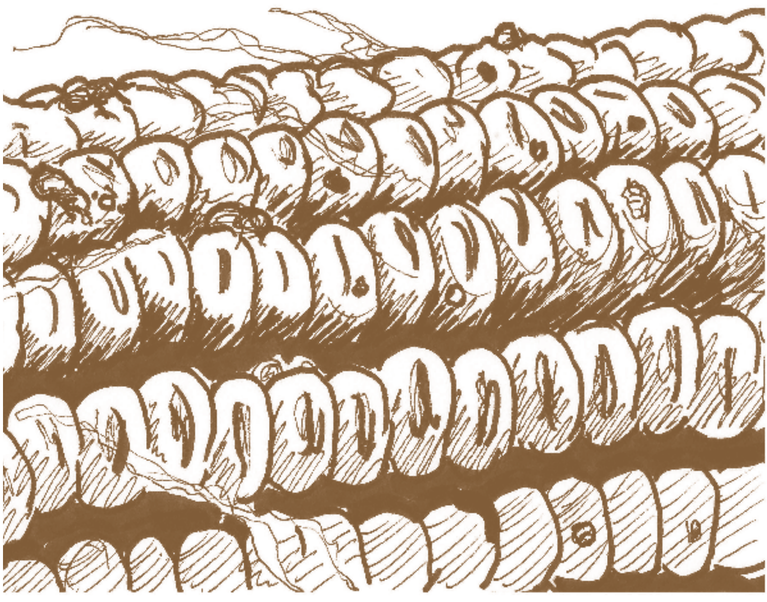
There are three types of grain weevil:

- Granary weevil (*Sitophilus granarius*):
  - One of the most destructive pests of stored grain in the world.
  - Adapted to temperate and warm–temperate climates, as both adults and larvae are cold hardy.
  - Infests transport vehicles, storage buildings and sacks.
  - Small, shiny, dark brown–black, adult is about 4 mm long; characteristic rostrum (snout with biting mouthparts at the front) protrudes from head; two club-like 8-segmented antennae; prothorax with distinct oblong/oblong–oval punctures; hindwings absent.
  - Adult lays ≤ 450 eggs singly in holes chewed in cereal grains. Each egg hatches into a white, legless larva, which eats the grain from the inside. The larva pupates within the grain and the adult then chews its way out. Exit holes are a characteristic sign of weevil damage.

- Rice weevil (*Sitophilus oryzae*):
  - Widely distributed in tropical and subtropical areas, often carried to temperate areas on imported commodities, breeds in stored grain, less cold hardy than the granary weevil.
  - Dark brown to nearly black (but less shiny than the granary weevil) with four clearly defined reddish spots on the elytra; adult is on average 2.5 mm long; characteristic rostrum (snout with biting mouth parts at the front) protruding from its head; two club-like 8-segmented antennae; prothorax with round or irregular punctures; hindwings present.
  - Adult lays ≤ 450 eggs singly in holes chewed in cereal grains. Each egg hatches into a white, legless larva, which eats the grain from the inside. The larva pupates within the grain and the adult then chews its way out. Exit holes are characteristic signs of weevil damage.
  - Winged (unlike the granary weevil), it may occasionally fly.

Wheat seed damaged by grain weevil

Maize seed damaged by grain weevil



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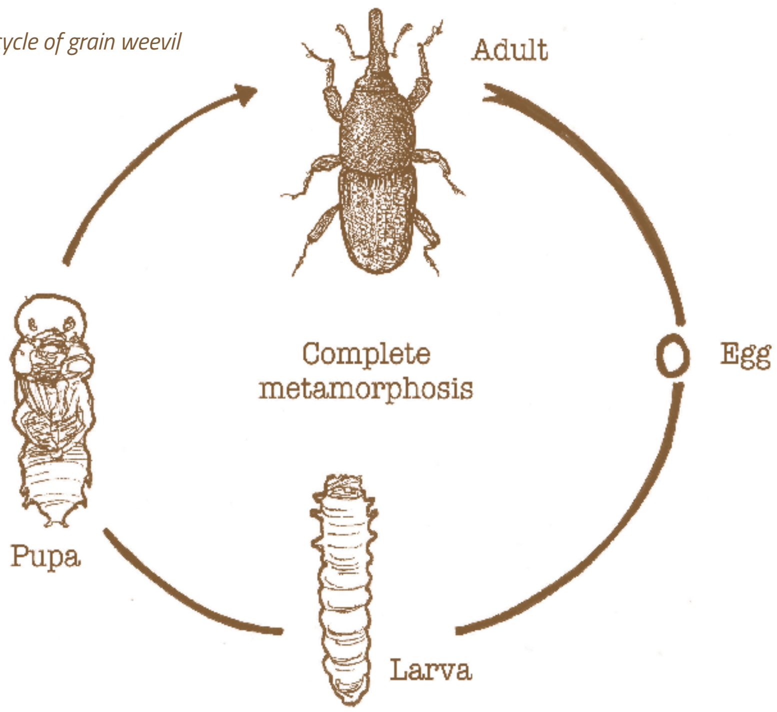
- Maize weevil (*Sitophilus zeamais*):
  - Widely distributed in tropical and subtropical areas, often carried to temperate areas on imported commodities, it breeds on maize in the field, less cold hardy than the granary weevil.
  - Very similar in appearance and characteristics to the rice weevil, except longer with adults reaching a length of 3–3.5 mm (average 3 mm).

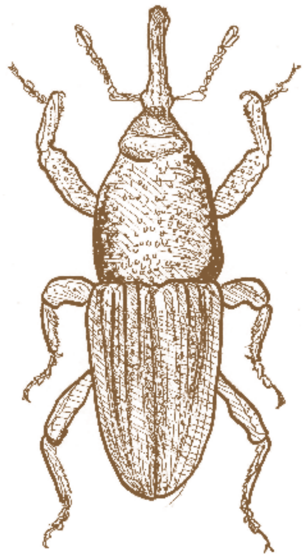
Life cycle: The weevil breeds in grain with MC > 9.5% and at temperatures of 13–35 °C. The female lays 2–3 eggs per day depending upon temperature and humidity, placing each one in a small hole bored in the grain and sealing it with a mucilaginous plug of saliva. The eggs hatch and the small, white, legless larvae feed on the endosperm of the grain. Only one larva develops in small grains (e.g. wheat and rice), but large grains (e.g. maize) support the development of several larvae. Larvae are never free-living and develop entirely within the grain. The larvae pupate within the grain and the complete life cycle takes about 1 month. The adults emerge and live for about 8 months.

Damage:
- The weight and quality of the grain decrease due to the larvae and adults feeding on the endosperm.
- The seed may germinate (since the embryo may not be affected), but the seedling will be weak and vulnerable to attack by moulds, bacteria and other insects.
- The activity of the insects can lead to heating of the grain, which accelerates insect development and makes the grain liable to caking, moulding and even germination. If high temperatures are reached, they may kill the insects.
- The emerging adults make large holes in the grain when exiting.

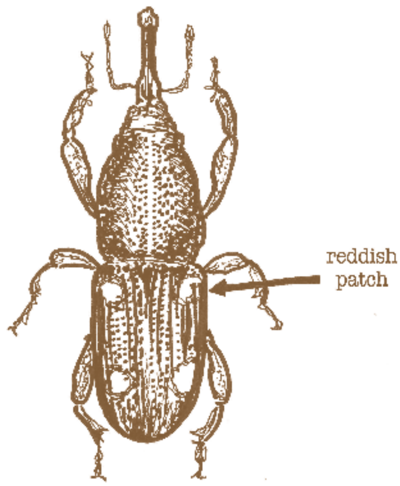
Life cycle of grain weevil



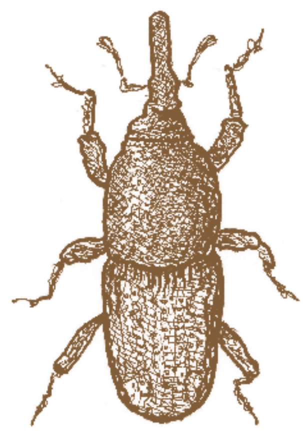
Granary weevil



Rice weevil



Maize weevil



notes

Angoumois grain moth *(Sitotroga cerealella)*

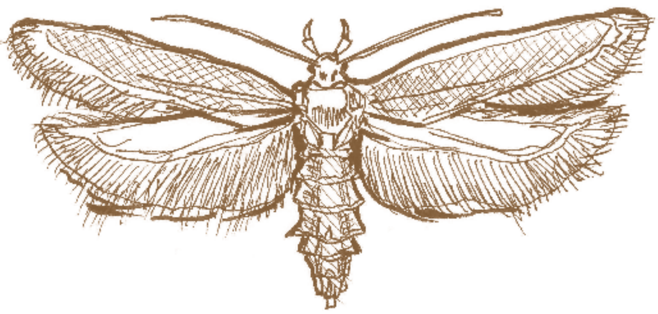
The Angoumois grain moth has nearly global distribution and is an important pest of rice, pearl millet, sorghum, wheat and maize. It is yellow–brown with dark markings and a wingspan of 12–20 mm.

Life cycle: Females lay ≤ 250 eggs on or near the surface of stored grain. The eggs hatch into a larva or caterpillar, which bores into grain kernels remaining inside until mature. It then eats its way out of the grain. The life cycle may be completed in as little as 5 weeks.

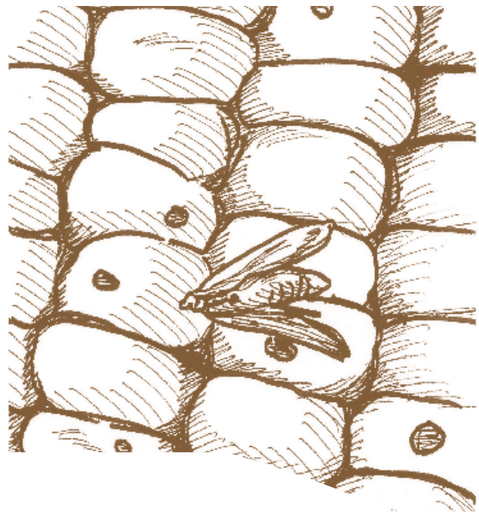
Damage:

- On emerging from the grain, the larva leaves characteristic exit pin-holes on the grain surface.
- The weight of grains decreases.
- Infestations impart an unpleasant smell and taste to the cereal.

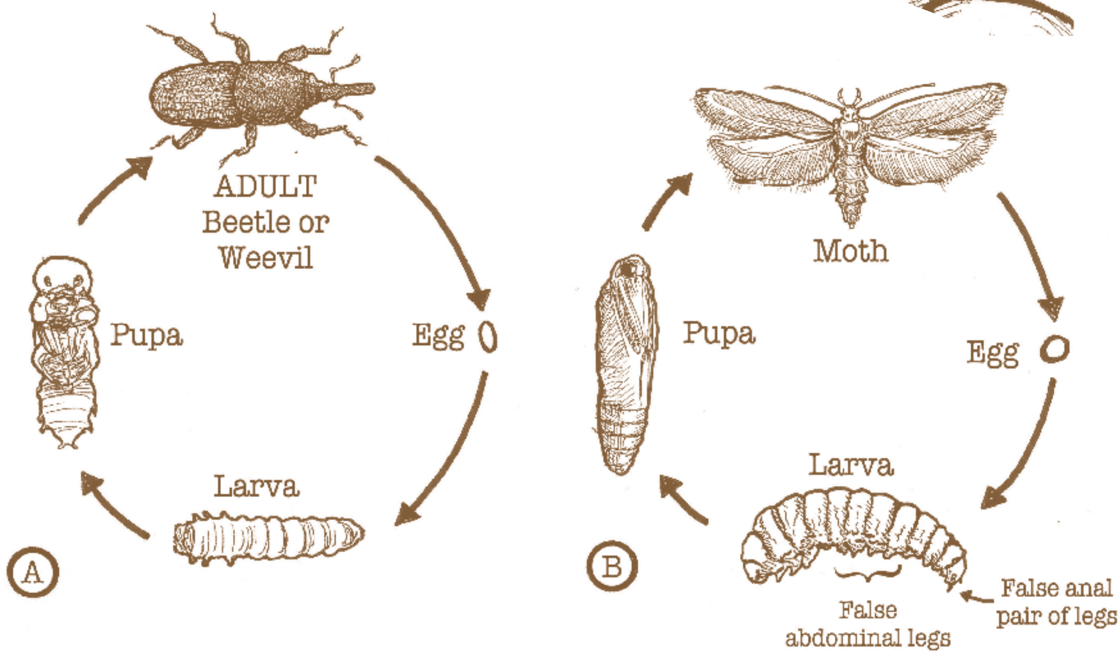
Angoumois grain moth



Maize seed damaged by Angoumois grain moth



Life cycle of moth



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Secondary insect pests

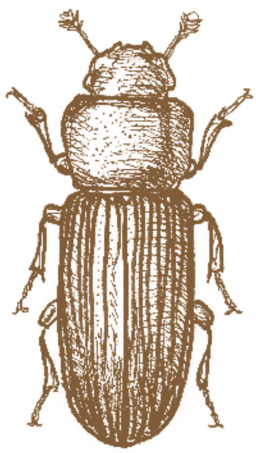
notes

Secondary pests attack **damaged materials** – already spoiled either by other pests (primary pests) or as a result of poor threshing, drying and handling – and **processed commodities** (e.g. flour and milled rice), where they sometimes account for the majority of insects present.

Flour beetles

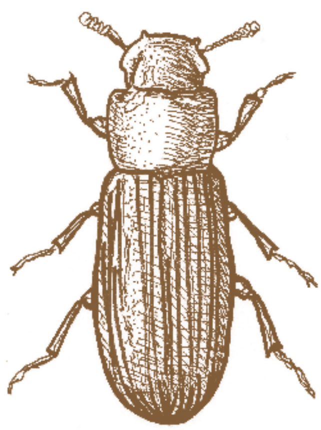
There are two different types of flour beetle: the rust-red flour beetle and the confused flour beetle.
While the rust-red and confused flour beetles cannot feed on whole, undamaged grain, they are often found in large numbers in infested grains, feeding on broken grain, grain dust, and other household food items (e.g. flour, milled rice, dried fruit, nuts and beans). In addition to creating a foul odour, their presence encourages the growth of mould.
They have similar **physical characteristics**: flat and oval in shape, small (usually around 3 mm in length), and their exoskeletons are reddish brown with a shiny and smooth texture.
Their small size allows them to manoeuvre through cracks and crevices, and once they are present in areas with potential food sources, they infest material such as flour, giving it a sharp odour and mouldy taste.

Rust-red flour beetle



- **Rust-red flour beetle** (***Tribolium castaneum***). The final three segments of the antennae are greatly enlarged forming a club shape. Young adults are pale brown and become darker with age. Females lay ≤ 1 000 eggs loosely scattered throughout infested grain. Cream-coloured larvae with biting mouth parts and three pairs of legs hatch and remain free from the grain, feeding on cereal dust and damaged grains. A generation takes about 1 month to complete under summer conditions, but longer in cold weather. Adults may live ≤ 1 year. The adult is winged and may fly short distances.
- **Confused flour beetle *(Tribolium confusum)***. The confused flour beetle is a common insect pest known for attacking and infesting stored flour and grain. It is one of the most common and destructive insect pests for grain and other food products stored in silos, warehouses, grocery stores and homes. The main physical difference from the rust red flour beetle is the shape of its antennae, which increase gradually in size and do not have a distinct three-segmented club at the end. The confused flour beetle is more often found in flour mills than on farms, preferring more finely divided materials. Confused flour beetles do not fly.
  Note that "confused" in the beetle's name refers to the fact that it is easily confused with the rust-red flour beetle; it does not refer to its behaviour pattern.

Confused flour beetle



Life cycle: Flour beetle eggs are usually white, sometimes colourless. They are very small and have a sticky outer covering that causes certain food particles to stick to them. The larvae have 6 legs. The pupal stage is a cocoon-like form and usually white or brownish in colour. The beetle life cycle lasts ≥ 3 years, with the larval stage from 20 to > 100 days, and the pupal stage around 8 days.

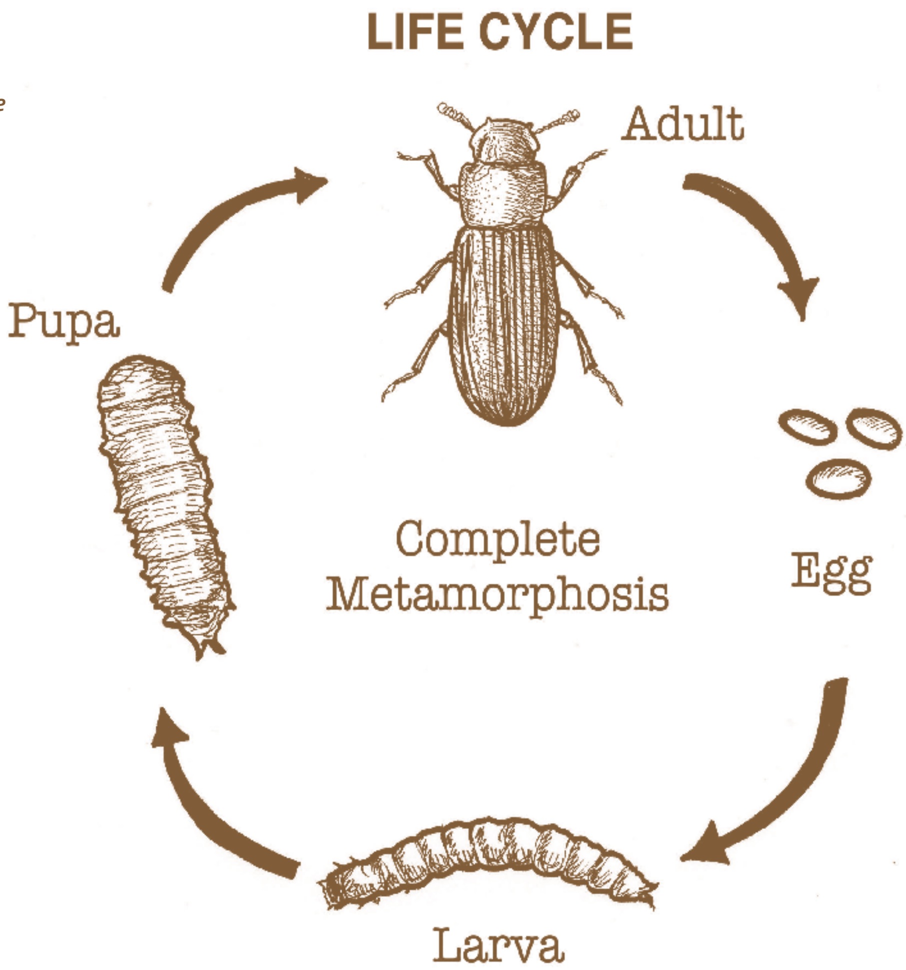
notes

Khapra beetle *(Trogoderma granarium)*

The Khapra beetle is one of the world's most destructive pests of stored grain products and seeds, causing 30–70% of the insect damage in stored products. **Early monitoring is essential**. Its distribution is cosmopolitan and it is among the world's top 100 invasive species. It is a serious pest of stored wheat grains, but it also attacks rice, oat, maize, pulses and oil seeds. The damage to the grain is caused by the larvae, while the adults are harmless and do not feed. Infestation occurs mainly in the superficial layers of the grain, as the pest cannot penetrate deep; the first sign of infestation is cast larval skins. The major damage caused is the destruction of the embryo end of the grain, but heavy infestations result in destruction of the whole grain. **Infestations are difficult to control because the Khapra beetle**:

- can survive without food for long periods;
- is adapted to dry conditions;
- prefers low-moisture food; and
- is resistant to many insecticides.

Life cycle of flour beetle

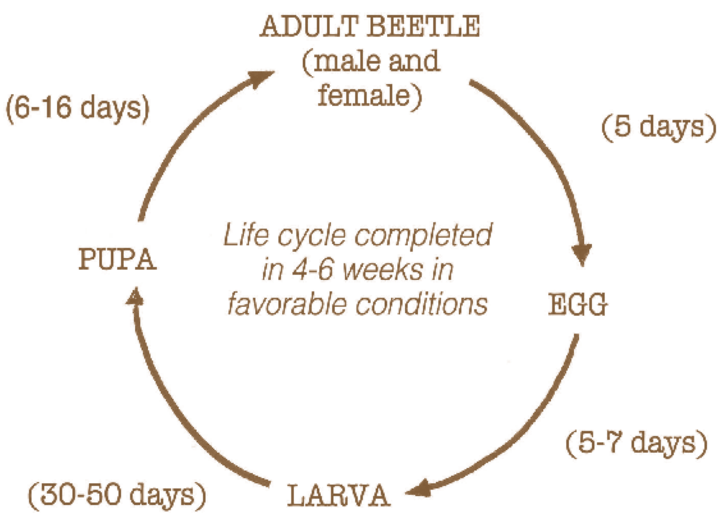


Khapra beetle

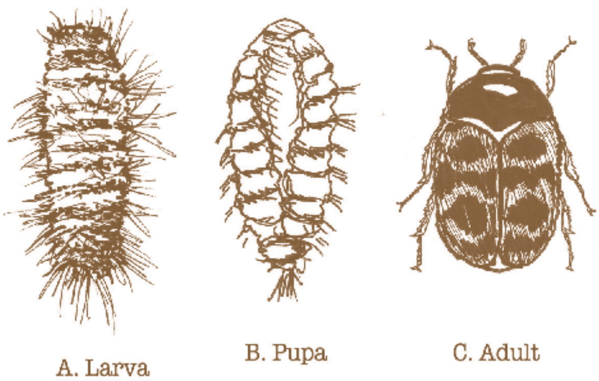
The adults are oblong–oval, approximately 1.6–3.0 mm long and 0.9–1.7 mm wide, with wings (but they apparently do not fly). Males are brown–black with indistinct reddish brown markings on their elytra. Females are slightly larger than males and lighter in colour. The head is small and deflexed with short 11-segmented antennae. The adults are covered with hairs.

Life cycle: The mating period occurs about 5 days after emergence, and egg laying begins almost immediately. The female lays an average of 50–90 eggs loosely scattered in the host material (e.g. grain heaps). The eggs are white and cylindrical and hatch in 1–2 weeks depending on temperature and humidity. In a humid atmosphere, the incubation period is 5–7 days. The larval period lasts 30–50 days; under favourable conditions, the male larva moults 4 times. Larvae are yellowish brown in colour, and the body is covered with bundles of long, reddish brown, movable and erectile hair. In the terminal segments, the hairs form a sort of tail. Young larvae feed on floury debris left by older larvae, because they cannot attack the whole grain. A fully-grown larva measures 4.5 mm in length. After 6–16 days of pupal period, adult weevils emerge and become sexually mature in 2–3 days. An adult lives for 10–30 days after reaching sexual maturity.
The life cycle – complete development from egg to adult – can take 4–6 weeks in favourable conditions (i.e. optimum development temperature of 35 °C); under cooler conditions, development takes longer (e.g. 220 days at 20 °C). Development can occur when relative humidity is as low as 2%; survival is difficult in conditions of high relative humidity.

Grain damaged by Khapra beetle



Life Cycle of *Trogoderma granaria*



Trogoderma granaria

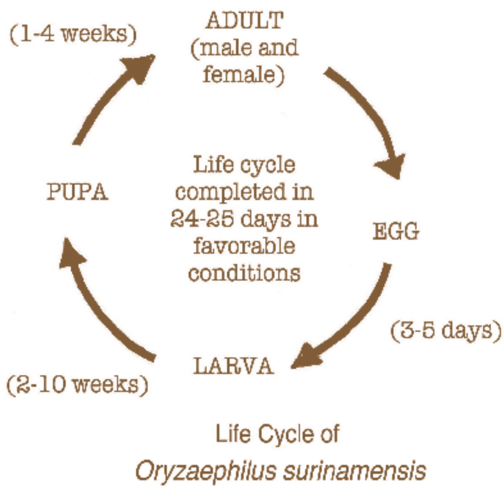
Saw-toothed grain beetle *(Oryzaephilus surinamensis)*

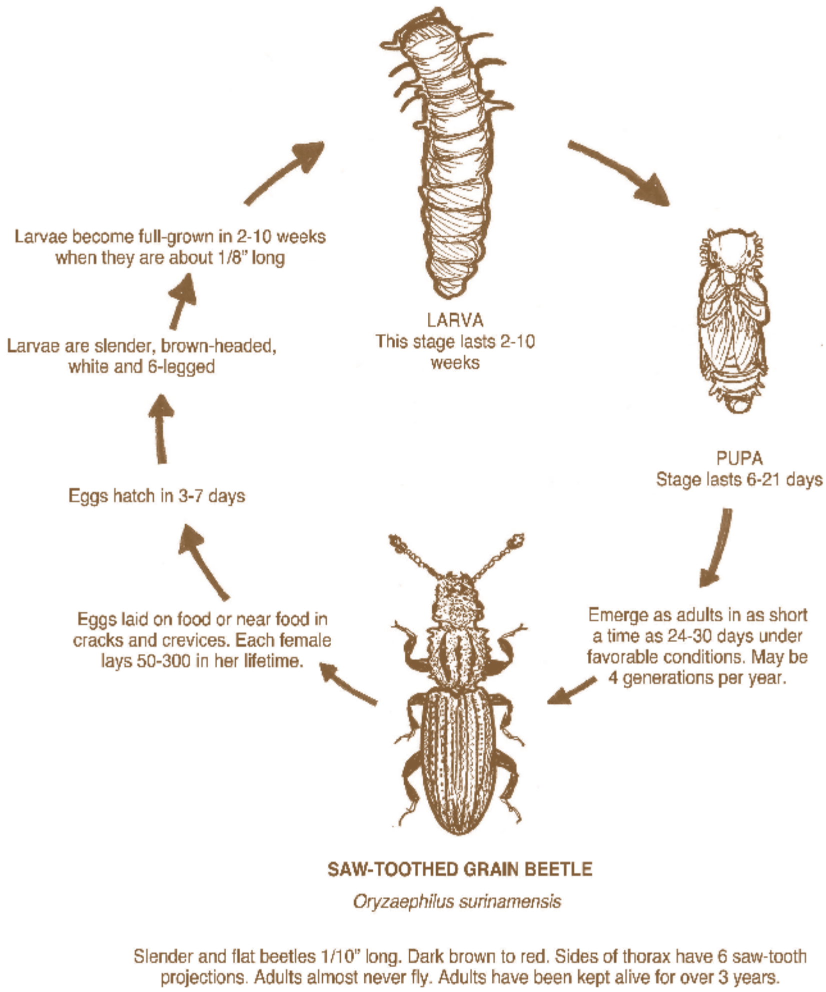
Saw-toothed grain beetle

The saw-toothed grain beetle is found all over the world and infests cereals – mainly milled products (e.g. flour and poultry feeds). It does not usually attack whole seeds, but tends to colonize cereals damaged by other pests. Adults are dark brown to black, 2.5–3.5 mm long. It has 6 saw-toothed projections on each side of the thorax, the abdomen tapers towards the tip and it rarely flies.

Life cycle: In her lifetime, the female lays ≤ 500 eggs, loosely spread through flour or lodged in crevices in the infested grain. The eggs hatch in 3–8 days to produce free-living larvae with a caterpillar-like appearance. The larvae and adults feed externally on grain dust and sometimes cereal embryos. They are unable to feed on undamaged grains. The larval period can be as short as 2 weeks, followed by the pupal period (1–4 weeks). The pupal stage is characterized by a unique process: the beetle sticks together pieces of food material to form a protective covering around its body in the form of a silken cocoon within which the mature larva pupates. A complete generation may need as little as 3 weeks at 30 °C and RH 70%, but adults can live ≤ 10 months. The optimum temperature for development is 30–35 °C. The saw-toothed grain beetle is very tolerant of low humidity (even as low as RH 10% at 30 °C). The adults frequently hide in cracks and crevices of buildings and machinery.

Life cycle of saw-toothed grain beetle





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Storage mites

notes

Mites are the smallest of the stored-product pests. They are of microscopic size and hard to see with the naked eye and therefore often go unnoticed. However, they have a high reproduction rate and can manifest themselves on surfaces as a brownish or greyish dust or as fluffy material, or in severely infested grain they may appear with a wave-like floating motion. "Mite dust" is often a warning sign and indicates that there are more heavily infested areas not far away.

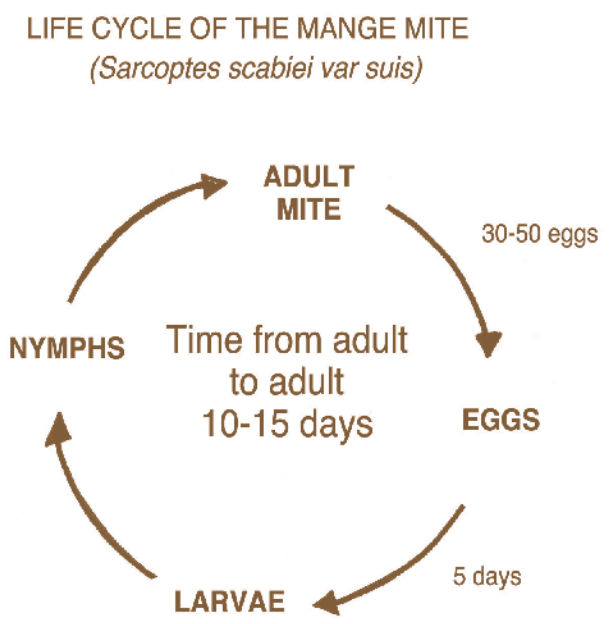
Unlike adult insects, which have a distinct head, thorax, abdomen and six legs, the adult mite has a sac-like body with 8 legs, while the larva has 6 legs. Mites are cold-hardy; most feed on broken grain, weed seeds and moulds. Mites commonly occurring in farm granaries and elevators include the grain mite, long-haired mite, cannibal mite and glossy grain mite.

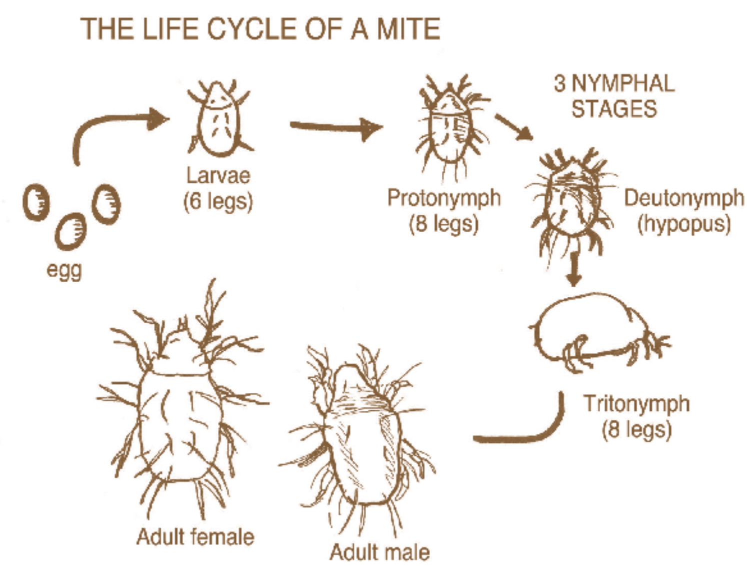
Moisture content of the grain influences mite activity and mites are common in grain stored at MC 14–17%; at MC > 15%, mites can develop even in relatively cool conditions. In warm, humid conditions, mites proliferate and very large populations can develop rapidly, often in conjunction with fungal growth.

Life cycle: The life cycle of a mite comprises egg, 6-legged larva, two or three 8-legged nymphal stages, and the 8-legged adult.

Damage: Mites attack microscopic cracks in the seed-coat and feed primarily on the seed embryo, inhibiting germination. They also feed on other parts of the grain and on mould growing on the grain; mites are responsible for the spread of various fungal spores throughout the grain mass. When present in large numbers, mites can cause grain heating and promote sweating, which gives a foul odour to the grain. Mites are usually a nuisance rather than a direct storage pest.

Life cycle of storage mites





notes

Grain mite *(Petrobia latens)*
The grain mite is a pale to whitish, wingless, soft-bodied arthropod about 0.2–0.5 mm long. Generally, the life cycle from egg to adult takes about 2 weeks at room temperature (9–11 days under optimal conditions of RH 90% and 25 °C). The female is estimated to lay about 800 eggs during its life span. The eggs (approximately 20–30 per day) may be deposited singly or scattered at random over the infested material.

MANAGEMENT AND CONTROL OF INSECT PESTS OF STORED SEED

Insect pests can survive from one season to the next within infested residues in the field, in storage structures and in natural habitats (e.g. natural vegetation). Therefore, fresh produce or new seed can become infested by the active migration of pests to the crop in the field or to seed in the store. Infested material may sometimes even be placed in the store.
Seed **losses arising from the activity of storage insects** include:

- reduction in germination – due to seed embryo damage;
- reduced seed weight and loss of vigour – as insects feed on the grain endosperm; and
- promotion of mould development – caused by respiration water from insects.

Effective control of insect pests is critical for the **maintenance of seed quality** and for **food production** in general.

Insect control measures

A wide variety of techniques are available to control insect pests in stored produce, from **simple techniques** at the traditional farm level to more **sophisticated measures** adopted by companies handling large volumes of seed. This section discusses practical techniques suitable for use in small- to medium-scale seed storage, mostly under tropical conditions. However, the **technique adopted depends on a range of factors**:

- seed value;
- pest type;
- level of resistance;
- farming system; and
- availability of insecticides.

When selecting a technique, consider its effectiveness against target pests, any hazards to the farmer and workers, and whether the result covers the cost of treatment. Insect control measures can be categorized as **preventive** and **curative**.

3

Preventive measures

notes

“Prevention is better than cure” and preventive measures should cover all stages of storage from harvesting through to final distribution and use by the farmer. **Recommended preventive measures:**

- **Hygiene, sanitation and management:**
  - Construct stores soundly to enable maintenance of correct storage conditions and allow for easy cleaning. Ensure that stores are insulated, well ventilated and damp-proof. Keep cracks and crevices, which may harbour beetles, to a minimum.
  - Ensure that no secondary sources of infestation are in close proximity (e.g. food residues, stored commodities and bird nests) in order to prevent insects breeding and developing to infest new seed materials. Destroy or fumigate all infested commodities.
  - Clean all harvesting and threshing machines/equipment before use.
  - Locate threshing floors and areas away from other possible sources of insect infestation
  - Clean threshing floors and areas to ensure they are free from insect infestation.
  - Maintain free from insect infestation trucks, trolleys or animal carts used for transportation of seed material.
  - Clean storage structure and facilities before receiving newly harvested seed crop.
  - Remove, and dispose of or destroy all dirt, rubbish and sweepings from stores.
  - Plaster or permanently seal all cracks, crevices and holes existing in floors, walls or ceilings.
  - Choose carefully packaging material to help deter insect attack (generally, thick, tough materials with a smooth, shiny finish are preferred). Ensure that packs are strong and well sealed.
  - Stack bags neatly above floor level using pallets, away from walls and not touching the ceiling. Leave a gap between stacks to allow for ventilation, regular inspection, cleaning and, if necessary, treatment with insecticides.
  - Dry all seed taken into store to a suitable moisture content and temperature.
  - Do not mix new grain with old. Remove or thoroughly fumigate old, infested material. Clean storage structures and machinery, and disinfect bags and baskets by sunning or chemical treatment as appropriate.
- **Disinfestation of stores and receiving areas:**
  - Before use, disinfest reception areas and store rooms. For large structures: spray with safe and approved residual insecticide (e.g. Malathion 50% EC, dilution 1:100, application 3 litres/100 m2; or a commercial mix of Pirimiphos-methyl + Lambdacialotrina [50% + 5%], dilution 1:50, spray 5 litres/100 m2; or Chlorpyrifos-methyl [48%], dilution 1:200, spray 5 litres/100 m2. For small local stores: smoke.
  - Whitewash storerooms each season before putting seed into storage.

notes

- **Pest quarantine:**
  - Impose relevant quarantine regulations to prevent the entry of insect pests into a particular area.
- **Other measures:**
  - Take advantage of natural resistance, since crop varieties differ in their susceptibility to storage pests. Certain traditional varieties may be more resistant to storage pests than improved varieties (e.g. local maize with good husk cover offers greater resistance to field infestation).
  - Use hermetic storage where possible – under airtight conditions, reduced oxygen and increased carbon dioxide arrest insect and mould development.

Curative measures

Once an infestation is underway, take curative measures to control the activity of the grain insect pests in the storage facility. Curative control measures may be **non-chemical** or **chemical**.

Non-chemical control:

- **Environmental control measures**. The development and the multiplication of insect pests in stored grains largely depend on temperature, relative humidity and the grain's moisture content. Proper management of these three factors can significantly influence the level and progress of infestation, with attention to the design and construction of storage structures and the use of best storage practices.
  - **Temperature:** manipulate storage temperatures to destroy many stored product pests. Heat treatment kills some pests outright; cold treatment usually blocks their development. Temperatures of 20–40 °C accelerate the development of insects; > 42 °C and < 14 °C retard reproduction

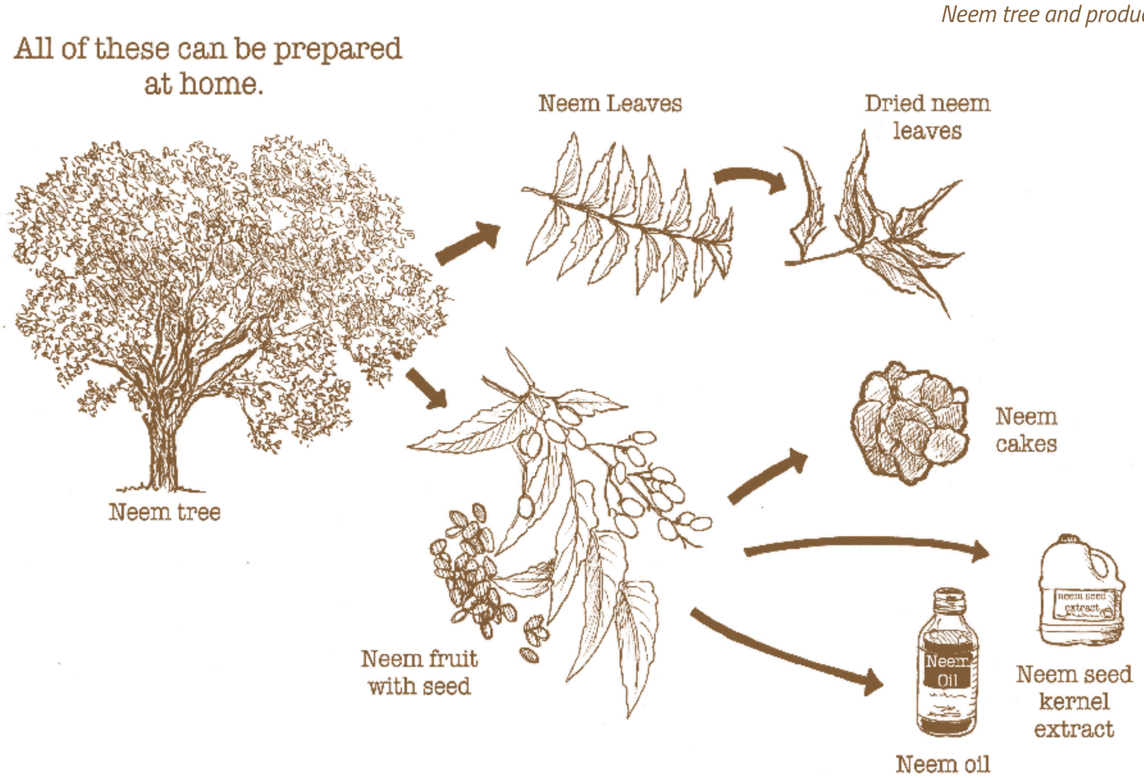
Disinfecting a seed store

3

and development; prolonged temperatures > 45 °C and < 10 °C may kill insects. Heating grains to 50 °C is lethal to insects; however, this is not advisable, as the grains are affected and lose their viability.
  - **Relative humidity** and moisture content: manipulate storage relative humidity to inhibit the activity of many storage pests. Moisture is critical for safe storage of food grains. Grains stored at around MC 10% escape attack from insects (with the exception of the khapra beetle). Grain mites cannot survive at RH < 55–60% or MC ≤ 12%.
- **Mechanical control measures.** Mechanical devices are designed for both monitoring and mass trapping of stored product insects. It is possible to exploit the behaviour of the stored-product insects using different kinds of traps: light traps, bait bags, adhesive traps and pheromone traps.
- **Desiccants:**
  - Combine dusts (e.g. silica gel or diatomaceous earth) with certain stored grains to protect against insect damage. The dusts kill target insects by desiccation.
  - Use diatomaceous earth to control grain-feeding insects in many stored grains. It damages the cuticle of the insects, reducing their ability to retain moisture. The insects eventually die from dehydration.
- **Traditional preservation.** The traditional method for preserving seed in storage is to treat it with **special plant products** or with **smoke**. Parts of certain common plants (e.g. leaves and oil of the **neem tree**) can be made into effective pesticides. Neem is a large evergreen shade tree grown in parts of Asia and Africa. Its important parts are the fruit, seeds, leaves and

notes

Neem tree and products



notes

bark. A large part of the seed weight consists of the kernel, which contains ≤ 35% oil – neem oil is more effective than the leaves. While dried neem leaves help to keep stored grain free of pests, the chemical present in the **neem seed repels insects**, deterring them from landing, feeding and laying eggs on crops by reducing their growth and development or making them infertile or eventually killing them. **Wood ash** is a safe and effective pest control material. Note that while some traditional methods may be suitable for small seed volumes, they may become cumbersome for larger quantities.

- Store cereal seeds mixed with neem leaves and wood ash in bags or baskets made from date palm fronds, with the top portion of the container plastered with cow dung, to prevent entry and spread of insects.
- Mix an equal quantity of seed with wood ash or sand to prevent attack from beetles and other storage pests in closed containers.

Chemical control

- **Fumigation**. Common **chemicals** used in fumigation include phosphine gas (e.g. tablets of aluminium phosphide, which release phosphine gas on contact with moisture in the air), and ethylene dibromide, methyl bromide and carbon tetrachloride (volatile liquid fumigants available in various combinations and formulations). Capsules and sachets are available for small-scale applications and pressure cylinders for large-scale operations.
  - Fumigate with aluminium phopshide (3-g tablets at a rate of 3 tablets per tonne) for ≥ 7 days to achieve desired mortality.
  - Provide **airtight conditions** for ≥ 3 days when applying aluminium phosphide (or 1 day for Ethylene dibromide) after adding the chemical.
  - Adjust the concentration of gas (+ 50%) when fumigating mite eggs, which have higher tolerance than insects.
  - Consult qualified personnel prior to application, because these products are **highly toxic.**
  - Adopt fumigation for seed in closed containers or for bagged produce (if covered by tarpaulin or plastic sheets) – it is crucial to protect grain from re-infestation as fumigation is effective only at the time of application.
- **Treatment with insecticides.** It is critical to use **safe and approved insecticides**, effective for safe long-term storage and maintenance of germination capacity and vigour. Products are usually **admixed** with the grain in diluted form, at 10–15 ppm active ingredient (AI) at loading or bagging. Suitable chemicals include organophosphorus insecticides, Pirimiphos-methyl (normally 50% AI) and Chlorpyrifos-methyl (normally 48% AI). **Commercial insecticides** usually comprise a small quantity of the toxic compound (AI) and other "filler" substances. It is important to be able to convert from one basis to another. For example, if the recommended application of Pirimiphos-methyl is 15 ppm AI, apply 15 g of AI to every million grams of seed (i.e. to 1 tonne).

notes

For example:
Starting with 5% dust, 100 g of crude product (CP) contains 5 g of AI. The dose of chemical to be applied is:
5 g AI ≡ 100 g CP
∴ 15 g of AI ≡ (100/5) × 15 = 300 g of CP/tonne of seed

WARNING

Pesticides are poisonous. Insecticides kill insects, but are also toxic to humans and animals to varying degrees.

Insecticides do not kill all insects and mites. Choose either a "broad spectrum" chemical or one that specifies toxicity to moths and beetles. Note that mites may require special treatment.

Preparing stacked seed for fumigation (seed bags must be totally covered during the process of fumigation)

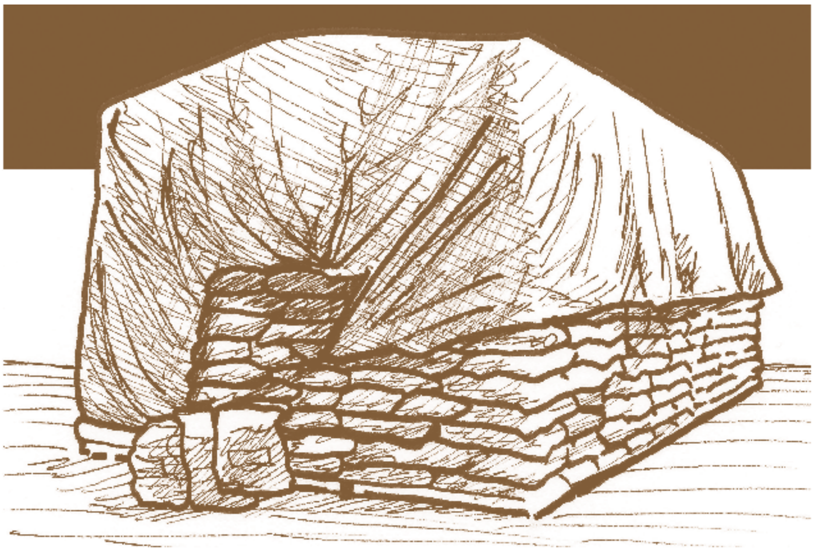
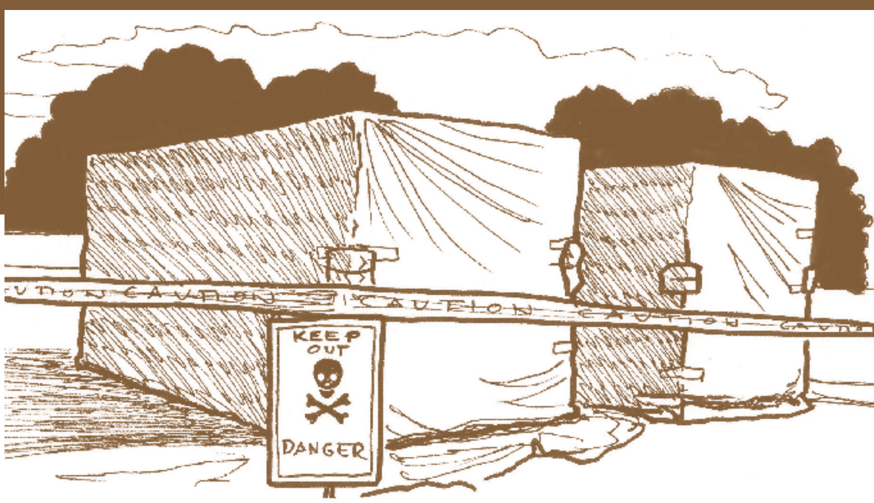


Figure 49. Seed covered for fumigation



notes

Insecticides are not persistent. They tend to lose their effectiveness when exposed to high humidity, high temperatures and sunlight.
Pests develop resistance to insecticides. It takes many years and considerable resources to develop and test new compounds; it is essential to adopt preventive measures:

- Apply the correct dosage – widespread, excessive and/or inappropriate use of chemicals may lead to insects evolving resistance to insecticides.
- Adopt high standards of farm hygiene and clean carefully all machinery and buildings used for storing and transporting grain.
- Note that insects exposed to a single insecticide may develop resistance to related compounds of other insecticides.

Health and safety is fundamental:

- Read safety precautions on insecticide labels and follow directions precisely.
- Handle carefully and store in original labelled containers out of reach of children, pets and livestock.
- Dispose of empty containers immediately after use, in a safe manner and place. Do not contaminate grazing areas, streams or ponds.

Fumigants are highly toxic. Technical knowledge is required for their proper use. Contact qualified and approved pesticide applicators to perform fumigation.

STORAGE PATHOGENS

Bacteria and fungi are **micro-organisms** potentially affecting seeds in storage.

- **Bacteria have no significant role** in the deterioration of stored seeds because they require free water for growth and proliferation. Storage bacteria require ≥ 90% RH for growth: they only become significant when fungi are already very active. Moreover, if the moisture content of the seed is sufficiently high for bacterial growth, it is more likely that the seed succumbs to deterioration for other reasons (e.g. fungi, respiration, heating or premature sprouting).
- **Fungi are responsible for maximum damage** or spoilage of seeds in storage. When fungi are present, they cause unpleasant odour, grain discoloration, loss of seed viability and loss of grain nutritive value.

Storage fungi

Storage fungi are different from field fungi – they grow under limited moisture conditions in which field fungi cannot survive. These fungi begin mainly as spores in the soil and on decaying plant debris; unlike other fungi, they are not removed during seed harvesting and cleaning, and they make their way into stored seed. Storage fungi are usually inactive at low grain-moisture levels. However, when the grain becomes wet and the moisture level increases (e.g. > 14% in cereals), the spores germinate.
The **principal storage fungi** with airborne spores are *Aspergillus, Pénicillium* and *Alternaria* spp. They commonly occur worldwide and have the following **characteristics**:

- Incapable of growth and reproduction if seed moisture content is low.
- Present in large numbers in the air and on surfaces of materials in seed storage areas.
- Activity largely determined by moisture content of seed, and by ambient temperature and relative humidity of storage area.
- Development enhanced by high temperatures and high moisture levels.

Consequently, the fungal population reflects the nature and efficiency of the post-harvest handling, conditioning, and storage environment of a seed lot. In particular, **mechanical damage** allows quick and easy access for microflora to enter the seed.
Storage fungi infect the seeds and induce deterioration by producing toxic substances (mycotoxins). Mycotoxins not only destroy the cells of seeds, they also cause harm or fatality to humans and animals. All storage fungi are completely inactive < 65% RH and show very little activity ≤ 75% RH. As relative humidity rises above this level, the fungal infestation of seed lots may increase exponentially. Therefore, **to minimize the risk of fungi invasion: store seeds at low moisture content, low temperature and low relative humidity.**

Control of storage fungi

In general, it is advised to adopt **preventive measures**:
- Practise good storage hygiene and sanitation.
- Avoid damaged and cracked grains - they provide ideal places for lodging of fungal spores.
- Clean seeds thoroughly.
- Dry seeds to a safe moisture content as soon as possible after harvest.
- Store seeds in an environment where they will not absorb moisture – most storage fungi cannot invade seeds that are in moisture equilibrium with ≤ 65% RH (at this level, moisture content of starchy seeds is about 13%, and oily seeds about 7%).
- Measure and monitor seed moisture content accurately. Although the moisture content of the seed lot is at a safe level, it represents an average, and individual seeds may contain an unsafe amount of moisture. Pockets of moist seeds are susceptible to invasion by storage fungi, which then spread throughout the lot, leading to **hot spots**.
- Control moisture and temperature of the grain and the store.

In addition, **fungicides** can control seed-borne pathogens and are often the **cheapest** and **most effective** means for control. They kill or inhibit growth of storage fungi and can be systemic or non-systemic in their action. Highly selective systemic fungicides are most effective. However, adopt preventive measures first: **fungicides are a last resort**.

notes

notes

RODENTS IN SEED STORAGE

Rats and mice that attack grain and seeds during storage are pests of **economic importance**, causing significant damage to grain and seed stores in developing countries, affecting food security and reducing the income of smallholder farmers. They feed directly on and spoil the grains, and also damage materials (e.g. bags and electrical fittings) with their gnawing action.

Apart from consuming and destroying large quantities of stored grain and food, rats and mice **destroy thousands of kilograms of seed each year**. Rodents not only eat seeds, they scatter and mix them, as well as contaminate them with droppings, urine and hairs. The estimated loss due to damage caused by rodents during storage is 2.50%.

Rats also **spread dangerous human diseases**, such as bubonic plague, rat (lassa) fever, typhoid and meningitis.

Types of storage rodents

There are three common types of rodents that cause damage to stored products, particularly grain and seed: the black rat (house rat), the Norway rat (common rat), and the house mouse.

Seed bags damaged by rodents

3

Black rat *(Rattus rattus)*

Black rat

- Common names: house rat, black rat, roof rat.
- Distribution: worldwide – thrives in tropical regions, largely driven out of temperate regions by the Norway rat.
- Appearance: medium-sized, relatively large ears, tail nearly always longer than body; black with lighter coloured ventral belly.
- Weight: 70–300 g.
- Body length: 160–220 mm.
- Tail length: ≥ 190 mm.
- Males longer and heavier than females.

Norway rat *(Rattus norvegicus)*

Norway rat

- Common names: common rat, street rat, Norwegian rat.
- Distribution: more successful than the black rat in cold regions.
- Appearance: large with a blunt nose, small eyes, small, short ears; brownish on dorsal surface, lighter grey or tan colour on the underside, fur coarser than that of black rat.
- Weight: 140–500 g.
- Body length: 200–250 mm.
- Tail length: 200 mm.
- Life span: 9–12 months, during which female can produce ≤ 7 litters, with 8–12 offspring per litter.
- Diet: omnivorous, eats almost any type of food, but mainly vegetarian.

House mouse (*Mus musculus*)

House mouse

- Appearance: pointed nose, large ears, small eyes; little fur, ranges in colour from light brown to black, with a white or buff-coloured belly.
- Weight: 12–30 g.
- Body length: 65–95 mm.
- Tail length: 60–105 mm.
- Life span: 9–12 months, during which female can produce ≤ 8 litters, with 5–6 offspring per litter.
- Diet: grains and cereal products.

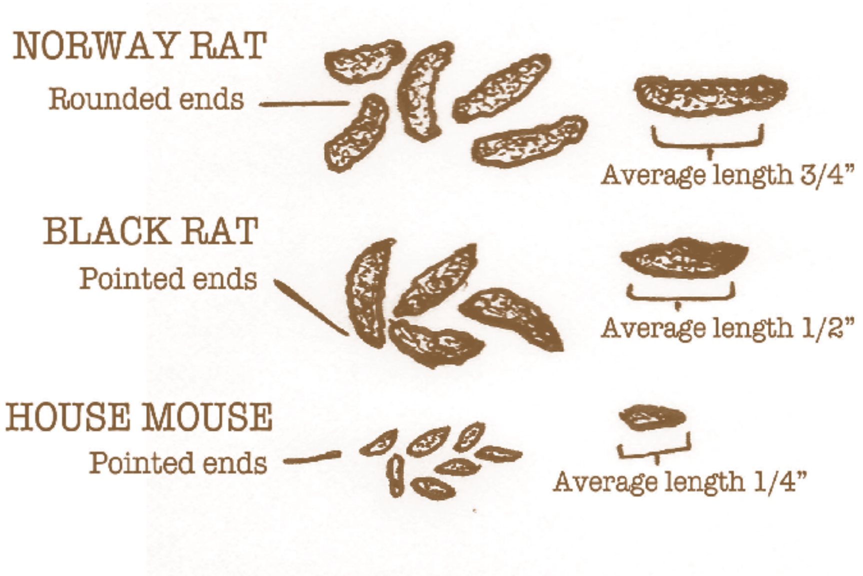
Characteristics of storage rodents

Like most rodents, rats and mice have poor eyesight and are colour blind; they rely on their acute senses of hearing, touch, taste and smell. They tend to not move very far from their nests and move along walls or other vertical surfaces so they can keep their whiskers in contact with the wall.

Behavioural differences:	
Rats	**Mice**
Shy, do not readily explore new areas or objects (including traps and bait stations).	Readily investigate new objects and enter bait stations. Active range limited to small areas, therefore numerous bait stations or traps have to be used in any storage facility
Shy, do not readily explore new areas or objects (including traps and bait stations).	Readily investigate new objects and enter bait stations. Active range limited to small areas, therefore numerous bait stations or traps have to be used in any storage facility
Prefer to nest near a source of water because need to drink water daily.	Drink much less and often obtain sufficient moisture from food.
One rat consumes 10 kg of food per year.	One mouse consumes 1 kg of food per year, but contaminates much more with droppings, urine and hair.

Besides physical sightings, other indicators of rodent pest infestation include faecal droppings, runways, tracks, burrows, gnawed materials, nests, signs of damage, and foraging sounds (particularly at night). Faecal droppings vary in size and appearance, depending on the type of rodent (Figure 54).

Faecal droppings of rodents



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Rodent control

notes

As with insect pests, control involves both preventive measures (to keep rodents out of seed storage areas in the first place) and remedial or curative measures (mechanical and cultural).

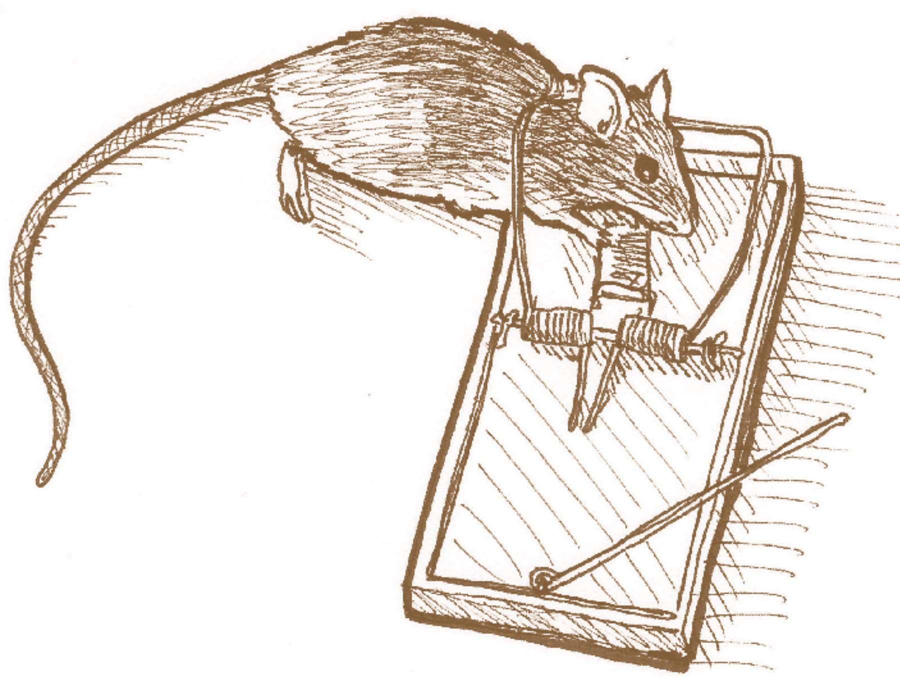
Preventive measures

- Make constructions rodent proof – eliminate points of entry (e.g. cracks and holes in walls and floors, unscreened ventilators), close rat burrows with a mixture of broken glass pieces and mud and then plaster with mud/cement.
- Maintain standards of good housekeeping and cleanliness inside and outside storage areas to keep rodents away and facilitate inspection.
- Fit ventilation openings with screen or wire gauze.
- Place anti-rat guards on storage structures.

Remedial measures

Mechanical techniques

- Place **traps** with bait to attract rodents. The bait can be any food that rats and mice like to eat (e.g. pieces of meat, dried fish, bread, coconut, onion). Rats tend to prefer sugar, molasses or sweet foods. Check the trap daily to make sure the bait is still there. After every successful usage, wash the trap washed thoroughly before re-using.
- Use **rodenticides** to kill rodents. Rodenticides (including anticoagulants) are widely used to kill rats and mice in and around structures and come in the form of baits, fumigants and tracking powders. The baits may be blocks,



Rodent trap

notes

pellets, meal, seeds, liquids or place packs. Attempts to eradicate local rat populations with poison have limited success because of rats' **bait shyness** – a form of avoidance learning in which rats quickly develop an aversion towards a new food or bait. The Norway rat, in particular, tends to avoid unfamiliar foods and may sample them tentatively. Once a rat takes a small amount of poisoned food and survives, it will never touch the same type of food again.

- Employ chemical repellents, such as Naphthalene, to repel rats and mice. Apply repellents around the perimeter of the structure or inside a specific area.

Indigenous and biological measures

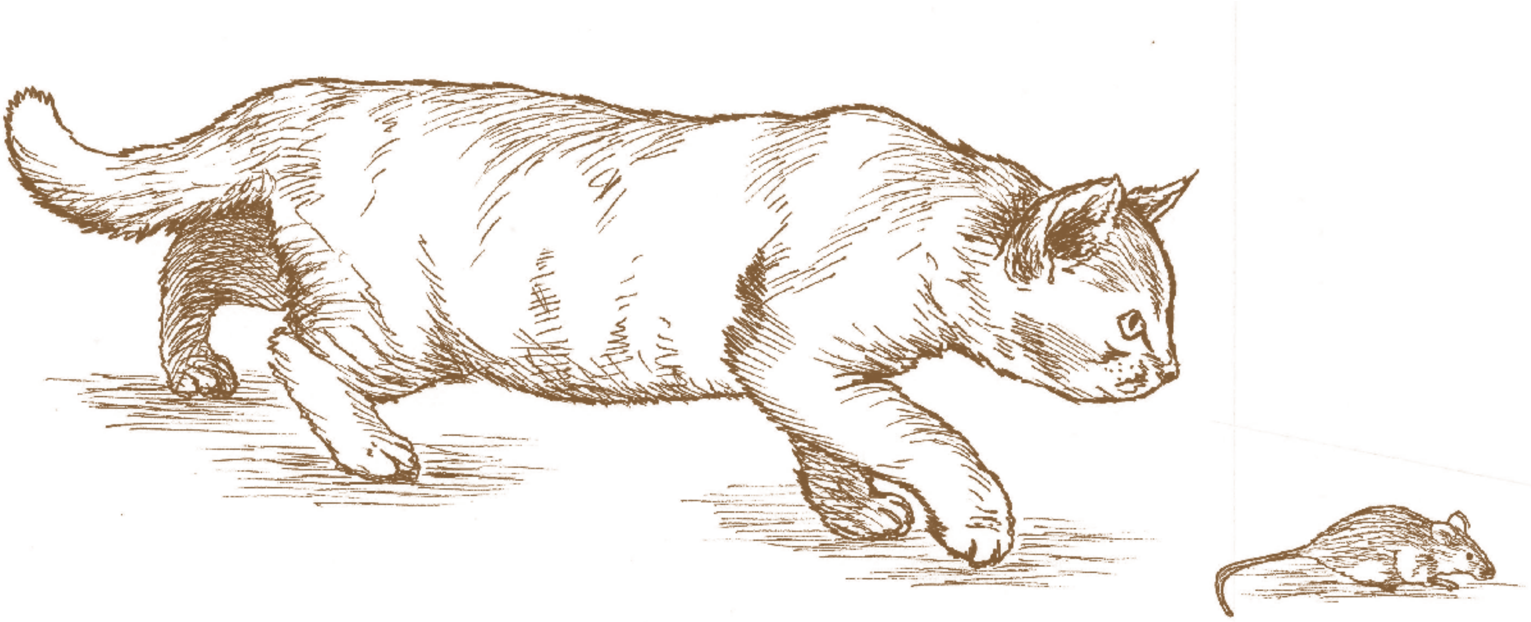
- Place unripe papaya fruit pieces in the corner of the store. When rats eat these fruits, the mouth tissues become damaged due to the chemical substance in the fruit. Keep 2–3 pieces per room.
- Take 2–3 kg of castor leaves and add 3 litres of water. Boil for half an hour and filter the extract. Add 2–3 kg of sorghum seeds and boil for half an hour. Put the seeds in a vessel and place in a corner of the storage room. Rats feed on the seeds and die.
- Keep a cat around a grain store for effective control.

Rat poison used as bait

No single method of rodent control is completely effective. Adopt an **integrated approach** combining:

- measures **to exclude rodents** from stored grain (e.g. good housekeeping, proofing and repelling); and
- methods to **minimize the damage** caused by rodents (e.g. trapping and poisoning).

Biological rodent control



3

PEST BIRDS IN STORES

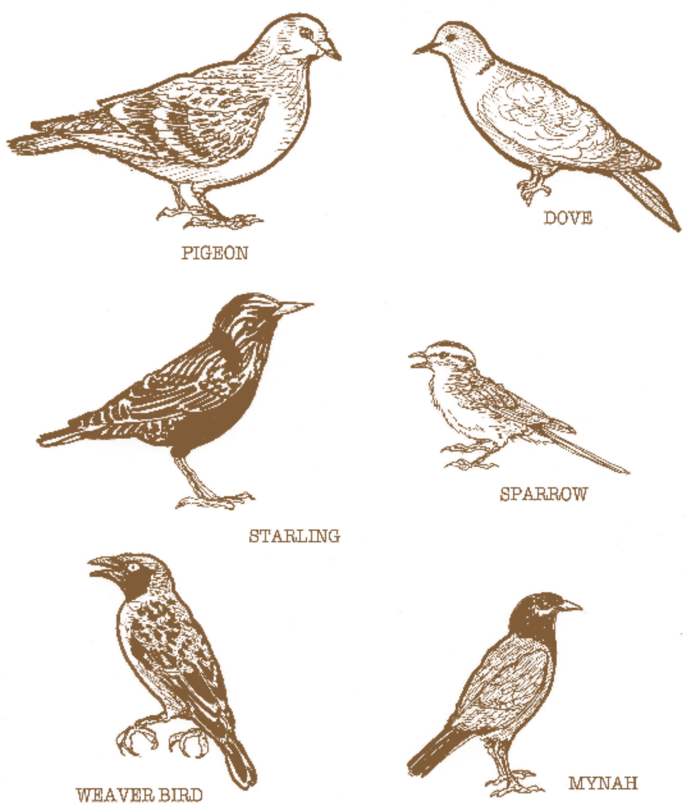
notes

Losses due to bird activity are small in comparison with those caused by rodents, because birds do not infest and live in storage structures as rodents do; they rely on their mobility to quickly search for places to feed. Only about 0.85% of grain loss at storage level is caused by birds. Seeds are vulnerable to birds when **exposed in outdoor situations** (for example, threshing in the field or in open clearings, or drying, when grains are spread on the ground in the tropical sun).
When grains are stored in open cribs, birds may enter storage structures, creating a nuisance and leading to unhygienic conditions, in particular:

- physical damage to or spoilage of seed by direct feeding;
- seed contamination with excreta and feathers;
- occupational health and safety risks (e.g. contamination of grain with diseases leading to respiratory problems and spread of other illnesses); and
- damage to storage buildings, machinery and vehicles.

Types of pest birds

The main pest bird species in post-harvest situations are: common pigeon (*Columba livia*), starling (genus *Sturnus*), common mynah (*Acridotheres tristis*), sparrow (genus *Passer*) and dove (*Streptopelia* species). In Africa, the most common pest birds in grain storage are sparrow and weaver bird (genus *Ploceus*).



Common pest birds

notes

Note that bats can also be a nuisance in seed stores if they left to establish colonies. Their droppings and urine do not only stain walls and ceilings, but also cause objectionable and persistent odours that may attract insects. Long-term accumulation of these droppings in attic spaces may lead to the spread of respiratory diseases.

Bird control

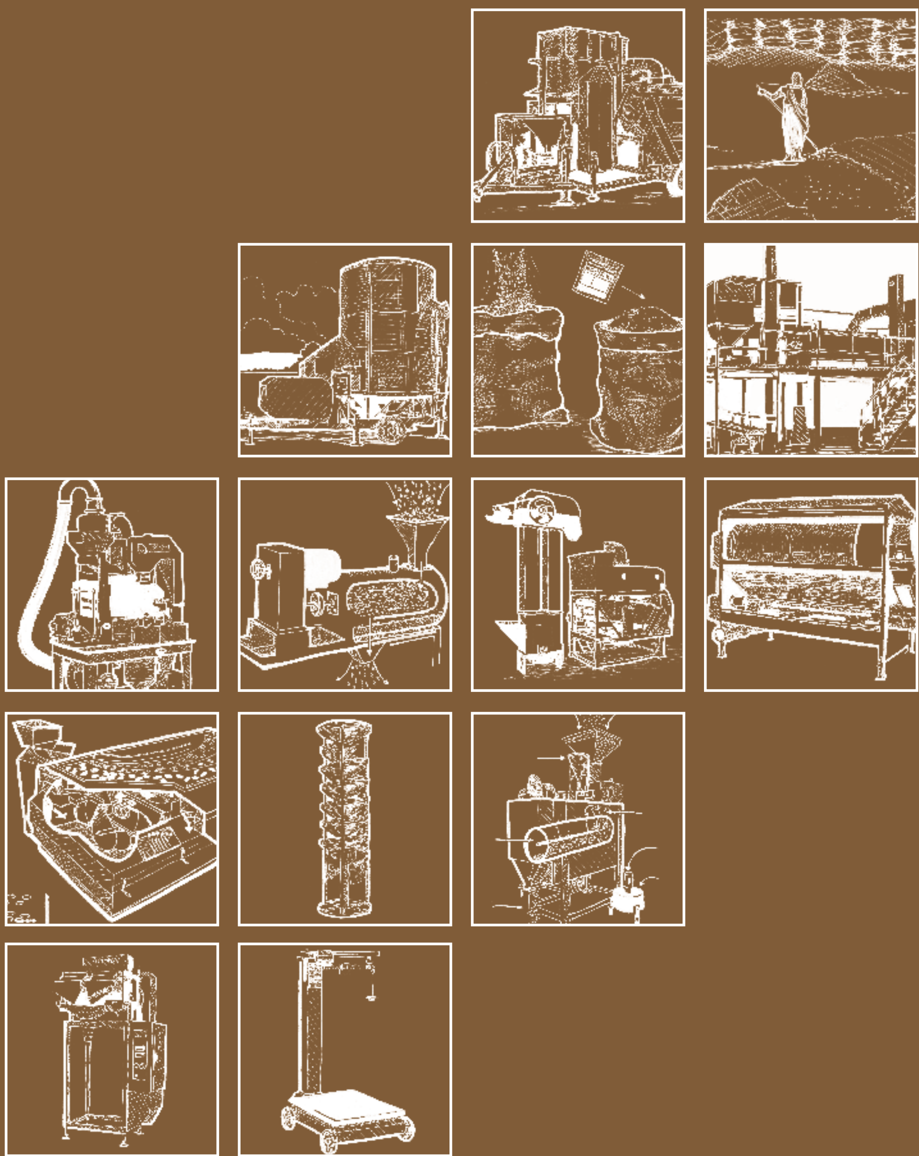
Some bird species have legal protection and it may not be possible to use lethal means (e.g. shooting, trapping and poisoning with avicides) to eliminate them. In many situations, **non-chemical methods** of reducing bird populations are successful: destruction of nesting sites, exclusion, sanitation, and frightening with noise. The easiest method of control is prevention of access to stored seeds. **Recommended bird-deterrent measures**:

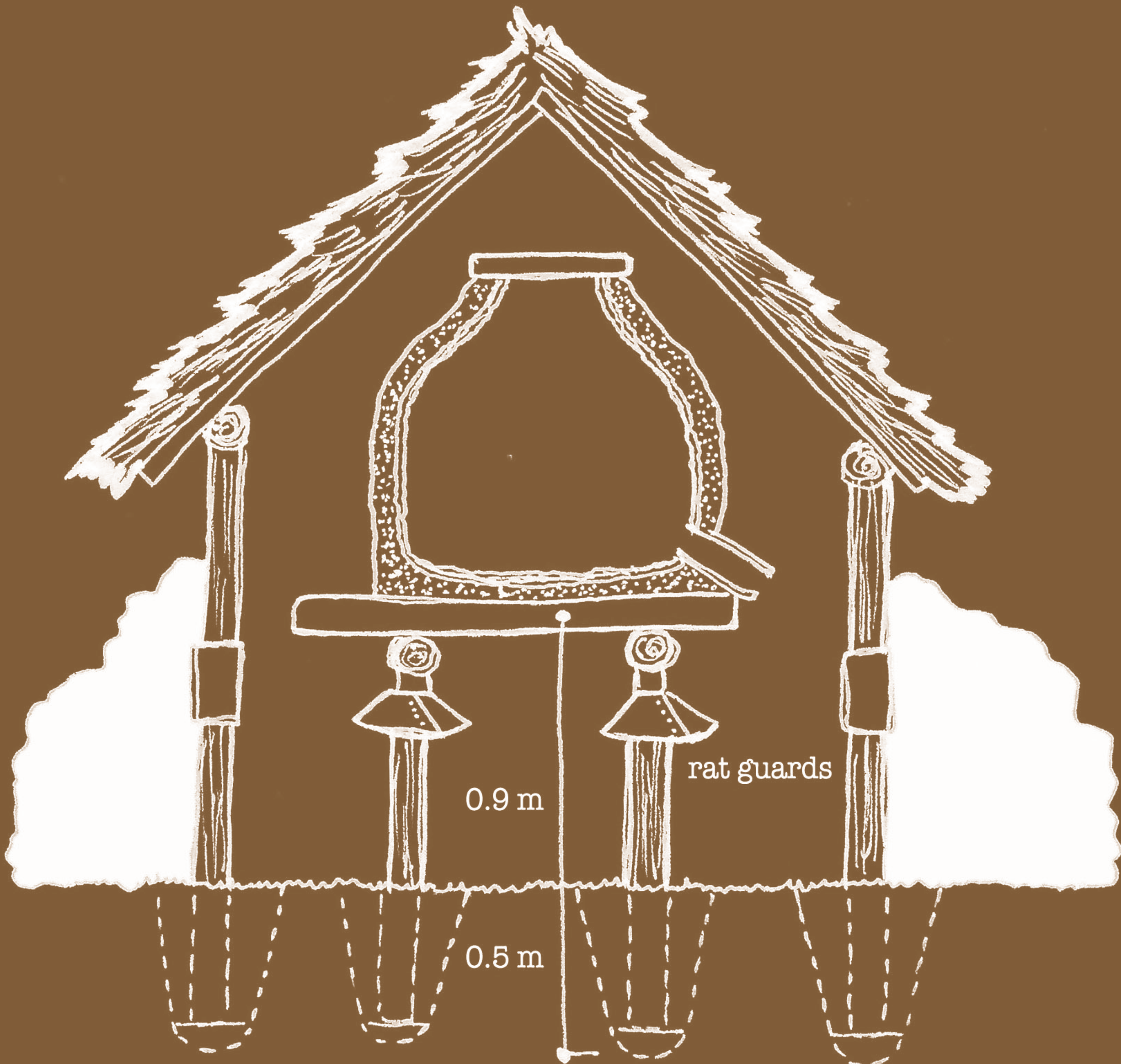
- Make seed stores bird proof – equip windows, ventilators and other entry points with wire mesh screening or locally made netting.
- Use bird-scaring devices (e.g. nylon or polythene strips) to keep birds away from the storage area.
- Destroy bird nests found near the storage area or in the eaves and crevices of storage buildings.
- Use approved and safe chemical repellents (e.g. those with an active ingredient that irritates the birds' mucous membranes, forcing them to leave) – usually suitable for both indoor and outdoor applications and causing no permanent harm to the birds.
- Employ sound deterrents to scare birds away. High-frequency ultrasonic pigeon and bird scarers are electronic devices producing high-pitch emissions (ultrasound) – too high for human hearing but within the hearing range of most bird species.

EXERCISES AND DISCUSSION POINTS

1. Identify a control measure common to all categories of seed storage pests. Explain how it is used to control these different pests.
2. Explain why certain curative insect control measures in a seed store require the supervision of qualified and approved pesticide technicians.
3. What quantity of Pirimiphos-methyl insecticide (5%) do you think should be applied to 1 tonne of wheat seed at a dose of 20 ppm AI?
4. Explain how preventive methods can help in rodent control. Compare this approach with trapping and other examples of physical rodent control.

4 Storage structures




rat guards
0.9 m
0.5 m

Storage structures

4

notes

PURPOSE OF STORAGE STRUCTURES

The primary purpose of any seed storage facility is to **maintain the viability and vigour of seeds** during the storage period. This period may vary from a few months to several years, depending on the kind of seed and its intended use. Therefore, the type of storage structure depends on the duration of the storage. During storage, it is fundamental to **keep the seed dry** – a condition governed primarily by seed moisture content and storage temperature, both of which must be carefully controlled within the storage facility.

However, a large proportion of the seed produced for agricultural purposes only requires storing through to the following planting season, in which case normal air temperature and relative humidity may be sufficient, depending on the kind of seed and the local climate. Storage structures must **protect seeds from wetting, overheating and infestation by pests.** It is only in areas with extremely high temperatures and relative humidity that additional protective measures (i.e. temperature and humidity control) may be required to maintain seed quality during storage.

Finally, storage structures should be fitted with locks and other appropriate security measures adopted, as required.

BASIC FEATURES OF SEED STORAGE STRUCTURES

A seed storage facility needs to be **economical** and **appropriate** for the specific situation.

Furthermore, a seed storage structure must **provide protection from the following**:

- **Water.** It is crucial to prevent seed in storage from coming into contact with any source of water – including rain and ground moisture – as this would increase the seed moisture content. High seed moisture content induces respiration, leading to heating, mould growth and possible sprouting, which spoil the seed and decrease its quality:
  - Keep the roof, floor and sidewalls free of holes and cracks that may permit the entry of water in any form.
  - Provide some kind of waterproof floor – an elevated floor or a concrete floor with a moisture barrier underneath – to counteract the possibility of contact with soil moisture.
- **Admixture.** A storage facility typically holds more than one type of seed and it is important that different kinds do not become mixed:
  - Construct and organize the facility to keep seed lots separate and prevent contamination.
  - For bulk storage, provide a separate bin for each variety; for bag storage, stack seeds of different varieties separately on pallets.
  - Clearly label all bags, bins and other containers with relevant details to facilitate identification and inspection.

notes

- **Insects.** Efficient cleaning is fundamental:
  - Facilitate insect control (including elimination of insect breeding places).
  - Make the store suitable for fumigation.
- **Rodents.** Maximum protection against rodents is essential to prevent them from entering and gaining access to the seeds – rodent control precautions vary according to the type of storage facility:
  - Use metal bins with tight covers.
  - Treat cloth bags.
- **Fungi.** Temperature differentials can cause water vapour to move from warmer to cooler areas of a storage bin, usually to the upper surface; this moisture movement can provide conditions favourable for fungus growth because fungi grow best under warm humid conditions:
  - Build storage structures to provide a cool and dry environment.
  - Adopt effective ventilation to prevent the accumulation of water vapour.
- **Fire.** It is important to minimize fire hazards, especially in wooden buildings:
  - Maintain cleanliness both inside and around the building.
  - Apply chemical treatment to wood to retard burning.
  - Use spark-proof switches and rodent-proof wiring to reduce the chances of sparks and electrical fires, as well as dust explosions.

TYPES OF STORAGE STRUCTURES

There are three main storage systems or packaging options for seeds:
- Bulk
- Bag
- Hermetically sealed containers

The system adopted depends on:
- type and quantity of seed;
- value of seed;
- purpose of storage; and
- intended length of storage.

The packaging method used conditions the choice of storage facility. For example:
- Packages allowing for free exchange of air (e.g. woven poly bags or paper bags) are best placed in conditioned storage, which provides a cool and dry environment that facilitates the free movement of air.
- Sealed containers (e.g. jars, cans or foil packets – typically used for high-value seeds) are best protected for extended periods in cold storage. This method is suited to situations where relative humidity is hard to control.

4

Storage facilities are generally classified as either **indigenous** or **improved/ modern**:

notes

- **Indigenous.** Smallholder farmers in rural areas have designed their own structures and methods for storing seeds in bulk or in a variety of smaller containers made from **locally available materials**. The **informal seed sector** predominates in many developing countries, and much of the seed farmers use is stored at local level in these indigenous storage facilities. Indigenous structures are not new inventions: they have survived the test of time.
  Their design and use vary according to climatic conditions, and reflect the tradition and cultural context of specific societies and an intimate knowledge of the environment. Consequently, many of the structures and practices at this level are **ecofriendly**. Depending on **local needs**, they differ in design, shape, size and function, and include: bamboo baskets, various wooden structures, underground pits, mud or brick structures, earthenware pots and gourds.
  The use of indigenous structures is closely associated with **local storage practices** and application of natural products as biological pesticides, insect repellents or disinfectants (e.g. neem oil and leaves, wood ash, cooking oil and cow dung).
- **Improved/modern.** Various kinds of traditional stores have been modified and improved to make them more suitable for **long-term storage**.

Bulk storage

Bulk seed storage takes place at both **traditional** and **formal/commercial** level. It involves the use of a wide range of storage structures.

Traditional or farm-level bulk storage

At farm level, seed is often stored in bulk in woven bamboo baskets or containers made from wood, metal or plastic. The containers are located inside the house or placed in special mud or wooden constructions. They vary in shape, size and capacity and are normally closed.

Advantages:
- Good protection against penetration by pests.
- Cool and dry microclimate (particularly in mud constructions).
- Airtight conditions – therefore oxygen is used up by respiration of pests and grains leading to self-destruction of pests.

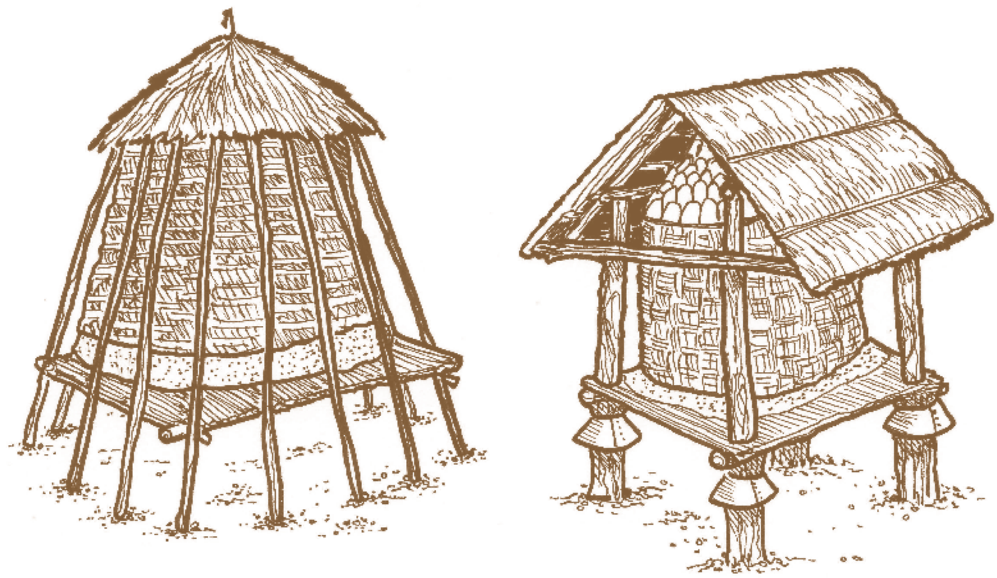
Disadvantages:
- Poor resistance to rain (mud constructions) – therefore regular repair work or rebuilding may be necessary.
- Appearance of cracks – providing ideal hiding places for insects.
- Risk of condensation (particularly in metal containers).

notes

Closed mud-walled bins or silos

Closed storage bins made of mud mixed with chopped straw are widely used in arid regions to store grain and seeds of sorghum, millet, pulses, paddy and peanuts. The silo usually has a lid; a straw roof provides protection against rain. It is raised above the ground to prevent soil moisture from entering, and guards are in place to keep out rodents. Moisture or condensation problems are virtually inexistent due to the low moisture content of the stored produce and the good insulation capacity of the mud used.

Mud-walled bins



Mud-walled thatched bins

4

Underground pit storage

On-farm storage in underground pits is a closed system for storing cereal seed and keeping it cool. It is used in dry regions of Asia, Africa and Latin America, where the water table does not endanger the contents. A **suitable site** must be chosen: relatively dry, with the right type of soil and free of termites.

There are several types of pits, most of them flask-shaped (i.e. wide at the bottom, tapering to a small opening at the top), covered with sticks, cow dung and mud, or with a large stone embedded in soft mud. The pit walls are covered with cow dung and mud, and made waterproof to prevent entry of both ground- and rainwater.

In areas with a sufficiently dry climate, underground stores are an excellent alternative to many other on-farm storage systems.

Advantages:

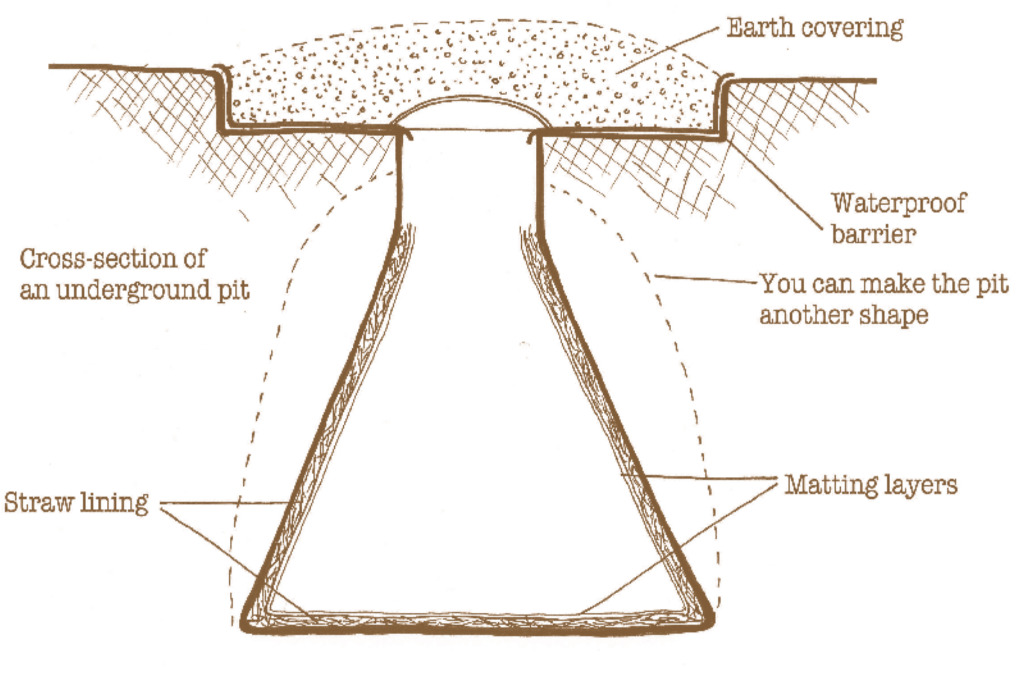
- Structure airtight and cool – not affected by fluctuations in temperature.
- Limited development of insects and mites and little growth of mould – if pit is kept satisfactorily air- and watertight.
- Environment more hygroscopic than the seed – tends to keep soil moisture away from the seed mass.

Traditional small bins

Traditional storage bins used by African farmers are small (e.g. calabashes, gourds, clay or earthenware pots, wooden containers and oil drums). They are used for closed storage of seed and pulse grains (e.g. cowpeas). They can be made hermetic by sealing the walls inside and out with liquid clay, and closing the small opening with stiff clay, cow dung or a wooden cork reinforced with cloth.

notes

Underground flask-shaped pit storage

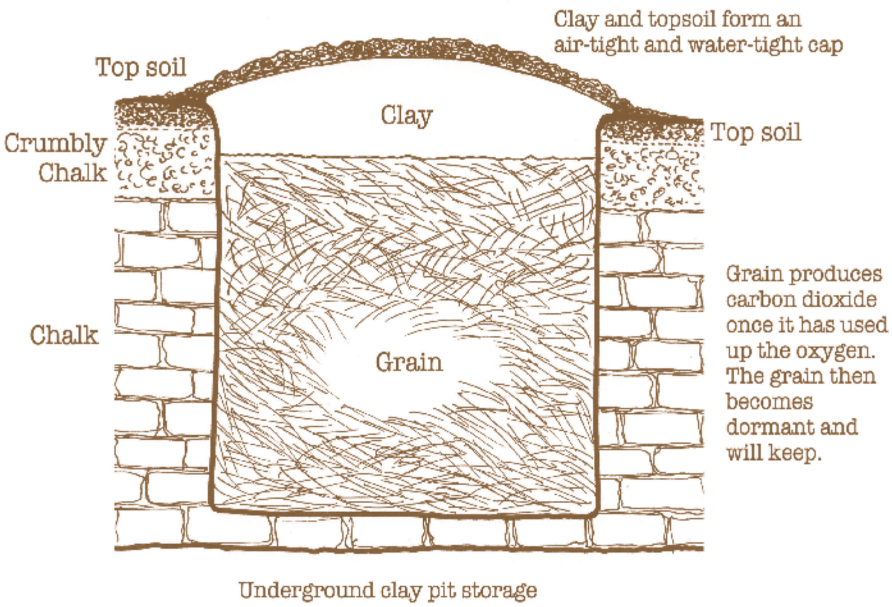


notes

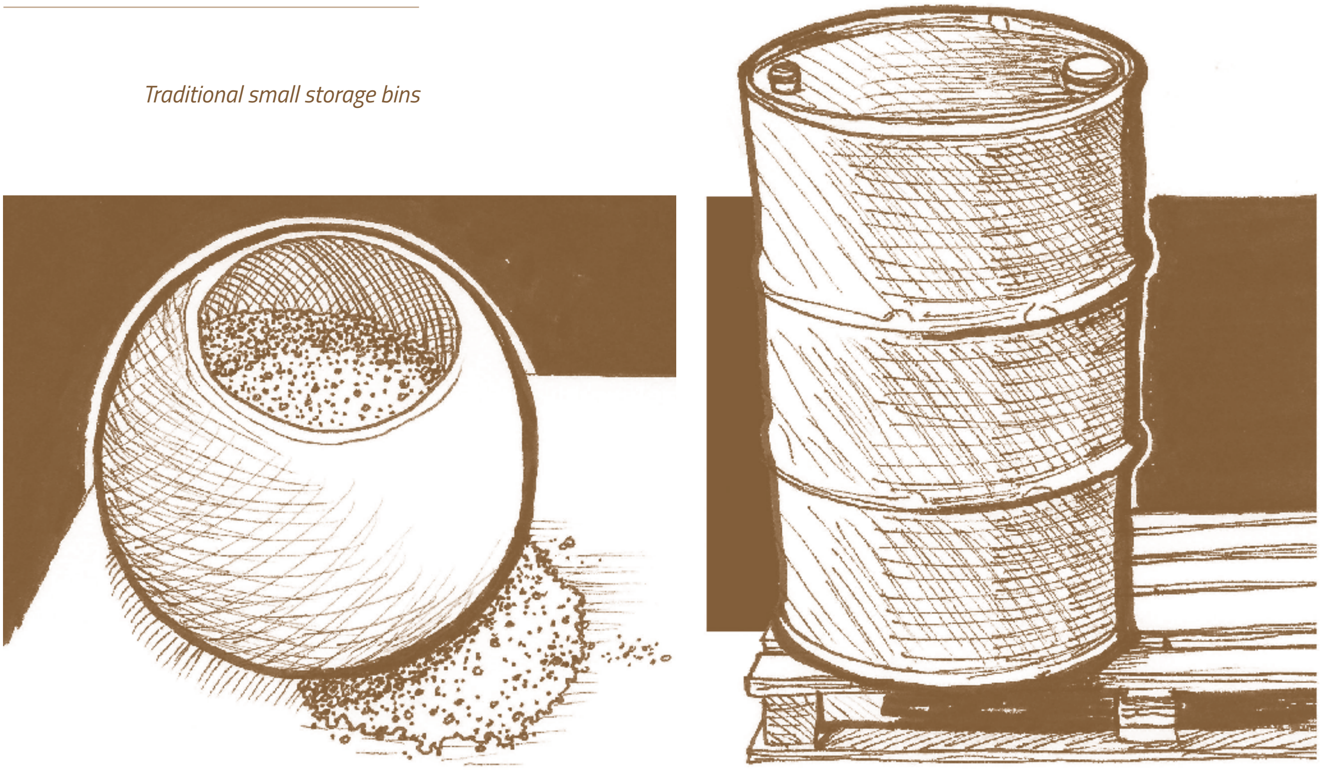
If the grain is dry (MC < 12%), small bins rarely present problems for storage. However, note that:

- condensation may occur in closed storage systems (especially in metal containers such as oil drums); and
- shade must be provided to maintain constant storage temperatures.

Figure 62. Underground clay pit storage



Traditional small storage bins



4

Plastered bamboo baskets

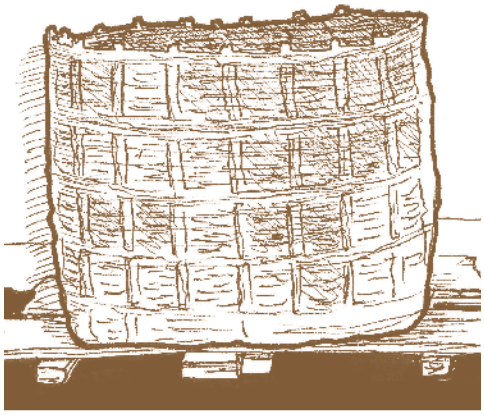
This is a traditional bin with large storage capacity. The walls are covered with a layer of straw and plastered with cow dung slurry. A layer of dried neem leaves is placed at the bottom. The cow dung slurry acts as disinfectant; the neem leaves act as insect repellent.

notes

Improved or commercial bulk storage

There have been several attempts to improve on traditional stores and make them more suitable for long-term storage. Many traditional stores perform excellently in their appropriate climatic conditions, while others can be improved with minor changes.

Plastered bamboo basket



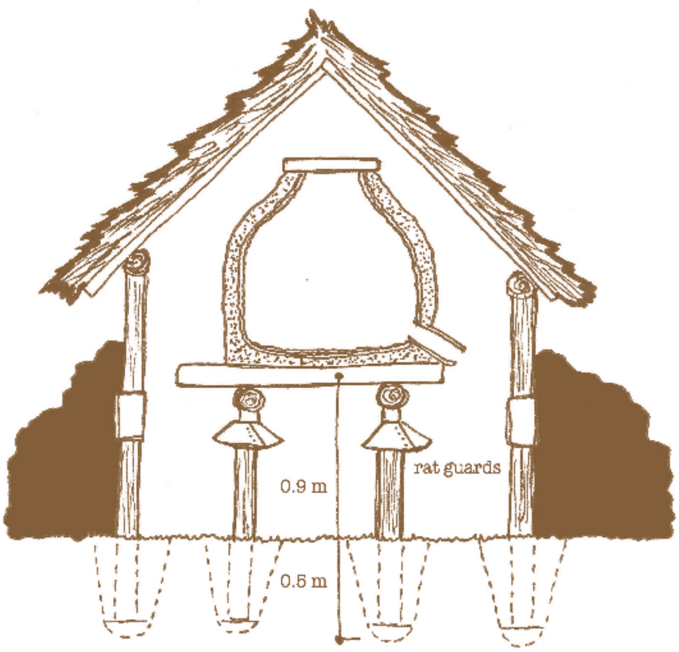
Improved mud bins

- Plaster the walls of traditional storage bins (woven baskets) with mud mixed with cement/lime (stabilized soil technique) to prevent cracks.
- Make the inlets and outlets more airtight by equipping them with lockable covers.
- Retain and improve other features (e.g. raised floor or platform, rat guards and thatched roof).
- Keep the surrounding area clean.

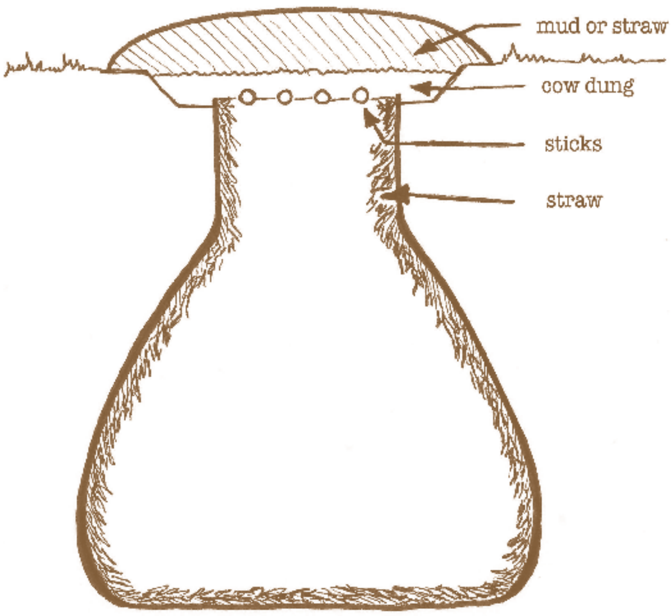
Improved underground pits

- Use plastic sheets or concrete mixed with mud and straw to improve the lining of the walls and make the pit more airtight.
- Seal the entrance to the pit and improve surface drainage around the pit to prevent seeds on the top and around the sides from becoming mouldy.

Improved mud bin



Improved underground pit



notes

Metal and concrete silos

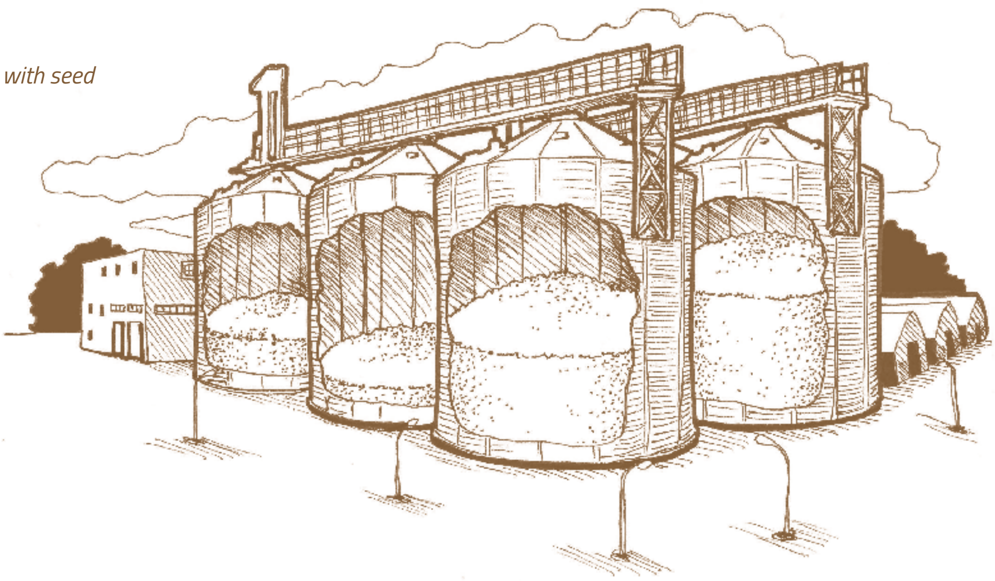
Large grain or seed collection companies sometimes use metal or concrete silos with a capacity of 20–2 000 tonnes. Silos are easily sealed for fumigation and little grain is spilt or wasted. On the other hand, they are not favoured in hot climates because hot spots and moulds form as a result of moisture migration inside the silo.

Advantages:

- Storage of large quantities.
- No need to purchase storage containers (e.g. poly bags).
- Low level of insect incidence (and when there are insect pests, fumigation is easier than in bag storage).
- No wastage (from leaking bags).
- Inspection easy, resulting in savings of labour and time.

Concrete silo

Metal silo with seed



4

Bag storage

notes

In many countries, the most common method for grain and seed storage is bag storage in a variety of buildings at smallholder, small-/medium-enterprise and large-scale commercial level. Building walls may be made of stone, local brick, corrugated iron, or mud and wattle, with or without plaster. The floor could be earth, stone or cement, the roof thatched or covered with corrugated iron sheets.

Advantages:
- Flexibility of storage
- Low capital costs
- Easy inspection

Disadvantage:
- Lack of protection against insects (therefore, some insecticide has to be used).

Bag storage of maize seed

Smallholder-level bag storage

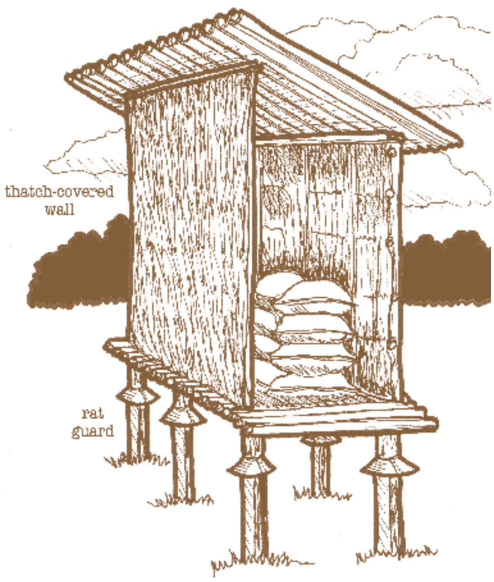
In dry climate countries, it is common practice to stack seed bags outside on raised platforms and cover them with a tarpaulin (or similar material) for temporary storage. If the seed is to be kept for a long period or if it is in large quantities, the bags should be stored in a building:

Corrugated iron sheet store

All openings between the floor and the walls should be closed (especially in warehouses with walls of corrugated iron sheets). The floor should be made of strong concrete to prevent rodents entering from below.

Corrugated iron sheet store

Ventilated crib with bagged maize seed



Ventilated crib

In relatively dry situations, bags of seed may be stored in a simple ventilated crib (traditionally used for drying maize) after making some minor adjustments:

- Cover the walls to provide protection against rain.
- Raise the floor to a ≥ 90 cm from the ground and equip the legs with conical rat guards made of metal sheets to make it rodent proof.

Stone, brick or mud warehouses

Long used for storing bags of grain, warehouses could be a multipurpose farm shed or even the farmer's own dwelling. Warehouse preparation entails the following:

- Cover the floor with cow dung paste to repel insect pests.
- Clean the mud floor and mud walls with cow dung and neem oil.
- Dip cloth or jute bags in neem kernel solution and hang in shade to dry – the neem repels storage grain pests.
- Insert a raised free-standing platform equipped with rat guards to protect bags from rats and mice.

Mud warehouse with bagged grain

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notes

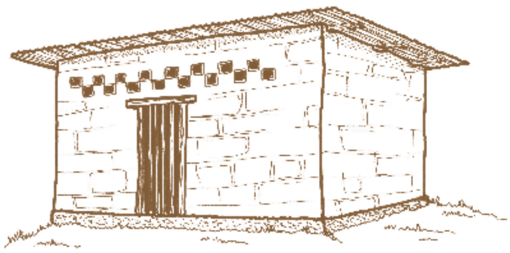
Improved or commercial bag storage

Small block-built warehouses

Large quantities of cereal seed may require a special building, such as a small block-built bag store (20 m², 15-tonne capacity). Improvements are necessary:

- Ensure that the floor is made of good quality concrete.
- Attach a tight-fitting door to prevent entry of rodents.
- Screen ventilation openings to keep out birds – if fine mesh is used to also prevent insects from entering, carry out regular maintenance: brush away dust and repair holes immediately.
- Close gaps between the wall and the roofing sheets with cement.

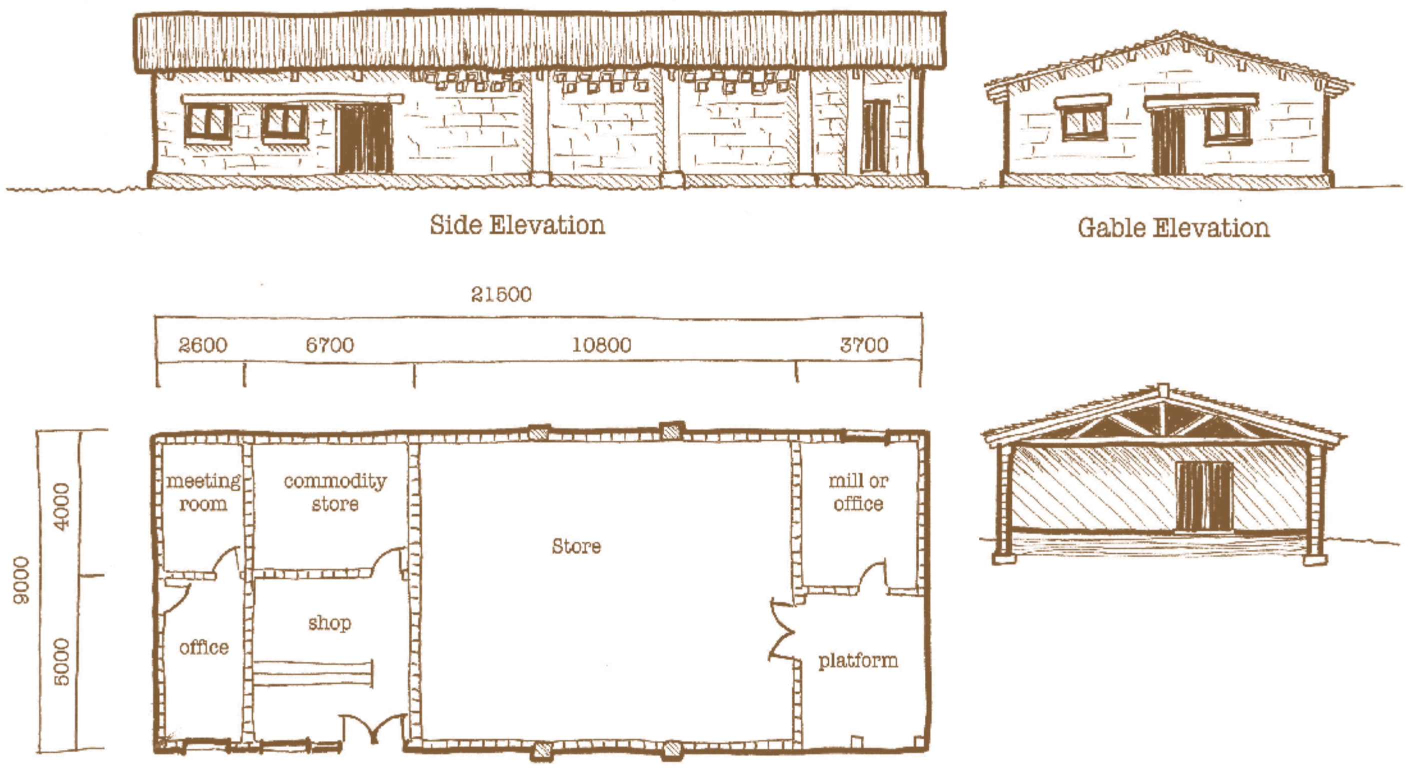
Small block-built bag store



Multipurpose stores

For commercial purposes and large quantities, one solution is a multipurpose store with 90 m² (extendable) bag storage space suitable for village cooperatives and other small-scale enterprises.

Design of multipurpose store



notes

Hermetic storage

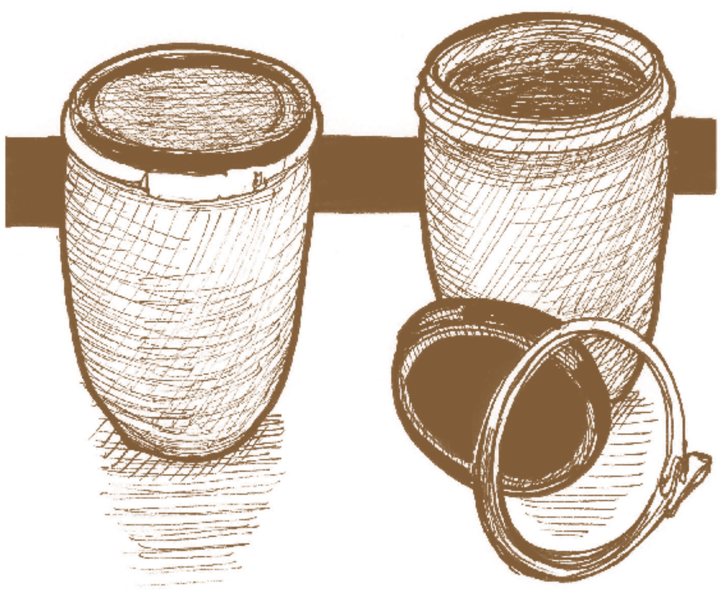
Sealed or hermetic storage systems are a very effective means of controlling seed moisture content and insect activity, especially in tropical conditions. They **provide moisture and insect control without pesticides**. Seeds are placed inside an airtight container, creating a barrier between the seed and the outside atmosphere, which prevents movement of oxygen and water between the outside atmosphere and the stored grain.
Hermetically sealed containers are used to store many crop seeds, including vegetables, cereals and legumes. They come in different forms, shapes and sizes, and can store from a few grams (high-value vegetable seeds) to 2 000 tonnes (cereal seeds). They may be made of glass, laminated foil or metal. In transparent glass containers, both the seeds and the humidity indicators are visible, facilitating monitoring.

Advantages:
- Stable moisture content of stored seed.
- Death of most insects as biological activity inside the sealed container consumes the available oxygen.
- Extended viability of seeds due to reduced oxygen content, which slows down the seed respiration rate while retaining sufficient oxygen for germination when needed.

Rural-level hermetic storage

Not all farmers are able to purchase commercially marketed containers. However, containers used in local markets can be easily **converted into hermetic storage systems** – for example, special polyvinylchloride (PVC) containers or sealed 200-litre metal oil drums. When closed, the container should be airtight: **lids with rubber** seals clamped onto the container are much more effective than ordinary screw lids. It is important to keep the container closed until planting, when the seeds should be used all at once.

Hermetic storage PVC container



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notes

Improved or commercial hermetic storage

Custom-made bags and containers are manufactured for hermetic seed storage and marketed for use by smallholders. Generally, the moisture content of seed in hermetically sealed containers should be 2–4% lower than that of seed in conventional storage.

Cereal and legume seed solutions

- **Cocoon** – two plastic halves are joined together with an airtight zipper that is closed once the cocoon has been loaded with sacks of seed.
  Advantages:
  - Extended germination life of seeds.
  - Chemical-free insect pest control.
  - Simple ground-level storage on concrete floor or pallet.
- **Bulk bags** – water-resistant and gas-tight, these bags are equipped with heavy-duty ultra-hermetic zippers and gas-proof, UV-resistant liners. They can be placed on any elevated platform that allows the grains to be unloaded through a downspout.

Cocoon hermetic storage bag

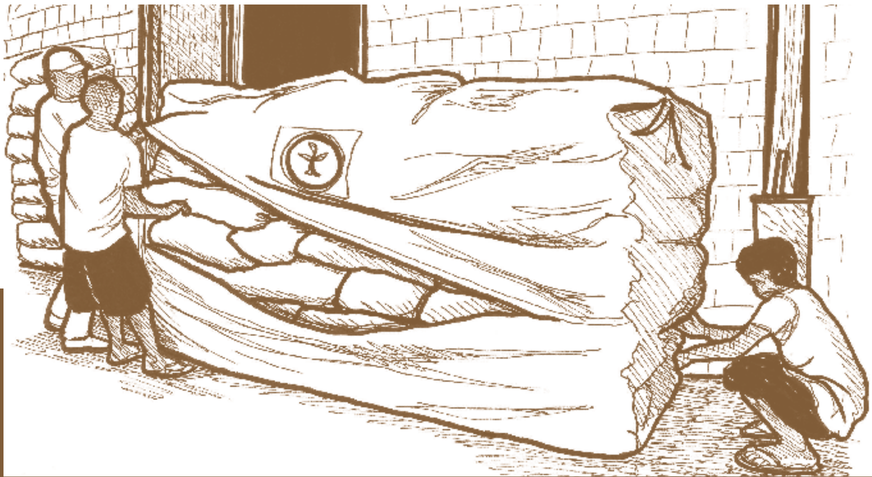
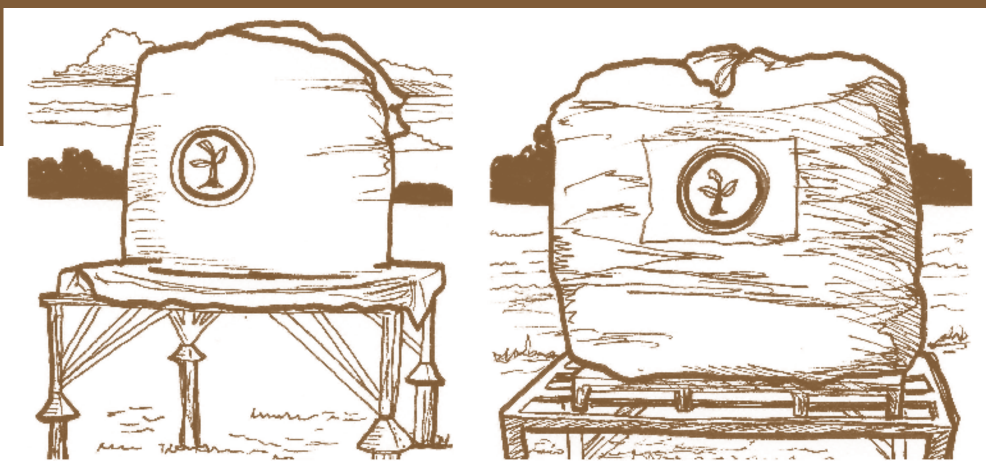


Figure 77. Hermetic storage bag



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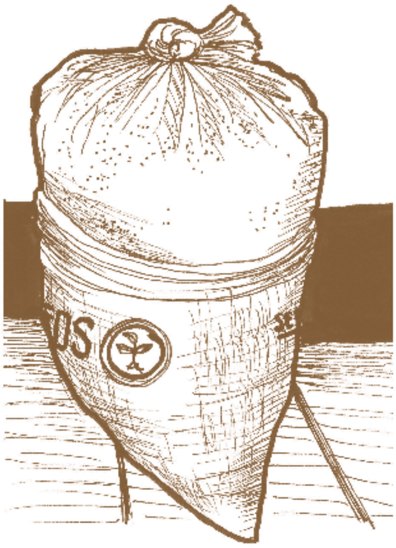
Triple-layer sacks for grain storage



- **Triple-layer sacks** – comprise two high-density polyethylene plastic liners and a printed woven polypropylene bag for reinforcement. They contain 50 or 100 kg of seed (i.e. more than the average farm household requirement), but can be compressed to store smaller quantities (e.g. 20–25 kg). Different seed lots are stored in separate, non-hermetic sacks, then placed inside the larger sacks.

  Advantages:
  - Storage from > 1 household or > 1 crop.
  - Effective long-term grain storage.

- **Silos** – most large commercial steel and concrete silos used in industrialized countries for bulk storage can be **sealed** to serve as hermetic storage systems. They can also be temporarily sealed for **fumigation**. For **long-term** hermetic storage, special plastic enclosures should be used.

Vegetable seed solutions

Most pre-dried vegetable and flower seeds moving in international trade are stored in moisture-proof hermetically sealed containers (e.g. aluminium cans or laminated aluminium-foil sachets or pouches). Metal cans are used for 100–2 500 g of vegetable seeds; aluminium-foil pouches are used for 50–250 g of pre-dried vegetable and flower seeds. Seed remains viable for several years.

OPEN STORAGE

In addition to bulk, bag and hermetic storage, seeds can be stored in open systems especially at **traditional level in tropical countries**. Under hot and humid climatic conditions, open storage systems may be the only option at farm level, because seed is still moist when put into storage. Open systems are generally **simple constructions** and strict storage hygiene can be difficult to apply.

Hermetic storage of pre-dried vegetable seeds

Advantages:

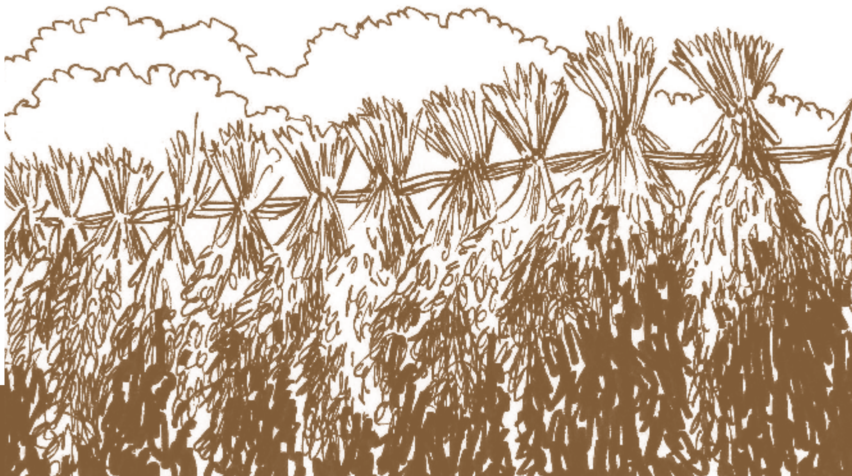
- Continuous drying while in storage due to strong natural ventilation.
- Restricted development of fungi, also due to natural ventilation.

Disadvantage:

- Unrestricted access by insects, rodents and birds.

Farm-level open storage systems:

- **Hanging platforms** – platforms resting on wooden stakes, on which cobs or panicles are stacked in layers; a straw roof provides protection against the rain.
- **Hanging over fire and smoke** – seed crops hung under the roof of farm-houses; the fire and smoke dry the seed and repel insects.



Farm-level open storage practices

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Improved open storage systems

Seeds are stored in semi-open cribs, well-ventilated but protected from rain and rodents.

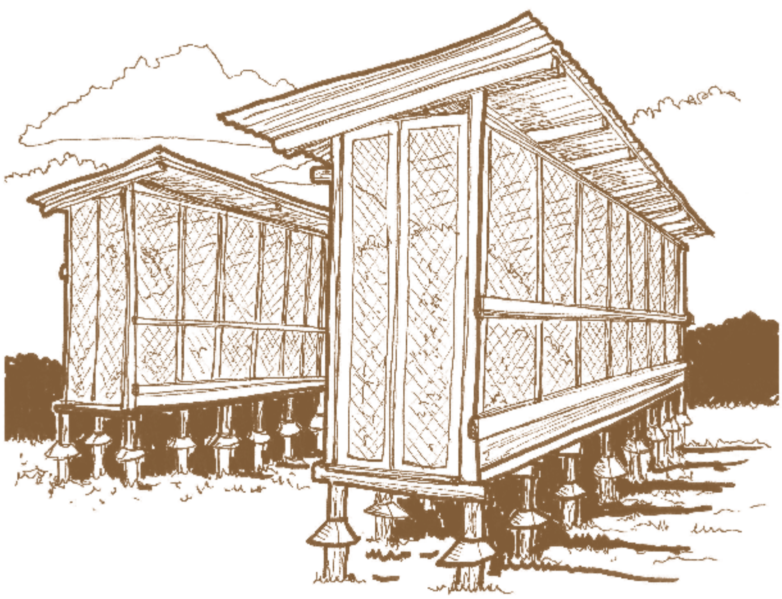
STORAGE MANAGEMENT

Storage management is important for all types of storage. However, herein the focus is on **bag storage** – the most common organized system of seed storage. The storage of bagged seed requires a warehouse facility, designed and constructed according to certain specifications regarding location, technical design, dimensions and supplementary structures and facilities. Once the **warehouse** is constructed, fully equipped and in operation, the day-to-day **routine management** of the facility becomes critical.

Location

- **Topography of area.** Erect the warehouse on level or slightly raised ground, well-drained and not prone to flooding.
- **Characteristics of soil.** Ensure that the soil is firm enough to bear the warehouse load and has good drainage characteristics.
- **Proximity to main road.** Site the warehouse as close as possible to a main road for easy access and movement of stocks, including raw seed from contract farmers, materials from suppliers and processed seed to customers. Ensure that there is sufficient space for easy movement of vehicles around the warehouse and for erection of additional warehouses and utility buildings in the future.

Improved open storage for bulk seed



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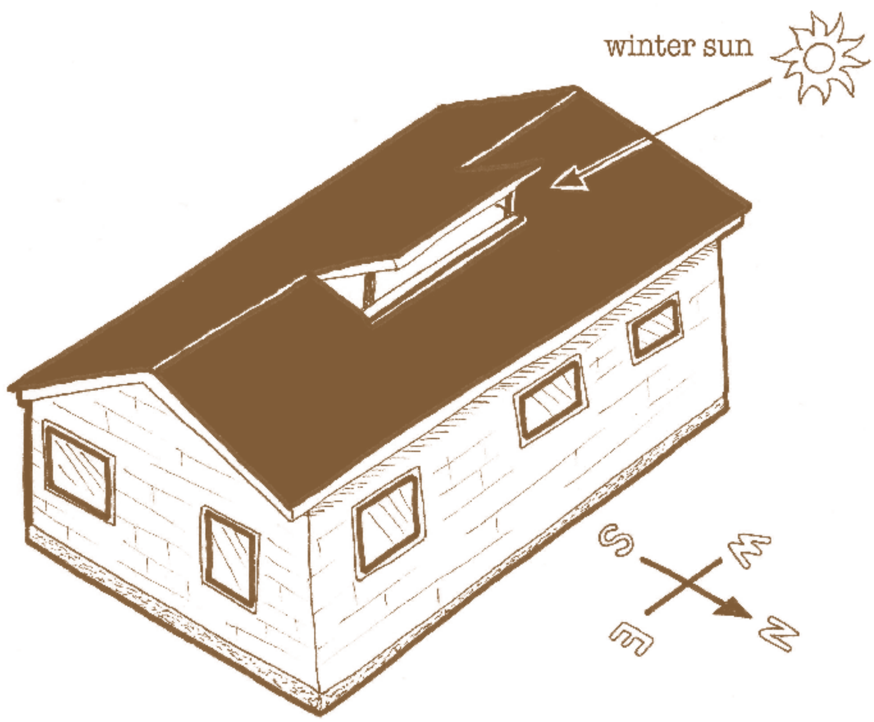
- **Orientation of warehouse.** In tropical countries, orient the long axis of the warehouse as close as possible east–west, to reduce exposure of sidewalls to the sun and to minimize temperature variation inside. If east–west orientation is not feasible, situate across the direction of the prevailing wind to benefit from cross ventilation and effective cooling.
- **Proximity to residential homes.** Situate the warehouse at a safe distance from dwelling houses, market centres and other public areas to protect people from the toxic gases used in fumigation.

Technical design

The basic components of a warehouse are: floor, walls, roof and door(s). The details and construction vary, and may include additional features (e.g. ventilators, windows and artificial lighting). **All warehouses must:**
- ensure that seed quality is not affected by moisture and temperature;
- provide protection from rodents and birds;
- be easy to clean and maintain; and
- offer good working conditions.

Particular attention should be paid to the following **features**:
- **Foundations and floor.** Build strong foundations, ensure that the floor can bear the weight of the stacked grain, and render it impermeable to groundwater. Position the floor sufficiently above ground level to ensure that water does not enter – even after the heaviest rainfall.

Orientation of seed warehouse



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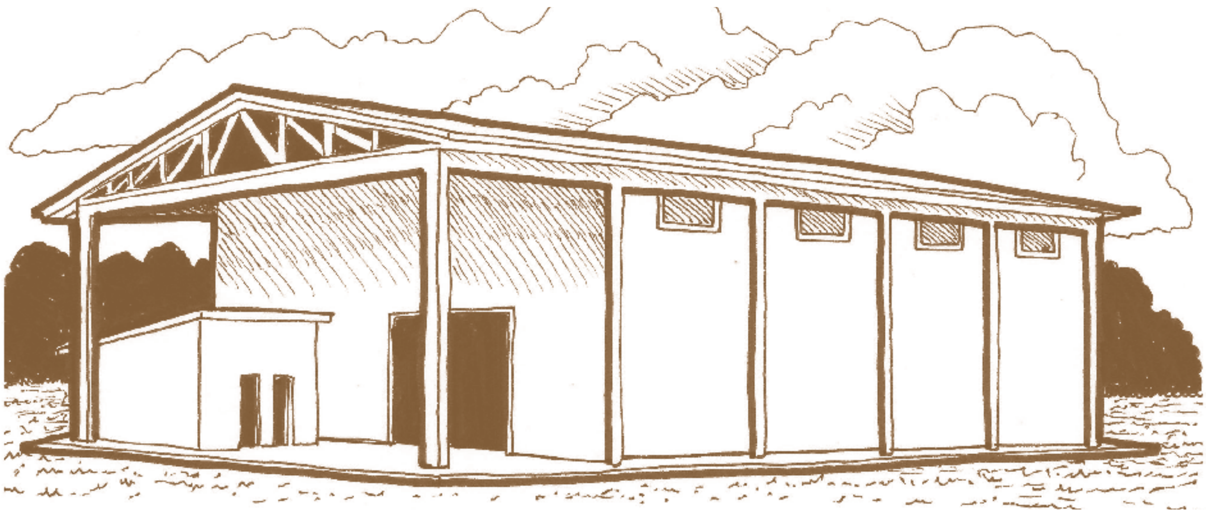
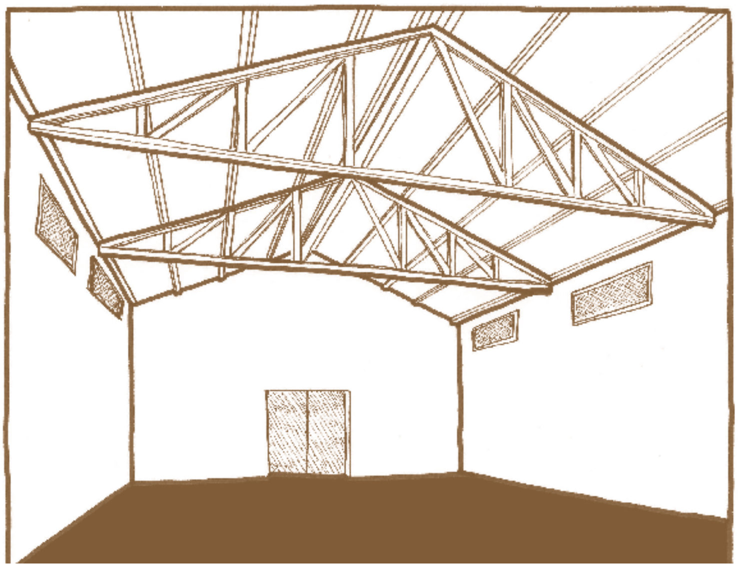
- **Walls.** Leave the internal surfaces of the walls smooth and free from projections to facilitate cleaning of the store, protect against rodents and avoid interference with other operations. Paint the walls white: on the inside to facilitate detection of insect pests, on the outside to keep the warehouse as cool as possible.
- **Roof.** Cover the roof with corrugated iron or aluminium sheeting. Fix the roof so that it overhangs the gables: to ensure that rainwater is shed well clear of the walls; to keep the walls cool; and to protect ventilation openings from rain.
- **Ventilation.** Incorporate ventilation openings: to allow the cross movement of air, reduce the temperature inside and permit light to enter. Place ventilation openings sufficiently high under the eaves to prevent the entry of water, rodents, thieves etc. Fix anti-bird mesh grills on the outside and anti-insect mesh screens on the inside (removable for cleaning).

Inside views of standard seed warehouse





Source: Cruz and Diop (1989)

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- **Doors.** The number of doors varies depending on the size of the warehouse. If possible, include ≥ 2 doors, to enable rotation of stocks on a "first in–first out" (FIFO) basis. However, this may not be possible or practical in a very small warehouse. Use double sliding steel doors if possible, and ensure that they are close-fitting to protect against rodents. Doors must be sufficiently large, and swing doors should open outwards to maximize storage capacity. Build a roof extension or a separate cover if possible, to protect doors from rain.
- **Illumination.** Provide sufficient light for the safety of workers inside the facility. In most warehouses, the daylight filtering through ventilation gaps, windows and doors is adequate when all open doorways are in active use. However, when no workers are inside the warehouse, keep doors closed to protect from theft and rodents. Use artificial lighting only in warehouses regularly accessed during hours of darkness.

notes

Dimensions

To calculate the dimensions of a warehouse, there are four main parameters: specific volume of seed; maximum tonnage; stack height; and lot separation.

- **Specific volume (bulk density) of main seed type to be stored.** Refer to Table 5 for the specific volumes of a range of warehouse storage products (note that specific volume is defined as the volume occupied by 1 tonne of the bagged seed [m^3/tonne]).
- **Maximum tonnage (maximum weight that the facility can store).** Consider the purpose for which the warehouse is required, including projected long-term requirements.
- **Stack height (maximum stack height desired).** Height depends on the purpose for which the warehouse is required, the nature of the seed and the type of bag used. Bags made of woven polypropylene tend to slide on each other: stack ≤ 3 m high. Jute sacks bind together: stack ≤ 6 m high. Do not allow stack height to exceed wall height, and allow ≥ 1 m between the tops of stacks and roof frames.

Table 5. Specific seed volume of different commodities

Commodity	Specific volume (m^3/tonne)
Bulrush millet	1.25
Beans, peas, lentils	1.30
Wheat, milled rice, coffee	1.60
Maize, sorghum, decorticated groundnut, palm seed	1.80
Soybean, cocoa	2.00
Wheat flour, maize meal	2.10
Cotton seed	2.50

notes

- **Lot separation (the extent to which separation of lots is desired).** Lot separation is important for identification purposes and to prevent contamination. Provide gangways between and around stacks for better stock control. Leave 1-m width between stacks and between stacks and the walls. Provide one or more areas ≥ 2 m wide to handle incoming and outgoing stocks.

The box contains an example of how the dimensions of a warehouse are calculated using the above parameters.

Example
A warehouse needs to store 1 000 tonnes of maize in jute bags in 4 separate lots, each 5 m high. The warehouse is to be rectangular, with the length approximately twice the width. It comprises: a main handling area (3 m wide) situated along the axis of the warehouse; a gangway (2 m wide) across the centre of the warehouse; and an inspection space (1 m wide) around the entire stacking area. Calculate the **floor area** required and percentage utilization of the building.

Solution
The total volume of the seed stock is equivalent to the total tonnage multiplied by the specific volume of maize (see Table 4):

1 000 (tonnes) × 1.8 (m^3/tonne) = 1 800 m^3

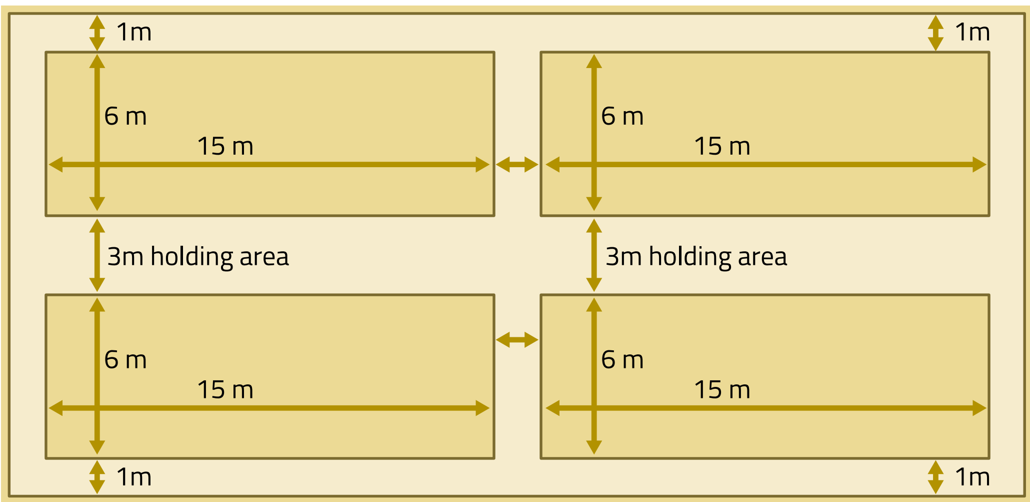
If the sacks of maize are stacked 5 m high, the required floor area is:

$$\frac{1\,800}{5} = 360 \text{ m}^2$$

If length (L) = 2 × width (W), then:$2W^2 = 360 \text{ m}^2$, or W = 13.4 m

Let W = 12 m; then, for an area of 360 m^2, L = 30 m

Considering that the stock is kept in 4 separate lots (each measuring 6 × 15 m), and respecting the floor space requirements, the internal dimensions of the warehouse are illustrated as follows:



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The internal dimensions of the warehouse are:

- Width (W) = 1 m + 6 m + 3 m + 6 m + 1 m = 17 m
- Length (L) = 1 m + 15 m + 2 m + 15 m + 1 m = 34 m
  giving a total **floor area** of **578 m²**.

If the warehouse has a trussed roof, the walls should be at least 1 m higher than the intended stacking height: in this example, 5 m + 1 m = 6 m.
The **percentage utilization** of the building will then be:

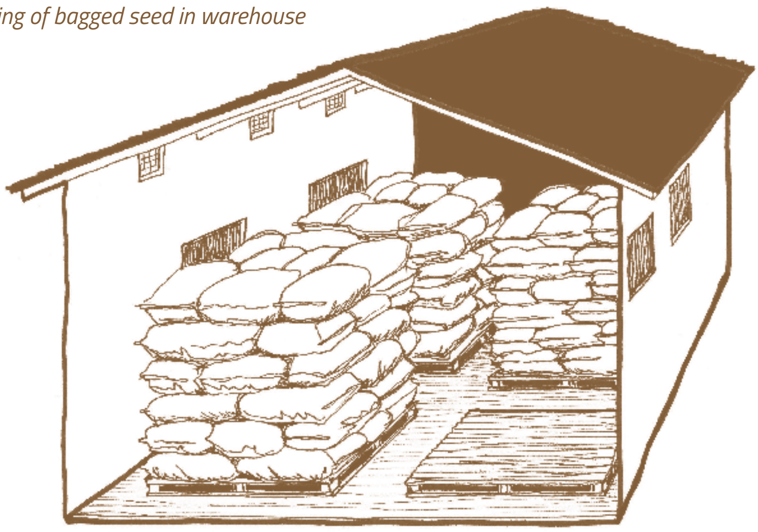
$$\frac{1\,800}{578 \times 6} \times 100 = \mathbf{52}\%$$

A storage structure should be economical and suitable for a particular situation. In small-capacity warehouses (10–30 tonnes), only about 20% of the space is usable. In medium-capacity warehouses (50–100 tonnes), about 30% of the space is usable. **The larger the warehouse, the more economical it is in terms of cost of construction per tonne stored.**

Routine storage management for bagged seeds

General storage management is the task of the **storekeeper**, who should manage the warehouse properly, keep it in good condition, and make sure all activities are carried out properly and completely at the right time. Even with the best storage facilities, seeds deteriorate and costs can increase significantly if management procedures are inadequate to keep the seed in good condition and maintain favourable storage conditions.
In most parts of Africa and Asia, cereal seed is stored in 40–80-kg bags made from either jute or woven plastic. Bags are normally organized in stacks comprising ≥ 1 labelled seed lots. Carefully construct the stacks to maximize use of space, maintain hygienic conditions and facilitate good storage management (including loading and unloading). For **bag storage**, routine warehouse management must take account of a wide range of considerations, described in detail below.

Stacking of bagged seed in warehouse



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Protection from moisture and excessive temperature

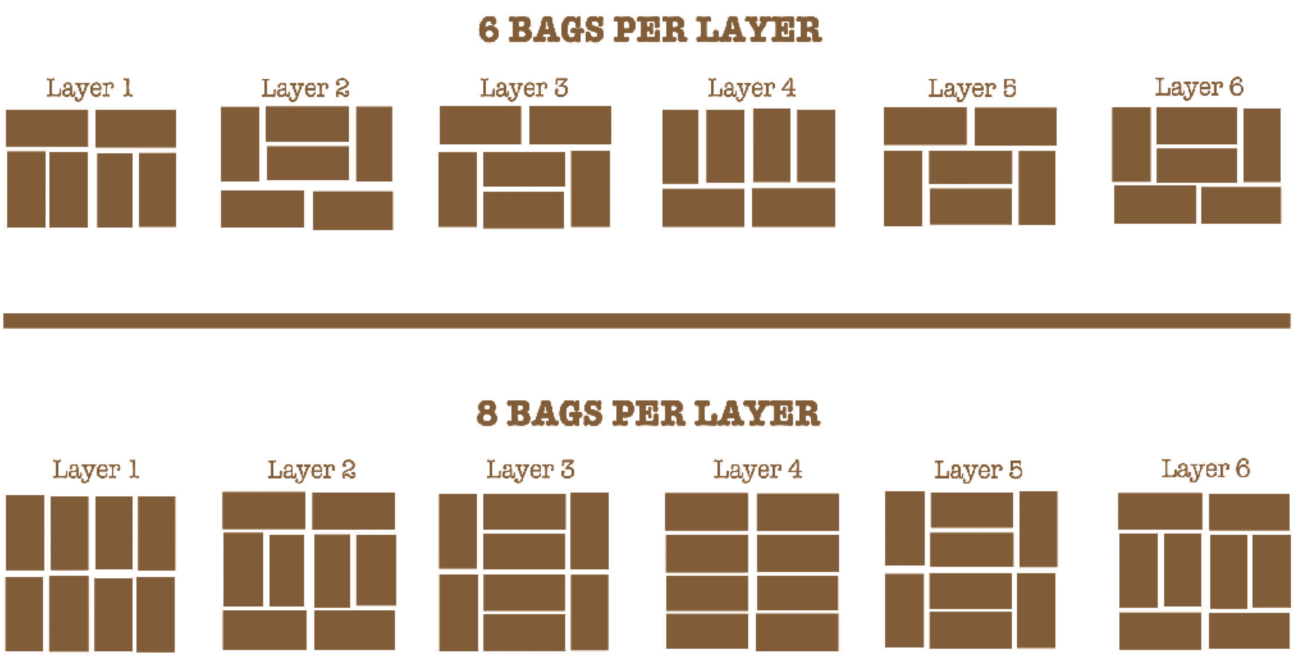
- Stack bags on pallets off the ground to prevent damp from the floor reaching the seed.
- Position stacks away from the walls to protect seeds from damp and heat.
- Include proper ventilation and use damp-absorbing materials to avoid damp and minimize heat from the roof.
- Leave a 1-m gap between and around stacks and 1–1.5 m clearance between the top of the stack and the roof to allow ventilation and prevent sweating of bags.

Height of seed stacks and pattern of construction

Proper stacking is an important factor in storage management. It ensures efficient use of storage capacity and prevents damage to seed. Excessive height can cause mechanical damage to seed at the bottom (due to pressure or weight) and to seed at the top (if bags fall or slip).

- Stack bags on pallets in a pattern to prevent them falling or sliding.
- Do not stack > 6 layers of bags on a pallet.
- Do not stack jute bags > 5 m.
- Do not stack plastic bags > 3 m – plastic bags are slippery and the stacks are less stable.
- Ensure that there is overlap or interlocking in each successive layer of bags – bags laid exactly on top of each other in successive layers results in instability.

Stacking patterns for different layers on bags in a seed stack



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Storage hygiene, inspection, stock control and fumigation

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Furthermore, good stacking of the seed bags has other benefits:

- Hygiene – there is easy access for sweeping the floors.
- Inspection – stacks are easily checked for incidence of insects and rodents.
- Stock control – bag counting is simple.
- Fumigation – stacks of set dimensions can be sealed with a single fumigation sheet.

Control of insects, rodents and birds

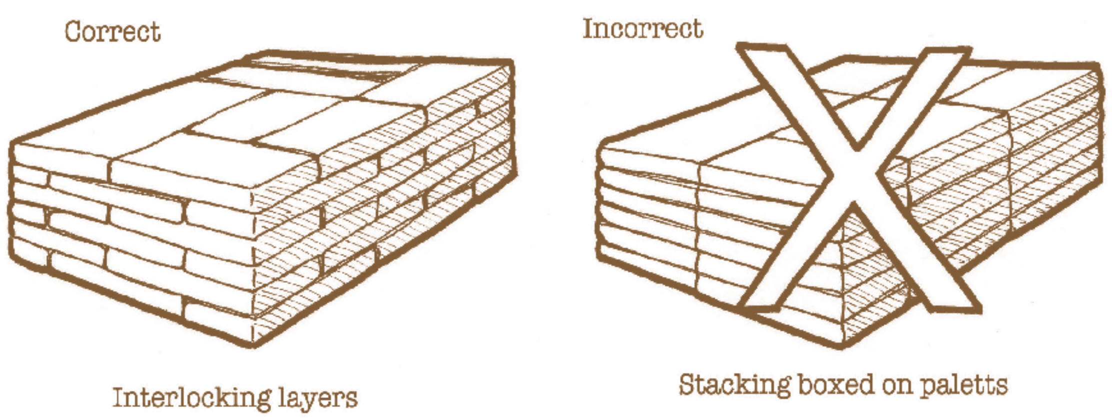
- Ensure the building is rodent and bird proof.
- Treat the building and seeds against pests.
- Keep the warehouse clean.
- Close all holes (in doors, roof etc.) through which pests could enter.
- Repair cracks in walls where pests might hide.
- Remove and destroy infested residues that could contaminate new seed stocks.

Maintenance of seed lot identity

Loss of a seed lot's identity corresponds to loss of its value. Maintain seed lot identity:

- Identify every bag with secure labels providing detailed information about the seed lot.
- Divide the storage space into small numbered areas using painted lines on the floor.

Correct and incorrect bag-stacking methods



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Preservation of seed purity

Contamination and mixture of seeds result in decreased value and reduced quality. Prevent loss of purity:

- Keep bags in good condition, in their correct lots and assigned areas.
- Avoid scattering of seeds.
- Stack each seed lot separately.

Management of carry-over

Proper management of carry-over seed is essential to minimize deterioration:

- Estimate anticipated carry-over at harvest time and ensure it is placed in safe storage as soon as possible.
- Carry over only lots with high seed viability and vigour.
- Sell immediately lots with relatively low viability and vigour.

Record-keeping

- Adhere to a general rule of FIFO to minimize storage duration (and costs) and limit the effects of deterioration due to ageing.
- Maintain accurate records of incoming and outgoing seed stock on bin cards.
- Keep updated on a computer spreadsheet and/or on a separate card for each seed lot the following information:
  - Lot number
  - Crop and variety
  - Year of production
  - Initial total weight and number of bags
  - Weight of each seed bag
  - Quality test dates and results
  - Storage location
  - Date and amount of each quantity sold and delivered
  - Date and address of delivery
  - Amount remaining after each sale

Preparation of progress reports

Planning is fundamental and the seed enterprise manager and the marketing unit require up-to-date and regular reports in order to plan the marketing process properly, for example, arranging to move excess seed from one area to another. Reports should include the following:

- Storage unit name and location
- Lot number
- Crop and variety
- Amount and dates of seed sales and delivery
- Destination address
- Seed quality information (germination and date of tests etc.)

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STORAGE OF EARLY-GENERATION SEED

notes

High-value early-generation (breeder and foundation) seed may be deliberately stored for extended periods. This is an **efficient strategy,** as it means that it is not necessary to produce every season seeds for which there may only be limited demand during any given season.
However, it involves **high costs**. Therefore, early-generation seed production and storage is often part of a centralized system meeting the needs of various seed companies, which can thus benefit from **economies of scale**.
Early-generation seed should be stored in air-conditioned facilities. Although costly to acquire and maintain (especially if large seed volumes are involved, such as cereal and legume seeds), **air-conditioning is a necessary investment** – especially in tropical areas, where high temperatures and high humidity result in equilibrium moisture content above safe levels for normal storage under ambient conditions. An example of early-generation seed requiring air-conditioned storage are minitubers of potato produced through tissue culture for use in the production of disease-free certified seed potato stocks.

An alternative to air-conditioning is **dehumidification**. Desiccant dehumidifiers control the air around the seeds to prevent them absorbing excess moisture that can lead to fungus growth.

STORAGE OF PLANT GENETIC RESOURCES

Collections of seed and clonal material are traditional ways of storing genetic resources. They are placed in **gene bank** facilities in **long-term storage** and tested for viability every 5–10 years.
Seeds are normally held under conditioned storage, usually at –18 °C in foil bags, but sometimes cryopreserved in liquid nitrogen (–196 °C). Seeds stored in foil-lined paper bags may be bar coded for identification and tracking. Seeds are sometimes stored underground on movable shelves under controlled conditions of temperature and humidity. Long-term germplasm preservation for tissue cultures is possible through freeze-preservation of cultured cells and meristems. All these methods require the use of **sophisticated techniques** and **expensive equipment**.
A cheap alternative is **cold storage** of cultures at 0–15 °C. This method can be as simple as placing a container of sterile shoots in the refrigerator.
For more information on storage of plant genetic resources, refer to the *FAO Genebank Standards for Plant Genetic Resources for Food and Agriculture* (2014).

STORAGE OF RECALCITRANT SEEDS

In contrast to orthodox seeds, the **deterioration of recalcitrant seeds is difficult to control**: the seeds are already damaged by drying, and sub-zero temperatures would result in death from freezing due to ice formation. The physiological basis of recalcitrant behaviour is not fully understood, and there

notes

has been much research on the storage physiology of recalcitrant seeds, with little success in developing a viable storage method to extend their shelf-life.
The only methods available are for **short-term storage**. Most recalcitrant seeds can only be stored for a few weeks or months before viability is lost. The seeds are treated with fungicide and placed in thin polythene bags in a moist, inert medium (e.g. charcoal or sawdust), so that they remain moist with access to oxygen.

STORAGE OF PLANTING MATERIALS

As with recalcitrant seeds, **long-term storage of vegetative planting materials is difficult**. Indeed, the availability of healthy planting material is a major limiting factor in the production of root and tuber crops, such as Irish/white potato, sweet potato and cassava.

Sweet potato

The successful production of sweet potato depends on the selection of high-quality planting material in the form of **undamaged fresh cuttings** from healthy mother plants. Vines should be fresh and clean with approximately 6–8 nodes per 20–30 cm length. The period between cutting and planting may affect yield, depending on the **storage conditions of the cuttings**:
- Storage for 1–2 days in humid conditions may be beneficial, promoting rooting at the nodes.
- Storage for > 2 days may adversely affect establishment, due to desiccation and depletion of energy reserves in the cuttings.

Various techniques are applied to **reduce losses**:
- Strip leaves from the lower portion of the cutting.
- Wrap bundles of cuttings in a wet cloth or sack and keep them in a cool, shady place away from wind.
- Preserve planting materials in swamps, shady areas of the household yard or around drainage areas.

Note that if roots develop during storage, they should be planted carefully to minimize damage to the roots.
In some areas, farmers purchase planting material from **specialized suppliers** with good access to water. However, such sources **are not accessible** to the majority of smallholder farmers, in particular women farmers.
When insufficient stem cuttings are available, or when the level of pest and disease infestation is high and it is difficult to produce healthy vines, storage roots of sweet potato may be used for **propagation**.

Sweet potato production in dry areas

In areas with a **prolonged dry season**, farmers are unable to access planting material from the previous field crop, because the vines die due to lack of moisture or they are eaten by livestock. Moreover, when the rains do come, farmers

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cannot plant straight away, as no planting materials are available: they have to wait until the rains cause old roots left in the field at harvest to sprout and produce new foliage and vines; this causes **delays in planting**.

Lack of planting material at the onset of rains is a major constraint to sweet potato farming in sub-Saharan Africa.

In order to ensure access to sufficient high-quality planting materials at the start of the rains, dry-season storage or preservation is necessary. Farmers in parts of sub-Saharan Africa with an extended dry season adopt a technology known as **"Triple S"** (Storage–Sand–Sprouting): storage roots are stored in sand, then planted out and watered to encourage sprouting before the rains. The **advantages of the Triple S** technology include:

- early planting;
- production of large amounts of planting material; and
- high yields (because farmers take full advantage of the rains).

Preserving sweet potato root in sand (left) and sprouting into vines (right)

Cassava

Pests and weather conditions can predispose cassava cuttings to dehydration, leading to loss of viability and reducing the availability of planting materials. Efficient storage permits the preservation of good quality planting material in the form of **stem cuttings from mature and healthy plants**. Like sweet potato vines, cassava cuttings should be thick, fresh, with no bruises and have about 6–8 nodes per 20–30 cm length.

A **cassava stem shed** is used for storage, as it:

- provides a cool environment;
- promotes humidity; and
- permits sufficient ventilation.

In **Africa**, the cassava stem shed is constructed using **farm materials**:

- Roof – thatched.
- Sides – covered to half of the height by thatching; the remaining half is uncovered.
- Floor – excavated; the topsoil is removed and replaced with porous soil (preferably from river-bed sand).
- Inside – lined with wooden planks on which the bundles of cassava stem are laid.

Gradual mixing of neem ash with water for dipping of cassava stems

Preparation of the cassava planting material involves the following steps:

- Cut selected cassava stems into 1-m lengths and tie into 50-stem bundles.
- Dip the cassava bundles into Actellic solution or neem tree ash solution and air-dry.
- Package the stems in perforated polythene bags for preservation in dry areas.
- Place the bundles upright ensuring that the rare ends of the stems touch the shallow porous soil in the cassava stem shed.
- Wet the soil twice weekly (reduce to once weekly when sprouting is noticed).
- Remove sprouts as necessary.
- Use stems when conditions are suitable for planting.

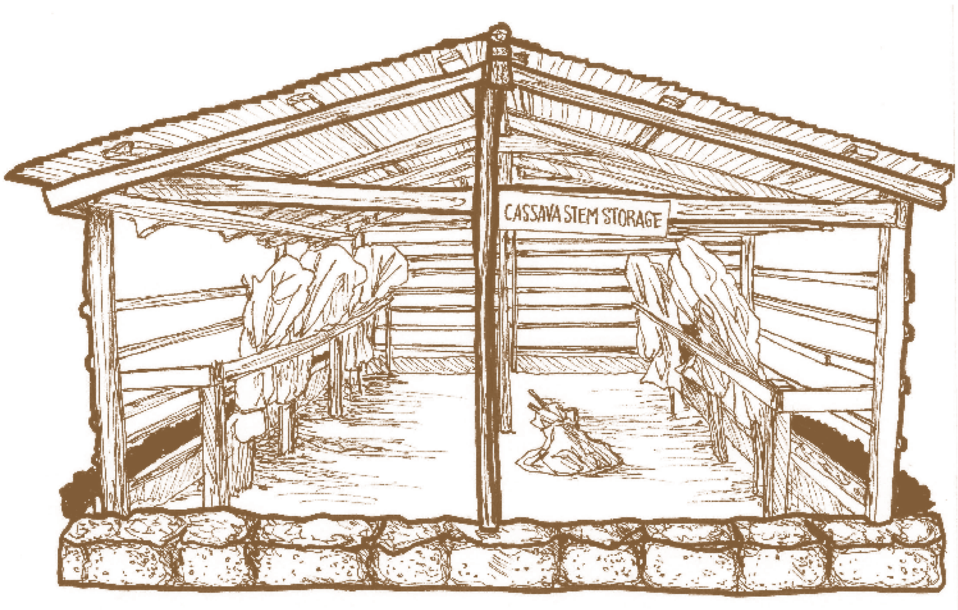
notes

EXERCISES AND DISCUSSION POINTS

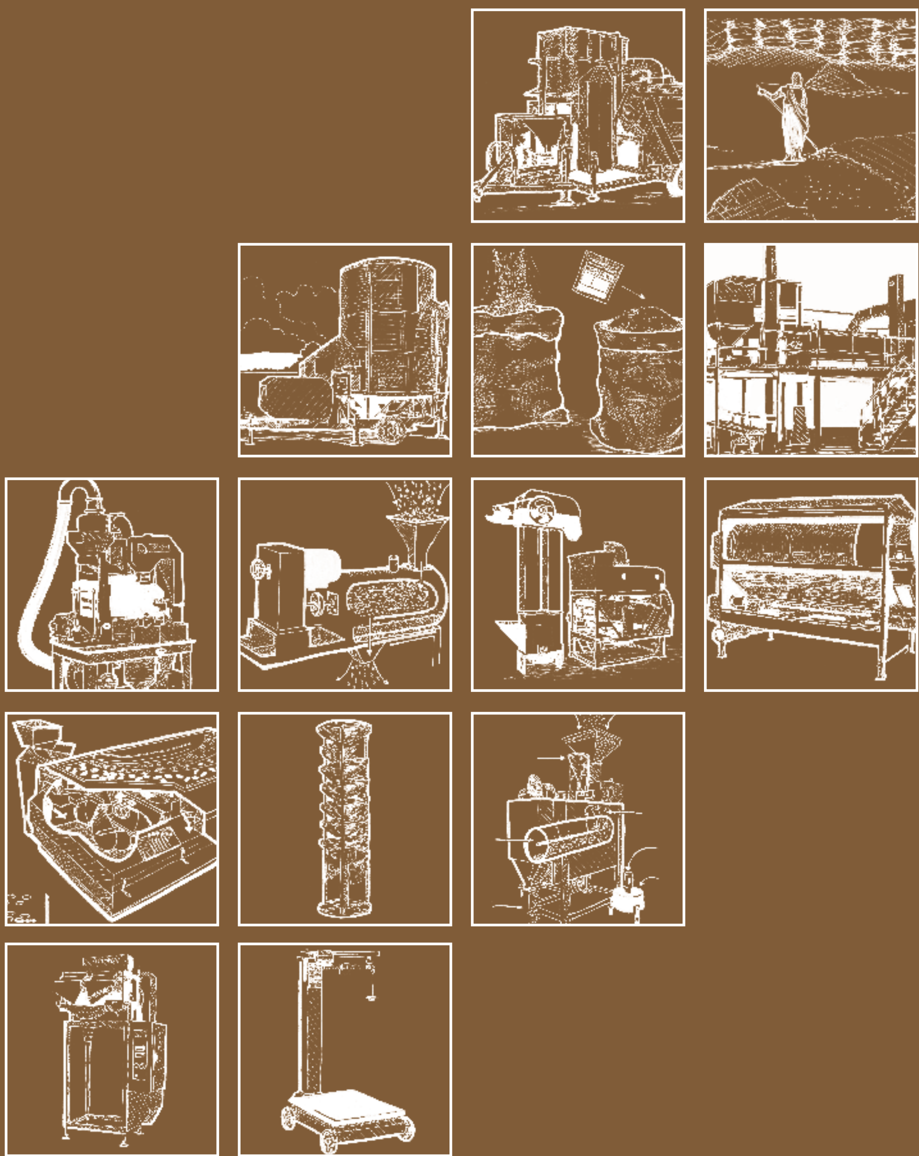
1. Consider the case of a warehouse with a trussed roof and walls 1 m higher than the intended seed stacking height. The storage requirement is 2 000 tonnes of rice seed (1.6 m3/tonne specific volume) in jute bags, in 8 separate lots each measuring 6 × 15 m and stacked 5 m high. The warehouse should be rectangular in shape, with the length approximately 2 times the width. There is a main handling area (3 m wide) along the axis of the warehouse, a gangway (2 m wide) across the centre of the warehouse, and an inspection space (1 m wide) around the entire stacking area. Sketch the layout of the floor, and calculate the area required and the percentage utilization of the warehouse. What other measures would you take to enhance the utilization of the warehouse?
2. Identify three structures used for storing seeds at local community level in your country. Explain how these could be modified for more effective longer-term storage of seeds.
3. Explain why closed PVC containers may be more suitable than calabashes and earthenware clay pots for hermetic seed storage at local level.
4. Describe three possible methods for storing quality seed of cereal and legume crops. Which do you think is most suitable for storing foundation seed of these crops for several months? Give reasons for your answer.

Covering bundle of cassava stem with perforated polythene bag to prevent rapid dehydration

Typical cassava stem shed with ends of each bundle touching the shallow soil



5 Economics of seed storage



Economics of seed storage

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For seed storage to make economic sense, **the marginal revenue during storage should be equal to or exceed the marginal cost of keeping the seed in store**.

- **Marginal revenue** is the difference between the price (value per unit) of the seed when it enters the warehouse and the sale price when it leaves the store.
- **Marginal cost** involves the costs of storage space, handling and maintaining the quality of a unit of seed during the storage period.

A seed enterprise chooses between two storage methods: in a store owned by the business itself, or in a specialized storage agency for a fee. In both situations, the enterprise retains ownership of the seed for as long as it expects the benefits of storage (in terms of higher expected selling price) to exceed the costs of storing the seed.

When non-infested seed dried to a safe moisture content is placed in store, the cost of maintaining quality is likely to be low. In contrast, storage of infested seed or seed of high moisture content entails higher costs and losses are likely. In such cases, it is necessary to remove seed for further drying, take frequent samples for monitoring and fumigate infested seed – all activities involving costs.

The unit cost per tonne of storing seed depends on several factors:

- Type and quantity of seed stored
- Size of seed storage facility
- Use or annual capacity of storage facility

Storage costs may be **fixed** or **variable**.

FIXED STORAGE COSTS

These are **direct costs** and do not depend on the amount of seed stored or on the period of storage. Therefore, the greater the annual throughput or output of a storage facility, the lower the cost per unit of seed, since the fixed cost is spread over a larger quantity of seed. Fixed costs of seed storage comprise the following:

- Interest on capital investments
- Insurance costs on capital
- Depreciation
- Repair and maintenance costs
- Administrative expenses

The interest charge depends on the rate at which the capital is borrowed. Interest and depreciation constitute the largest components of fixed storage costs.

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VARIABLE STORAGE COSTS

Operating costs entailed in operating a seed store cover a wide range of variable costs:

- **Interest on working capital (seed stock) and consumables.** There can be wide fluctuations, especially in situations where interest on working capital varies directly with prevailing rates of interest. Interest represents the opportunity cost of holding stocks of final processed seed. It is an allowance for what the stock could be earning or saving if it was used otherwise. Therefore, it is important for an enterprise to assess the turnover of different types of seed to avoid keeping capital locked up in stocks. Keep as short as possible the handling frequency – i.e. the length of time a particular kind of seed is held in storage – and increase the total quantity of seed stored to benefit from economies of scale.
- **Insurance premium on inventory.** Expressed in $ per unit per year, it is based on the average cost of inventory on hand.
- **Inspection and sampling fees.** Expressed in $ per unit inspected or certified, they are charged by a seed certification agency.
- **Electricity**. Close monitoring and supervision are necessary as costs can become considerable.
- **Wages of storage labour**
- **Miscellaneous expenses**

RISK PREMIUM

The risk premium is an **indirect cost**. It is the risk of a price fall resulting from holding stock over time with the uncertain expectation of a higher seed price. Carrying stock over from one year to the next is a source of risk for seed enterprises. An enterprise may be obliged to hold carryover stock due to unforeseen changes in seasonal pattern or unexpected market conditions, or could be motivated to carry over stock in expectation of higher prices.
A seed enterprise may decide to minimize the risks associated with carryover stock by choosing not to chemically treat all processed stock, in order to have the option of selling seed as grain. In this case, seed is treated later once an order is confirmed. When carryover stock is substantial, it is important to value it at a realistic price. It is misleading and financially damaging for a business to apply current seed prices when estimating turnover, because the stock may actually only be worth the much lower price of grain.

CALCULATING THE COST OF STORAGE

See Box for an example of calculating storage costs.

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notes

ECONOMIES OF SCALE IN SEED STORAGE

Variable costs depend on the length of time seed is stored: the longer the period, the higher the variable costs. On the other hand, variable costs do not necessarily vary in line with the volume of seed stored. There are **economies of scale associated with the quantity of seed stored**. Economies of scale in seed storage can be explained in two ways:

- **Decrease in storage cost as throughput increases.** For a given storage facility and a given seed crop, the cost per tonne decreases as annual throughput increases, because the fixed costs are spread over a larger quantity of seed. The decreasing costs are also partly accounted for by variable costs, which do not increase linearly with the volume of seed stored.
- **Decrease in storage cost as size of storage facility increases.** For storage facilities of different sizes, the cost of storage per tonne declines as size increases, assuming maximum throughput and optimum use of storage space. At maximum capacity, the storage costs per tonne in 500-, 1 000- and 1 500-tonne stores are $1.20, 1.15 and 1.0, respectively (see example case). Large storage facilities with high inventories permit increased specialization, resulting in lower costs per unit of seed stored.

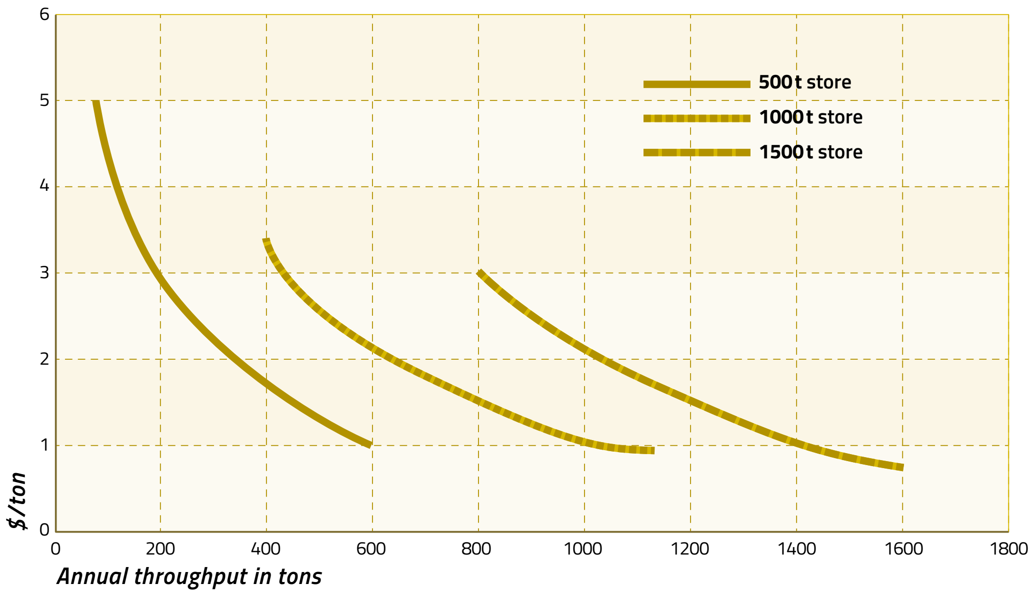
The second table illustrates the reasoning behind the concept of economies of scale in seed storage for an increase in throughput from 100 000 bags (5 000 tonnes) to 180 000 bags (9 000 tonnes) – i.e. almost doubling the storage capacity. The fixed costs per tonne fall rapidly, since the total fixed costs (which remain the same) are distributed over a larger quantity of seed. The variable costs do not necessarily increase in direct proportion to the volume of seed. This partly accounts for the declining value of total storage costs per tonne of seed.

Calculating storage costs – example case

Consider a storage facility that holds its maximum storage capacity of 100 000 50-kg bags of maize seed. The capital investment is $300 000 with an economic life of 50 years. Assume that the cost of repair and maintenance is 3% of the purchase value of the asset, insurance on investment 1.5%, interest on capital 17%, and total administrative expenses $15 000. Let interest on inventory (working capital) be 15% per tonne, insurance on inventory 1% per tonne, and other variable costs (casual labour, inspection and sampling, power and lighting, and miscellaneous expenses) $20 000. The procurement price of seed is $60/tonne and the final selling price is $100/tonne.

The table below provides a detailed breakdown of the costs.

Cost description	Cost for 1 month of storage	Storage period (months)		
		1	2	3
Seed stored (tonnes)	$[10^5 \times 50]/1\,000$	5 000	5 000	5 000
Fixed costs ($/tonne)				
- Depreciation	$30 \times 10^4/[50 \times 12 \times 5\,000]$	0.10	0.20	0.30
- Repairs	$[30 \times 10^4 \times 0.03]/[12 \times 5\,000]$	0.15	0.30	0.45
- Insurance on capital	$30 \times 10^4 \times 0.015]/[12 \times 5\,000]$	0.08	0.16	0.24
- Interest on capital	$[30 \times 10^4 \times 0.17 \times 0.05]/[12 \times 5\,000$	0.43	0.86	1.29
- Administrative expenses	$15 \times 10^3/[12 \times 5\,000]$	0.25	0.50	0.75
- Total fixed costs		1.01	2.02	3.03



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Cost description	Cost for 1 month of storage	Storage period (months)		
		1	2	3
Seed stored (tonnes)	$(10^5 \times 50)/1\,000$	9 000	9 000	9 000
Fixed costs ($/tonne)				
- Depreciation	$30 \times 10^4/(50 \times 12 \times 9\,000)$	0.06	0.12	0.18
- Repairs	$(30 \times 10^4 \times 0.03)/(12 \times 9\,000)$	0.08	0.16	0.24
- Insurance on capital	$30 \times 10^4 \times 0.015)/(12 \times 9\,000)$	0.04	0.08	0.12
- Interest on capital	$(30 \times 10^4 \times 0.17 \times 0.05)/(12 \times 9\,000)$	0.24	0.48	0.72
- Administrative expenses	$15 \times 10^3/(12 \times 9\,000)$	0.14	0.28	0.42
- Total fixed costs		0.56	1.12	1.68
Variable costs ($/tonne)				
- Interest on inventory	(100×0.15)/12	1.25	2.50	3.75
- Insurance on inventory	(100×0.001)/12	0.008	0.016	0.24
- Miscellaneous expenses	2×104/(12×9 000)	0.19	0.38	0.57
- Total variable costs		1.45	2.90	4.56
Total storage costs ($/tonne)		2.01	4.02	6.24

Economies of scale in seed storage

The above analysis demonstrates that for a given situation, the seed storage facility should be as large as possible and used to a sufficient extent to achieve minimum cost per tonne. It is not advisable to have excess capacity without the required throughput; on the other hand, the warehouse should have space for a sufficient quantity of seed to enable efficient operation of the facility.

The warehouse may need to be in an area where it can procure seed from contract growers located within a wide geographic radius. In other cases, it may be cheaper to buy short-term storage to keep raw seed while awaiting processing and final storage. Seed stores are rarely fully used because of the seasonal nature of production and distribution. However, a storage facility operating well below optimum capacity can incur high costs per unit. The **critical factor in determining the unit cost of storage is the extent to which storage space is used**.

Consider the case of a warehouse for which the cost of storing seed amounts to $1/tonne when the storage space is used to optimum capacity all year. If the available space is used for only 6 months, the cost rises to $2/tonne. If the space is half filled with seed for 6 months, the cost may rise further to $4/tonne. The example shows that if a 1 000-tonne warehouse holds the maximum throughput of 1 000 tonnes/year, the cost is $1.15/tonne. The price rises to about $2.20/tonne if the same volume of seed per year is kept in a 1 500-tonne warehouse, since 1 000 tonnes corresponds to less than the annual throughput capacity of the 1 500-tonne storage facility. Renting storage space is a potential source of income if an enterprise is unable to fill the available space with its own products during less busy periods, For example, a cold store for potato seed could be rented to producers of perishable fruit if the fruit is harvested after potatoes have been issued for planting.

notes

PROFIT OR LOSS IN STORAGE

To determine the gain or loss resulting from storing seed in a warehouse, subtract the total costs from the total benefits: the marginal revenue during storage minus the marginal cost of keeping the seed in store. A positive figure indicates a profit; a negative figure means that warehouse storage is likely to cost money rather than make money. In the example, the difference (measured in $/tonne) between the seed price at the time the seed enters the warehouse and the sale price when it leaves the store must exceed the total storage cost of 2.60, 5.20 and 7.80 for 1, 2 and 3 months of storage respectively.

RETURN ON INVESTMENT IN SEED STORAGE

Providing seed storage is profitable, the margin ($/tonne) divided by the total initial capital cost of the storage ($/tonne) multiplied by 100 is the percentage return on investment (ROI). A return on investment is simply the return or income as a **percentage of the capital invested**. This figure can be used to compare grain storage to other investment options. An alternative to using ROI is to calculate the payback period – how many years it will take for the storage to pay for itself. This can be calculated by dividing the capital invested ($/tonne) by the margin or profit on storage ($/tonne).

EXERCISES AND DISCUSSION POINTS

1. With reference to Table 6, calculate the total fixed cost, total variable cost and total cost of storage if 15 000 tonnes of seed are stored in the warehouse for 1, 2 and 3 months. Discuss how these figures explain the concept of economies of scale in seed storage.
2. Maize seed sold at $500/tonne after processing is placed in a warehouse. After 4 months, the seed is distributed to farmers at the price of $550/tonne. Given a total fixed cost of $15/tonne and a total variable cost of $25/tonne, calculate the storage profit ($/tonne) during this period. Explain the importance of this result.
3. What steps would your business take if the interest rate on processed seed in your store increased significantly?
4. What financial risks are associated with carryover storage of seed from one season to another? What actions would you take if your enterprise anticipated substantial carryover of seed in its store?

Glossary

Aerobic respiration
Respiration occurring in the presence of oxygen and which is essentially responsible for the breakdown of carbohydrates, fats and proteins to carbon dioxide, water and energy. The energy liberated during aerobic respiration is used by the cells to fuel metabolic processes and is then released as heat.

Anticoagulant
Substances that inhibit blood coagulation. They are used as poison to cause internal bleeding in rodents.

Avicide
Pesticide used for bird control.

Cryopreservation
Process of freezing biological material, such as seeds, at extreme temperatures, most commonly –196 °C in liquid nitrogen.

Dehumidification
Removal of moisture from the ambient air by physical or chemical means.

Early-generation seed
Earlier generations of seed (breeder and foundation seed) verified by an official certification agency after inspection and used for the production of certified seed.

Equilibrium moisture content
Specific level of moisture content attained by seed when the vapour pressure of the seed moisture and the atmospheric moisture reach equilibrium while the seed is absorbing or losing moisture.

Fixed storage costs
Direct costs that do not depend on the amount of seed stored or on the period of storage.

Hygrometer
Instrument used for measuring the water vapour or relative humidity in the atmosphere.

Insurance premium
Storage insurance paid per unit of output per year based on the average cost of inventory on hand.

Intermediate seeds
Seeds that do not conform fully to either ortho¬dox or recalcitrant category; they may have a limited tolerance to drying but are sensitive to freezing temperatures.

Isotherm
Plot of the relationship between relative humidity and moisture content at a given temperature.

Meristem
Region of plant tissue, found mainly at the growing tips of roots and shoots, with cells actively dividing to form new tissue.

Micropropagation
Rapid multiplication of disease-free, high-quality plants using tissue culture techniques.

Minitubers
Potato tubers produced by stem cuttings obtained from tissue culture plantlets grown in the laboratory.

Moisture content
Amount of water in the seed, usually expressed as a percentage.

Mycotoxin
Toxic substances produced by storage fungi that destroy the cells of seeds, and cause harm or fatality to humans and animals.

Neem
A large evergreen shade tree grown in parts of Asia and Africa whose parts (e.g. fruit, seeds, leaves and bark) are used as natural pesticide.

Orthodox seeds
Seeds that can be successfully dried without damage to moisture content of 5%, can be packaged and tolerate freezing.

Planting material
Parts of plants used for vegetative propagation.

Primary insect pests
Grain insects with the ability to attack whole, unbroken grains.

Recalcitrant seeds
Seeds that are short-lived, cannot be dried to moisture con¬tent < 20–30% without injury and do not tolerate freezing, and are thus not amenable to long-term storage.

Relative humidity
Amount of water present in the air at a given temperature in proportion to its maximum water-holding capacity.

Risk premium
Indirect storage cost related to the risk of a price fall resulting from holding stock over time.

Rodenticide
Poison designed to kill rodents.

Secondary insect pests
Insect pests that attack only damaged grain, grain dust and milled products.

Seed longevity
Lasting effect of seed viability during storage.

Seed storage
Preservation of seeds under controlled environmental conditions that maintain seed viability for long periods from the time of harvesting until the seed is finally required for sowing by the farmer.

Storage pathogens
Micro-organisms (bacteria and fungi) that affect seeds in storage.

Tissue culture
Use of artificial medium to grow cells derived from living tissue.

Variable storage costs
Costs that depend on the length of time seed is stored, with longer periods associated with higher variable costs.

Vegetative propagation
Asexual or non-sexual reproduction by which new plants are raised from parts of the parent plant (e.g. roots, tubers, bulbs or stems).

Vigour
Capacity of seeds to germinate into normal seedlings that perform well in the field.

Weathering
Deterioration in seed quality, vigour and viability due to high relative humidity and high temperature during post-maturation and preharvest periods.

Seeds are the vehicle for delivering the improvements in a crop to the farmer's field. They are therefore a critical input in agricultural production. Seeds are unique in that they must remain alive and healthy when they are used and they are also the input that farmers can produce by themselves.

These factors were borne in mind in preparing the Seed Toolkit that comprises the following six interrelated modules:

1. Development of Small-Scale Seed Enterprises. This provides a stepwise guide for the establishment of commercially viable seed enterprises in farmers' communities. It covers the critical steps from the business plan to the production of seeds for sale.

2. Seed Processing. This presents the underlying principles of seed processing, the equipment used and the overall best practices from reception through conditioning to final delivery to customers. This module focuses on the use of affordable small-scale equipment for seed processing and sowing that may also be fabricated locally.

3. Seed Quality Control. This assists seed practitioners and other stakeholders in meeting the set quality standards for seeds and in implementing procedures for certification. The topics covered include field inspections and seed conditioning, packaging and tagging, storage, sampling/testing, and distribution.

4. Seed Sector Regulatory Framework. This provides information on the elements of the regulations that govern the seed value chain – from variety registration through quality seed production to distribution and marketing. The materials covered include information about national seed policy, seed law and regulations, their definitions, purpose and interactions.

5. Seed Marketing. This presents the underlying principles for valuing and exchanging seeds. This module describes all the activities that are undertaken in getting seeds from the producers to the end-users or farmers. The reader is provided with guidance on how to conduct relevant research of the market for seeds, develop effective marketing strategies, articulate a marketing plan and manage the associated risks.

6. Seed Storage. It is estimated that 25–33 percent of the world grain crop, including seeds, is lost each year during storage. To avert this obvious drawback to food security and nutrition, this module provides the underlying principles for effective seed storage and the associated practices. The module provides guidance on the preservation of seeds under controlled environmental conditions to maximize seed viability for the long periods that may be required from harvesting through processing to planting.

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