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This volume is the fourth edition of the Food Storage Manual, first produced for the World Food Programme (WFP) in 1969 and published by FAO in 1970. The first version was compiled and edited by M.F.S. Jamieson and P.I. Jobber in three volumes totalling more than 800 pages.

The second edition was published as a single volume in 1983 by the Tropical Development and Research Institute, a predecessor of the Natural Resources Institute, on behalf of WFP. It was a revised and condensed version edited by J.A. McFarlane.

The third edition, by D.J. Walker in 1992, was a joint publication of the Natural Resources Institute and WFP. It was updated, revised and rewritten as necessary. New material was incorporated and the manual was made easier to use.

This fourth edition has been revised and updated to incorporate new knowledge with the aim of making it more practical to use in the field while still retaining its function as an office reference text. It is recommended that it is used in conjunction with the recently revised WFP pictorial publication ‘Warehouse Management – A Handbook for Storekeepers of Food Aid’.

Changes in pesticide use, particularly the phase-out of the fumigant methyl bromide, are reflected in the revision, and new material is included on inspection and sampling, and recommended tests for fitness-for-purpose of food aid. The text has been expanded to include more practical and pragmatic advice to help readers respond more effectively to problems of food aid commodity management. There is also a glossary of food aid terms, a list of recommended warehouse equipment, case studies, and more references to further reading.

The valuable contributions made by earlier authors and editors are gratefully acknowledged, as are new contributions from S.R. Belmain (Pest management of vertebrates), J.A. Conway (Effects of climate in stores and in transportation), G. Farrell (Testing samples for fitness-for-purpose), and R.J. Hodges (Insect pests of food aid and Pest management of insects).

Although written for the guidance of staff of the World Food Programme, the new edition will be of interest and value to the many other organizations concerned with the safe and timely delivery of food aid worldwide.

Any errors or omissions remain the responsibility of the editors.
Food aid, by its very nature, is of significant and often vital importance to the individuals, communities and nations that it supports. It can take the form of developmental aid supplied on a planned basis to assist vulnerable groups such as the young, the sick and the elderly. Alternatively it can provide ‘food for work’ to support infrastructural improvements, or ‘food for education’. In other instances it is a major component of emergency operations to relieve the difficulties and hardships associated with food shortages arising from civil strife, military action or natural disasters.

The main components of any particular food aid basket will be selected to meet the needs and preferences of the beneficiaries, depending on availability and funding. However, whatever the nature of the food aid commodities, it is important to ensure they are procured to quality standards that will enable them to withstand the rigours of transportation, climate and storage so that they arrive in the recipient country in good and acceptable condition, and that this condition is maintained until the food finally reaches the beneficiaries.

Quality assurance assumes a major significance for food aid deliveries in landlocked and large countries where commodities have to be transported great distances overland. The transport and associated handling expenses are such that the cost of the commodity, when it reaches a remote town, could be five times that at which it was originally purchased on the world market. Additionally, in the event that some or all of a consignment becomes unfit for consumption, it may take many months to procure, despatch, ship, obtain clearance, and deliver the replacement stocks. In an emergency operation, in particular, such a long lead time could have serious consequences.

Food aid takes place in an increasingly political and transparent arena. If food aid consignments become spoiled or questions are raised as to the fitness of the food, for whatever reason, a sensitive situation could arise that may detract from the effectiveness of the operation.

It is clearly the responsibility of those involved to ensure all possible steps are taken during procurement, transport, handling, storage and distribution to assure qualitative and quantitative maintenance of food aid commodities. This requires a broad knowledge and competence in food aid commodity management, to which this text is intended to contribute.
This manual has been written with the specific aim of providing information and guidance on food aid warehousing and handling for staff of the World Food Programme. It is hoped that it may also prove of interest and use to other organizations, national and international, involved with food aid.
Chapter 2

Handling and storage of food aid commodities

This chapter is concerned with the technical and management issues that arise when handling and storing food aid commodities in a warehousing and distribution system. In normal commercial practice, deliveries into store take account of the pattern of supply, demand and storage capacity. Re-ordering procedures take account of the supply lead time. The need for a buffer stock will depend on the variation in demand, the lead time, and the trade-off between the costs of holding stock in store and a stockout. However, food aid commodity systems are characterized by the marked lack of control that managers have over the timing, nature and volume of the deliveries into and despatches from store. The consequences of a stockout could be unacceptable, thus there is a crucial need for management and logistical competence in food aid commodity systems.

With regard to food aid handling and storage, there are seven key steps to observe. These are:

- a good store must be selected and prepared (see Chapter 3)
- commodities must be received in good condition
- intake must be orderly and recorded
- quality maintenance must be assured
- security against theft and loss must be provided
- any loss incurred must be identifiable and accountable
- the end-use requirements must be met.

Food aid staff must be fully conversant with the relevant warehouse technical procedures and management practices in order to assess whether they are being implemented satisfactorily, and to offer adequate support if necessary.

RECEIVING COMMODITIES

Prior to receiving commodities, an assessment must be made of the usable capacity within the store. Note that the usable capacity is often much less than might be thought, and depends on the stacking equipment available and the number of different commodities or consignments to be stored. The greater the number of stacks, the smaller will be the usable capacity. A storage plan should be prepared that will take into account the expected pattern of demand the store will have to meet, and the likely size and frequency of deliveries and discharges that need to be achieved.
Typically, there might be a large volume of bagged grain, a smaller quantity of cooking oil and processed or blended foods, and less of other foods. Space should be allocated according to the volume of stock expected, allowing easiest access to the most frequently moving stocks. It should be remembered that there might be a need to construct a new stack while at the same time drawing down from an existing one. The recommended distance between stacks is a minimum of 2 m to allow two workers carrying bags to pass. Greater distances are required for mechanized handling systems. The storage plan must ensure working access to all stacks at all times.

Incoming stocks must be carefully inspected. Delivery is one of the few occasions when the storekeeper is able to inspect all parts of the consignment. This opportunity should not be ignored. All infestable bagged commodities should be examined for signs of live insects, and any infested bags must be segregated. Similarly, containers of oil should be examined for damage and leakage. Damaged items are best stored separately and re-packaged where necessary. Particular care must be taken with any commodities that have been wetted with rainwater during delivery. Wet bags must not be built into a stack. They must be issued and used immediately if possible, or the contents should be carefully dried before being re-bagged and stacked separately for early despatch.

**STORAGE OF COMMODITIES**

Every attempt must be made to store food commodities under a waterproof roof. Only exceptionally, as with emergency programmes, should outdoor storage under tarpaulins or plastic sheets be considered.

**STACKING**

Within a store, stacks should be built clear of all walls, buttresses and roof supports in order to allow access all round for inspection, pest control and physical audit, and to permit free circulation of air – which is important to reduce the risk of condensation and mould damage (Figure 2.1). The recommended space between the stacks and walls or roof supports is 1 m. The tops of stacks should be clear of the roof or roof supports so that it is possible for a person to pass easily around all sides and over the top of each stack. This space is essential for inspection and for fumigation or other pest control work. Stacks must be built in an orderly manner that permits reliable audit. Badly built stacks may collapse and injure people, or cause damage to the commodity and/or the fabric of the store. Similarly, stacking against walls may cause structural damage, and solar heat on the store exterior may be transmitted to goods that are stacked very close to the walls and roof.

Commodities, except those packed in strong, vapour-proof containers, should not be stacked directly on the floor because there is a risk of moisture from the ground rising into the stack. They should be stacked on a moisture-proof floor cover, such as polythene sheeting, or on dunnage such as wooden pallets. If pallets are not available, carefully laid loose timbers or poles will serve as dunnage, although this is less
satisfactory. Pallets (Figure 2.2) should be constructed to suit the packages or sacks that will be stacked on them to ensure these do not sag through or fall to the ground. Many stacking patterns can be used for any size of stack, in multiples of the basic units shown in Figures 2.3 and 2.4. If the number of basic units per layer is small, the stack height will be constrained because of the risk of collapse. To assist with physical stock checks, the number of bags in each layer can be written in a prominent position on one bag in every layer. It is common practice simply to alternate layers as shown in Figure 2.5. However, care should be taken to ensure the two bag units that form the corners do not separate and fall.

If sack elevators are not available, stacking can be accomplished by building the stacks step-wise from one end or one side. If this is carefully planned and executed (Figure 2.6), the loss of stacking space is minimized. Nevertheless, where very large quantities have to be handled, a bag elevator is likely to be needed.

Paper sacks and plastic sacks made of polyethylene and woven polypropylene are more difficult to stack properly than are jute sacks, because there is less friction between them. Special care is needed to ensure stack stability, particularly on corners. To ensure stability, the sides should not be vertical; they should slope inwards from the base upwards. Some plastic sacks have anti-slip characteristics specially incorporated into the surface, but this adds to the cost.

Commodities in strong, flat, wooden cases can be stacked in straight columns up to a considerable height, provided the cases are sound. However, where there are instructions on the case advising a maximum number of layers, this must not be exceeded. Damaged cases should be kept separately in low stacks to avoid crushing the contents. These cases should be issued first. If very large stacks are necessary,
it is advisable to slope the upper sides of the stack slightly inwards by decreasing the number of cases in every second or third layer. This should be done in such a way that the pressure is still borne mainly by the vertical sides of the cases.

Cardboard cartons are usually difficult to stack safely unless the layers are bonded in some way. A method of doing this must be devised for each shape and size of carton, following the general principles suggested for sacks. Fibreboard drums should be stacked upright, with suitable dunnage between each layer to ensure stability. They should not be stacked on their sides as this will cause the lower drums to collapse. Steel drums can be stacked horizontally up to three high. Vertical stacking is possible but dunnage is needed between each layer to give stability.
Remaining quantities of existing stocks should be rearranged within the store to make room for new incoming consignments. New stocks must not be placed on top of old stocks. Different consignments must not be mixed.

Figure 2.3 Stack layer patterns for two common types of stack

Figure 2.4 Layers of sacks with a length/width ratio 2:1 are built this way to form a tiered stack
ACCOUNTING FOR COMMODITIES

It is essential that daily tallies of intake and despatch are reconciled in the warehouse ledger or stock book. The officer in charge should always know at a glance what quantity of which commodity is in the warehouse. At intervals, the total stock should be verified by a physical audit undertaken by an independent official.

A sample unit weight check at receipt and despatch is a useful management aid. Pulses, cereals and their products should have their weight related to the recorded moisture content on both receipt and despatch so that any shrinkage resulting from the commodity drying over a long period of storage in a dry climate can be determined and accounted for. Excessive loss of weight other than shrinkage may be due to pilferage of a small amount from each bag or container. Loss due to spillage may be recoverable. In a well managed warehouse system, weight losses due to insect and rodent pests should be minimal.
INSPECTION OF THE STORE AND ITS CONTENTS

The purpose of inspecting is to generate information on which managers can make decisions concerning quality assurance procedures and the future shelf-life of the commodity. Inspection must be done regularly, not less than once per week, and should include a complete walk around the store, inside and outside, and all stocks, looking carefully for signs of theft, pest infestation, dampness, mould damage, spillage or leakage of stored commodities, roof leaks and any other structural faults or security problems. The condition of pest control measures such as vertebrate pest baits or proofing, which may have been disturbed by loading or discharging in the store, should also be noted. Appropriate action should be taken as soon as possible to repair any damage or correct any faults. In some instances, the outcome of the inspection could indicate the need to take representative samples of one or more commodities to determine their condition more precisely.

STOCK RECORDS AND STOCK CONTROL

Records of receipts and despatches, together with a daily record of stock balance, are the minimum documentation requirements for the normal management of a warehouse. They will provide the basis for physical audits. This information will commonly be compiled in a stock ledger for the warehouse or depot. Information concerning each individual stack must be recorded on a stack card positioned prominently, ideally at eye level, on each stack. Stack cards also provide the opportunity to record any information relevant to the particular stack, for example, dates and details of pest control, any problems with packaging, roof leaks, etc. A good documentation system will provide a brief, reliable account of all that takes place in the store insofar as it may affect the age, quality and quantity of the goods.
stored (Figures 2.7–2.9). Adequate documentation and regular physical audits provide possibly the best long-term protection against fraud and theft. Minimum stock levels and re-order levels may be established for those programmes having good access to supplies and regular issues.

**STORE HYGIENE**

The store must be kept clean by regular sweeping of the floors which should be undertaken at least once every day. Regular floor cleaning will enable most grain spillages to be recovered and re-bagged. If the floor is swept clean at the end of the working day and spillage is observed at the start of the next day, it will be clear to managers that there has been unauthorized activity in the warehouse or that there was heavy rodent infestation during the night or weekend. Every month it will be useful to sweep the walls and also any ledges that permit the accumulation of spillage or dirt.

A simple broom is the most useful piece of pest control equipment in a warehouse that is mainly used for food grains and processed foods. The prompt removal of spillage prevents insect populations developing in cracks and crevices from where they can infest the stored food aid commodities.

Leakage of vegetable oil can be extremely problematic and needs to be cleaned as soon as possible before it becomes a safety hazard or contaminates other commodities.

<p>| Stack No.:________________________ |
| Commodity:_______________________ |</p>
<table>
<thead>
<tr>
<th>Date</th>
<th>In</th>
<th>Out</th>
<th>Balance</th>
<th>Signature</th>
</tr>
</thead>
</table>

*On reverse side*

<table>
<thead>
<tr>
<th>Date</th>
<th>Treatment given</th>
<th>By whom</th>
</tr>
</thead>
</table>

Figure 2.7 Stack record card
Contaminated sweepings should be promptly destroyed by burning or burying well away from the store in accordance with established management procedures. In practice this is not always possible because of audit or stock control systems put in place to prevent theft of stock.
Similarly, a procedure must be introduced whereby stocks that are declared unfit for human consumption can be removed from the store and from the stock records, and disposed of or salvaged without delay. Untreated insect infestations or mouldy commodities must not remain in the store where they can put other stocks at risk. The normal administrative procedures used by local organizations for writing off unfit commodities are often tedious and protracted. The food aid agency’s requirement for a responsible and rapid write-off procedure must be pressed strongly.

Attention should also be paid to the condition of the exterior walls of the store and the surrounding areas. The site must be kept clean. Condemned stocks must not be placed outside the store as they will attract vertebrate and insect pests.

---

**Are there live insects on the walls and floors?** ________________________________

**Is there evidence of rats or mice inside or outside the building, e.g. signs of gnawing, rat or mouse droppings, rat or mouse holes?** ________________________________

**Are there any other matters which need attention, e.g. security of store, access, condition of site, storage machinery, etc.?** ________________________________

**COMMODITY INSPECTION REPORT**

<table>
<thead>
<tr>
<th>Commodity in store</th>
<th>Quantity in store at the time of inspection</th>
<th>Length of time in store</th>
<th>Is it in good condition?</th>
</tr>
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</table>

If a commodity is not in good condition give the reasons why, e.g. the rice is being eaten by insects, the cans of oil are leaking, etc.

**Record of pest control treatments:**

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**Figure 2.9 Commodity inspection report sheet**

Similarly, a procedure must be introduced whereby stocks that are declared unfit for human consumption can be removed from the store and from the stock records, and disposed of or salvaged without delay. Untreated insect infestations or mouldy commodities must not remain in the store where they can put other stocks at risk. The normal administrative procedures used by local organizations for writing off unfit commodities are often tedious and protracted. The food aid agency’s requirement for a responsible and rapid write-off procedure must be pressed strongly.

Attention should also be paid to the condition of the exterior walls of the store and the surrounding areas. The site must be kept clean. Condemned stocks must not be placed outside the store as they will attract vertebrate and insect pests.
DESPATCH OF COMMODITIES

‘First in, first out’ is a good general default rule for all food commodities because it helps to reduce the overall age of stock in the warehouse. This is important because food storage problems tend to increase in direct proportion to the duration of the storage period. However, there are occasions when it is necessary to despatch stock that is not the oldest, for example, if younger stock has been damaged or is considered to be at risk of deterioration, or a specific part of the stock has been requested by the user.

All issues must be fit-for-purpose and packed in sound containers, suitable to withstand the journey to the beneficiary. Commodities in badly damaged packaging must not be issued and transported, as excessive spillage and perhaps contamination may occur during the journey.

LABOUR MANAGEMENT AND SECURITY

It is, or should be, the storekeeper’s responsibility to ensure labourers working in the warehouse are adequately informed, trained and supervised, particularly with regard to taking care in handling commodities and their own safety. They should also be made aware of any pest control treatments that are in use and the associated potential hazards.

Details of recommended warehouse equipment are listed in Annex 3.

Materials for record keeping should also be provided and, where appropriate, suitable pesticides together with all equipment needed for their safe and effective use. All pesticides should be stored separately and securely, well away from food commodities. A reliable moisture meter should be available for use by a suitable and trained person where necessary, especially in stores where food grains are likely to be stored for several months.

The importance of minimizing the loss of commodities through theft cannot be overemphasized – food aid commodities in food deficit situations are highly attractive and are naturally a temptation to warehouse personnel, transport drivers and others. Thorough paper checks on the amounts received and delivered, and physical checks of the amount in store, must be seen to be done regularly. Clearly designated staff must be made responsible and accountable for any losses.

REPORTS

Detailed reports may or may not be called for by the local organization, but the storekeeper should, in any case, be encouraged to make relevant and accurate reports whenever he or she observes any signs of serious stock deterioration, structural faults or labour difficulties. The problem and any recommended action to be taken must be clearly stated. The responsible person should, if possible, ensure all reports are made available to him or her, as well as to the responsible local
organization. The provision of triplicate report forms may assist this, especially at central depots. For outlying stores, other arrangements may be needed.

**SUPPORT TO THE STOREKEEPER**

Means by which the storekeeper can be supported are summarized below:

- ensure the storekeeper is aware of his or her responsibilities
- ensure the appropriate local or counterpart organization is also aware of these responsibilities
- encourage and, if possible, assist the appropriate organization to provide adequate staff for storekeeping
- support the storekeeper’s valid requests for necessary alterations and repairs to the store and for all necessary equipment
- facilitate suitable training programmes
- assist in locating and procuring all necessary assistance for pest control operations
- advise and, if possible, assist the storekeeper in the identification of causes of loss or damage and in the keeping of meaningful records
- assist the storekeeper to identify the reasons why any stock needs to be downgraded.

Subsequent chapters give more detailed information on the various pests of stored foodstuffs, the methods and materials used in pest control, and the various food aid commodities. A good basic understanding of warehouse management principles and the technical aspects will enable all concerned persons to offer better advice and to assist storekeepers and local counterpart organizations.

**FURTHER READING**

Chapter 3

Storage structures: selection and design

Field staff frequently have to approve the local arrangements made for receipt and storage of food aid commodities. It is often necessary to assist with, or even initiate, these arrangements. In some situations staff have to be pragmatic and improvise. In emergencies, where no suitable storage facilities exist, it is necessary to provide initial facilities quickly. Special portable or relocatable stores may be obtained, but frequently existing warehouses or other buildings not originally designed for food storage have to be used. Occasionally new buildings may be constructed specifically for use as food aid stores, and design specifications will then be needed.

SURVEY OF STORES

A survey of all existing available stores should be carried out before an informed decision can be made on warehousing. This survey will often reveal a larger storage capacity than was originally thought. It will also help identify and quantify stores that can be used during emergencies, and possibly clarify additional warehousing requirements.

The survey should include information on:

- location of the storage facility
- number of stores and their dimensions
- capacities, both nominal and actual
- construction materials
- state of repair
- hardstandings
- road access
- time and distance for delivery from a supply centre
- sustainability for routine or emergency food storage
- ownership
- source of data
- additional comments.

This information can be obtained from local records, surveys by field staff and data from government, non-governmental organizations and the private sector. The information should be stored on a computer database to facilitate updating.
FUNCTIONS AND REQUIREMENTS OF FOOD AID STORES

The main function of most food aid stores is to provide transit facilities. The storage period frequently cannot be determined in advance, but is usually less than 12 months and frequently less than 3 months.

Short-term food aid transit storage dictates the following major requirements:

- security from theft
- protection of stocks from rain, flash floods, rising damp, solar heating and pests, especially rodents and birds
- easy intake and despatch of goods, including good access to the store
- good in-store handling arrangements and access to all stocks for inspection, physical stock-taking and insect pest control where necessary
- easy maintenance of the store structure
- satisfactory working conditions for staff and labourers.

Security is listed first because it is particularly important in transit stores, which are frequently opened, often located in towns, and commonly contain fast-moving foodstuffs.

EXISTING BUILDINGS

Inspection

Before an existing building – whether originally designed for food storage or otherwise – is accepted, the following aspects should be considered and appropriate action taken.

Security

The buildings must be secure against theft, with strong locks on all doors and all other openings secure. In some situations, guards must be employed and a security fence with adequate lighting may be needed around the site.

Site

The area should be assessed for any risk of contamination from industrial pollution and rodent infestation. There should be no large trees near the store and the vegetation should be cleared. The site should be free from risk of flooding and drainage should be adequate. It should have good access by rail, road or water to facilitate intake and distribution of foodstuffs.

Roof

The roof should be inspected for leaks. This is most easily achieved during or just after rain. Corrugated galvanized roof sheets, if holed, should be replaced or mended.
with bituminous adhesive and hessian patches. A tar-soaked tarpaulin will serve as a temporary patch. A good roof is essential for food aid storage.

Floors
Concrete floors are preferable, but an earth or sand floor will suffice in emergencies. If there are rodent entry points the floor should be covered with 100 mm of concrete. Dunnage must be used on floors where ground moisture can penetrate.

Walls
These should be rodent-proof, with all known entry points well sealed. Any windows should be covered with at least 12-mm thick wooden planks or welded metal for security.

Hygiene
There will need to be sanitary facilities for staff, and provisions for the disposal of waste materials from the store.

Existing buildings should be thoroughly cleaned before use as food stores; dirty buildings need only be rejected if they cannot be cleaned.

In field situations, buildings that are far from ideal for food aid storage may have to be accepted, but any building that cannot be made secure, that is poorly sited or has a badly leaking roof which cannot be repaired, should be rejected.

Modification to existing buildings
Professional guidance is needed before specifications can be prepared, materials quantified and budgets drawn up. Where such assistance is not available, the following notes may be helpful.

Re-roofing
Tile roofs should be replaced if the battens supporting the tiles have decayed or if the nails or pegs that hold them in position have rusted or rotted away. The whole roof covering should be stripped, battens replaced and re-nailed, and the tiles re-laid. The possibilities for replacement by sheeting with galvanized steel or aluminium alloy should be considered. There is no need to renew battens when replacing tiles with sheeting, but additional purlins on top of the rafters will be needed for firm anchorage of the sheeting.

Re-flooring
Whenever possible, decayed wooden floors should be replaced with concrete floors; preferably with a damp-proof course, although in very dry situations this may be an unnecessary complication. Details of concrete floor construction are given later in this chapter.
Doors
Badly worn hinged doors are best replaced by metal sliding doors, hung from the top, installed to run outside the building.

Ventilation
If increased ventilation is needed, the simplest method of achieving this in a single-storey framed building is by installing (or enlarging) eaves ventilation. In each bay, the top 0.6 m of cladding can be removed if there is sufficient roof overhang to prevent the entry of wind-blown rain. Welded steel mesh should be installed in the space for security, and wire netting fitted to prevent entry of birds. In some climates it might be desirable to control this ventilation with adjustable covers.

Security
The most likely alteration or improvement for an existing building is the erection of a security fence. The fence should be at least 3 m high, constructed of chain-link fencing on steel posts. The fence should be clear of all buildings by 3 m and should be well illuminated at night.

Management
Old buildings often need more careful management than new buildings. It is very important that at least one trained person is clearly responsible for the store.

Single-storey buildings are usually the easiest to manage, but multi-storey buildings should not necessarily be ruled out. Schools, prisons and offices have all been used successfully as food aid stores in the past. However, long-term successful storage depends on both suitable structures and good management.

Good quality dunnage must be available.

NEW CONVENTIONAL WAREHOUSES
The two most important aspects to decide when constructing new food warehouses are what is needed, and how it should be built. Buildings designed specifically for the storage of food aid commodities generally fall into two categories:

• small 50–200 tonne capacity units, constructed locally
• medium 500–2000 tonne capacity, often using imported materials.

DESIGN CONSIDERATIONS
Capacity
The usable volume in a store is less than the store’s gross volume because of several factors. All the space above eaves level should be left for air to circulate and
ventilate; a clear space of at least 1 m must be left around roof supports, and between a stack and a wall; 2 m must be left between stacks. The bulk volumes of agricultural products can vary considerably, from about 1.3 m³/tonne for beans to 2.1 m³/tonne for flour.

For a small store of under 500 tonnes, the usable volume can be less than 50% of the gross volume below eaves level. Usable volume increases with store size to around 70 or 80% for stores of 5000 to 10 000 tonnes.

**SITING THE STORE**

(i) The soil load-bearing capacity is all-important. Weak soils can substantially increase building costs. Some soils, such as black cotton soils, should be avoided if possible.

(ii) Excessively wet areas, and dry areas that suffer from flash floods, are also difficult sites. Areas that remain dry all year are preferable. Groundwater problems can be reduced by excavating drainage channels.

(iii) The long axis of stores should be oriented at right angles to the prevailing wind, with the principal doors located on the long sides, unless other considerations prevail.

(iv) A sloping site has to be cut into. This is expensive, and requires one or more drainage channels to be made across the slopes uphill from the store, to lead drainage water around and away from the environs of the store without causing soil erosion. Drains that cross the building site need to be sunk deep, covered with 150 mm of concrete all round the pipe, and the trench filled with hardcore.

(v) Store floors need to be above ground level, with surrounding ground and road surfaces sloping away from the walls and doors.

(vi) Access by vehicles both to the site, and around the store to doors or ramps, is important and needs to be carefully considered in relation to the site. Local authorities may have planning requirements for roadways or recommendations on their construction. Widths of roadways suitable for today’s trucks may be inadequate for the large trucks of the future (think 5–10 years ahead). Road turning circles and concrete aprons in front of doors need to be generously proportioned. The installation of a weighbridge to avoid delays in loading and unloading will be needed at large installations.

(vii) An office may be needed for the store manager. A well ventilated store for pest control chemicals and a separate store for other equipment are advisable. These are best sited where they will not obstruct traffic and movement around the store.
Water, electricity, sewage disposal and general drainage may influence the choice of site. Any future expansion or development of the site should also be considered, and there should be adequate space for this. The building layout should be planned so that it can be efficiently incorporated into any expansion.

**SPECIFICATIONS**

**Dimensions of basic store building**

When first inviting manufacturers to tender for the design, fabrication and supply of the structure, they should be asked to state if minor modifications to dimensions would result in significant cost savings. Typical dimensions for a 1000 tonne capacity store are:

- Span: 19 m
- Length: 28 m; five bays each 5.6 m long
- Height: 5.5 m from floor level to eaves
- Roof pitch: 17–20° (approximately)
- Eaves overhang: 1 m along length, except over door where overhang is 3 m
- Roof overhang: 1 m at gables.

**MATERIALS AND CONSTRUCTION**

**Frame**

A frame building will commonly utilize mild steel universal section columns, portal rafters with galvanized pressed-steel or cold-rolled purlins, angle eaves’ rails, wind struts and side rails. Concrete columns can also be used with a conventional truss. Factory-made columns are more reliable, but expensive. Columns poured on the site require careful control if they are to be satisfactory.

**Roof**

Roof and awnings are generally covered with corrugated sheeting of galvanized steel or aluminium. The longitudinal lap minimum should be 0.2 m, side lap 0.15 m, and all laps sealed with mastic strip (or a layer of bitumen) to avoid leakage. Ideally there should be no transparent panels in the roof, but up to 5% of the total roof area as transparent panel is acceptable. Many transparent materials deteriorate rapidly in strong sunlight and hence have a short life. Overhanging roof extensions at eaves and gable ends are extremely important in shading both walls and ventilator openings from strong sunlight. An overhang of at least 1 m should be made (Figure 3.1). Care should be taken in areas prone to high wind speeds. Any gaps between the top of the wall and adjoining roof sheets should be sealed, preferably with a flexible mastic substance which moves as the roof expands and contracts. The roof outside should ideally be painted white. Gutters on the roof can become inadequate, so it may be best to let rain run off onto a wide concrete path, which slopes away from the wall, or onto a specially constructed drainage area.
Doors

Doors are best steel-framed, of a double-leaf sliding design, and clad with 0.8 mm galvanized steel or aluminium, giving a clear opening approximately 4 x 4 m. Two doors in each side wall are the minimum in a 1000 tonne store. All doors should run outside the building and be supplied complete with all tracks and door gear, including locks, door flashings, etc. For a desired size and shape of store, give

Figure 3.1 Roof overhang giving shelter from sun and rain

Doors

Doors are best steel-framed, of a double-leaf sliding design, and clad with 0.8 mm galvanized steel or aluminium, giving a clear opening approximately 4 x 4 m. Two doors in each side wall are the minimum in a 1000 tonne store. All doors should run outside the building and be supplied complete with all tracks and door gear, including locks, door flashings, etc. For a desired size and shape of store, give
careful consideration to the number and location of doors. Bear in mind that, as well as admitting produce, doors are important for ventilation and lighting, but can also admit rodents and thieves. Details of rodent-proofing are discussed in Chapter 14.

**Ventilation**

Control is crucial in areas that experience high relative humidity. Each ventilator opening should be covered by a flap-door which can be shut firmly when the outside air has a higher relative humidity than that inside the store. The most effective location for ventilators is high up on the walls, close underneath the eaves. Ventilators 0.6–1 m high, top-hinged, running the full length of the building on the front and back sides should be satisfactory. They must be convenient to open and fasten from ground level outside the store. The openings should be covered with bird-proof wire mesh.

**Walls**

Sheet steel cladding and hollow or solid concrete blocks are suitable. Reinforcement should be included to enable walls to resist impact. A damp-proof course is important. Slate or engineering bricks or a course of waterproofed concrete, which will maintain strong adhesion to the blocks, are preferable to plastic or bitumen.

**Construction of foundations, floor and walls**

The following information is for commodities packaged in bags, cartons, drums or similar. If it is likely that the building may be used to store any loose commodity in bulk on a future occasion, then the floor and walls will need additional reinforcement and further professional advice should be sought.

**Preparation of site**

The organic matter in topsoil shrinks as it decays, so all topsoil should be removed from the site. It is extremely important to have a firm base for foundations and floor. A loosely compacted base will settle over time and will probably settle unevenly. Eventually the floor or walls above will be insufficiently supported and will crack. Cracks are impossible to keep clean, and provide a home for insect infestations which will carry over from one consignment to the next.

**Foundations**

The weight of the roof is transmitted to the ground by the columns which rest in specially prepared concrete foundations. The manufacturers of the framework should be asked to give their recommendations for suitable foundations. The subsoil needs to be examined and identified as to type. The dimensions for wall foundations (Table 3.1) should be treated as minimal. Local expertise or professional advisers may see fit to increase them.
Foundation trenches

The bottoms of trenches should be made level and firm, and to the correct depth. Pockets of soft material need to be replaced with tightly packed, hard material. Trenches ought not to be dug until ready to be filled with concrete. If the trench bottom is softened by rain, it is necessary to remove the soft layer before placing the foundation. Wet concrete should never be poured into standing water.

Reinforcement

For normal flooring and walls, mild steel reinforcing bars approximately 15 mm diameter and about 2.5 m long are usually adequate.

Walls

It is best not to build masonry walls on an extension of the floor slab, but to build them directly on a wide concrete strip foundation. Vertical columns to carry roof rafters should have foundation pads which are deep and wide enough for all anticipated loads and stresses. Walls should not be bonded to vertical columns. Blocks must be correctly bedded, using suitable mixes for cement and concrete; good workmanship is essential. Correct bonding is important – vertical joints need to be staggered, hollows in the blocks to be filled should be placed accurately one above the other, steel reinforcing rods should overlap by about 600 mm, and the concrete filling the hollows should be well compacted. The inside surfaces of walls need to be rendered with a thin layer of plaster. Exterior surfaces should not be plastered, but given a good cement wash (a thin slurry of cement and water) and waterproofed with white or light-coloured bitumen paint. A thick coating of bitumen along the bottom of interior surfaces, from below the bottom of the floor slab to about 300 mm above final floor level, will ensure a dry wall.
Floor

Avoid filling the floor area with loose earth. Never use topsoil. If infill must be used, choose stones, rubble or broken bricks and consolidate these thoroughly in layers 150–300 mm thick, using sand or fine gravel to fill gaps. Cover the surface with 50–80 mm of moist sand that is beaten down firmly. Take particular care near foundations for walls and pillars. Lay the floor concrete after the roof is built. Design the final floor level to be higher than the adjacent roadway and ground levels which should slope away. An outfall slope to doors of 50 mm in 3 m is required for both the base and the final floor surface. The final consolidated layer of sand or soil-cement should be treated against termites and covered by a damp-proof membrane of thick plastic (such as polyethylene) sheeting. The sheets should overlap by 0.5 m, with ends being brought up the wall for 0.3 m. This membrane may be omitted if rainfall is less than 200 mm per annum. The floor concrete needs to be at least 0.15 m thick, increased to about 0.2 m at the edges for additional strength. Expansion joints 10–20 mm wide (to be filled later with bitumen or mastic) should be left every 5 m and around the bases of columns or pillars.

The best floor concrete is 1:2:4 concrete mixture (Table 3.2) made up with clean water (as little as possible) and washed sand and aggregate. Any clay, dirt or salt in the sand or water will weaken the concrete. If excess water is used in the mix it will leave voids as it evaporates, reducing final strength by as much as 40%. Formwork into which the heavy wet concrete is poured must be strong (for example, thick wooden planks) and should extend the full depth of the concrete slab. Conventional concrete-laying practices should be followed: lay the concrete in convenient wide bays (say 3 m); consolidate the concrete thoroughly by pounding with the edge of a heavy plank; and finish with an appropriate surface treatment, usually with a medium-stiff broom. It is particularly important that freshly laid concrete is prevented from drying rapidly. It needs to be kept damp for 10 days by covering with polythene sheeting, bitumen felt, or hessian (sacking), which is kept damp by spraying it with water. Keeping the concrete damp prevents cracking and ensures a strong, dust-free surface. Traffic should be kept off the setting concrete for at least 14 days, or a month if possible.

If heavy machinery is to be used in the building, high kerbs are advisable around the foot of each column to protect it from collision damage. The floors also need to be reinforced to strengthen against point loads. Concrete fillets or coving may be laid in all corners and along the intersection of floors and walls to facilitate cleaning. Openings at joints caused by shrinkage must be filled with flexible filler such as

### Table 3.2 Recommended mixes (proportions by volume) of concrete for foundations, floor and wall reinforcing

<table>
<thead>
<tr>
<th>Cement</th>
<th>Damp sand</th>
<th>Coarse aggregate (5–20 mm)</th>
<th>Water</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>4</td>
<td>0.6</td>
<td>4.75</td>
</tr>
<tr>
<td>1 bag</td>
<td>85 litres</td>
<td>140 litres</td>
<td>24 litres</td>
<td>170 litres</td>
</tr>
<tr>
<td>0.2 m³</td>
<td>0.4 m³</td>
<td>0.8 m³</td>
<td>125 m³</td>
<td>1 m³</td>
</tr>
</tbody>
</table>
bitumen-based mastic. Mastic should also be forced into all small openings where steel meets masonry, for example, under the roof.

**EMERGENCY STORAGE STRUCTURES**

**Locally available structures**

There may be unconventional structures or facilities available locally which could be utilized in emergencies to store small quantities of food aid for limited periods. Examples are:

- shipping containers
- bulk containers
- railway wagons
- barges
- ships’ holds
- tents.

Closed containers, railway wagons or barges may be subject to severe solar heating if not shaded. With tents, dunnage will need to be provided to protect the contents from rising damp. Storm drains may need to be constructed around the site. Barges and ships’ holds need to be checked to ensure the bilge water level is kept low and the hatch covers are leak-proof.

**New storage structures for emergencies**

Structures that can be either imported or built locally include:

- warehouses – steel, concrete or timber frame, foldaway type and Nissen type
- frameless buildings – prefabricated modular buildings and steel silos
- framed structures with flexible cladding – steel, aluminium or wooden frame with plastic, canvas or woven mat cover, or flexible silos supported by weldmesh
- frameless flexible systems – tarpaulin or plastic sheet, cover and plinth, or airwarehouses.

Structures suitable for air transport would require large aircraft, and delivery to remote areas would be correspondingly more difficult. However, many are designed to fit into shipping containers and are commonly transported by sea and land. The general advantages and disadvantages of these structures are as follows.

**Warehouses**

For emergencies that extend for 4 years or more, these are the most suitable structures in terms of economics and operations because of their durability and design. They are resistant against wind and weather damage. They take a long time to plan and build, and so plenty of warning is needed of an emergency to allow for construction of these stores. If imported they are bulky and heavy, hence freight will be expensive and difficult. After the emergency is over, warehouses are suitable for a range of alternative uses.
Frameless buildings

These usually have to be imported from an industrialized country and are bulky, heavy, expensive and can be difficult to transport. A reasonable amount of advance warning is necessary as foundations need to be prepared.

Framed structures with flexible cladding

Prefabricated relocatable warehouses

This type of warehouse is commonly used by food aid and relief organizations for a variety of emergency storage purposes. There are several suppliers, but the basic concept is a modular prefabricated building with a tubular steel frame covered by PVC-coated polyester fabric which is tensioned over the frame to provide a tight-fitting shell (Figure 3.2). The advantages of these tent-like structures are that they can be supplied quickly by air or sea freight, they are relatively simple and fast to erect, are relocatable, and can be extended in modular units if necessary.

Capacities vary from 50 to 3000 tonnes. The smaller units require no site preparation, while basic site clearance and levelling are required for the larger units. Both large and small units can be air-freighted or shipped in containers complete with all necessary tools and equipment.

These stores require minimal foundations, and the integral base frame can be effectively anchored to the ground. However, site selection is important because there will commonly be no existing provision for water drainage. This can be overcome by selecting a site that is not liable to flooding, and constructing adequate

Figure 3.2 A modular prefabricated building
storm drains around the periphery of the site and around each temporary warehouse. Ideally, the concrete floors should be laid to provide a solid and waterproof floor. However, time and money are often not available and the warehouses are erected over sand or earth surfaces. Protecting the stored contents from groundwater in these circumstances necessitates covering the floor with strong plastic sheeting and ensuring there are sufficient pallets to keep the stocks clear of the ground.

Although these warehouses are normally white to reflect the heat, it is usual for it to become quite hot inside on sunny days. The heating of the air facilitates the movement of water from ground that is not concreted or covered by plastic sheeting into the air inside the warehouse. When the temperature falls at night, the water in the air tends to condense on the steel frame and ‘internal rain’ from the roof beams can fall on the stored food. This problem can be reduced if most of the floor is covered with concrete or plastic sheets, if there is good ventilation during the day, and if plastic sheets are placed over the stacks in locations where condensation is observed to fall. Where there is a power supply it may be possible to fit ventilation fans into the end walls of the warehouse, but this is not common.

The absence of a concrete floor can permit rodents and termites to enter the warehouse. It is possible to use insecticides where termites are a serious problem, but knowledge of insecticides together with good management competence and practice is required to prevent contamination of the stored food.

Extra site security is essential as the fabric side walls are easily cut with a sharp knife.

**Flexible silos**

These are normally of 250–500 tonnes capacity (for bagged produce) and are fitted with rodent guards. They can be made operational very rapidly. After air-freighting and being transported to the site, each flexible silo can be erected in a day with unskilled labour when supervised by the supplier. Manual loading takes 3 or 4 days. The disadvantage of flexible silos is that, with constant filling and emptying, they may be so damaged that they become useless in 1 or 2 years. Additionally, they require a high level of management efficiency even in normal use. In an emergency their use may nevertheless be justifiable, because the silos provide better protection than tarpaulins from pests and weather. The silos do not require a plinth or dunnage. They need only a level, sand-covered base, and this is easy to provide.

**Frameless flexible systems**

**Cocoons**

These are tough but flexible UV-resistant PVC enclosures sealed with zip fasteners. They are very light when empty and can be delivered easily to site. Capacity ranges from 5–50 tonnes. The manufacturers claim that they prevent insect, water and water vapour penetration into the contents. Bagged grain or other commodities are stacked on the bottom half of the cocoon and then covered by the top half. The two
halves are joined together with an airtight zip fastener. Their most useful features are that they can be installed in minutes, and provide the potential for airtight storage which means any insect infestation will die when the available oxygen is used up. This is more likely to occur after several months’ undisturbed storage.

In practice, the contents might only rarely be left long enough for the oxygen concentration to fall sufficiently to benefit from the insect control potential, and rodents have been seen penetrating cocoons in use under field conditions. Rodent penetration will prevent airtight storage and will result in damage to the contents.

*Tarpaulins, plastic sheets, cover and plinth*

Stacks of bags or cartons constructed in a conventional warehouse have a flat top to facilitate construction, inspection and physical audit. However, when stacks are constructed outside to be covered with plastic sheets or tarpaulins, it is important that the tops are formed into a ridge to shed water easily. Ideally, the base of each stack should rest on a well made plinth, or at least on dunnage to provide protection from groundwater. This type of storage is common in some countries, such as India, and is sometimes referred to as cover-and-plinth. Plinths made of brick or concrete sometimes cost more than the tarpaulins, and if tarpaulins have to be imported the air-freight charges over long distances will be considerable.

Sheeted stacks may be susceptible to moisture condensation at the top. This can be reduced by insulating the top of the stack; for example, by providing a top layer of straw-filled bags on top of the bags of grain. Opening the side covers during daylight hours on dry days will facilitate the removal of moisture. High winds can tear the sheets which, therefore, should be securely lashed in place with ropes. Successful cover-and-plinth storage depends on advance planning and preparation and on having the necessary materials, and it is essential to have a high level of commodity management proficiency.

*Airwarehouses*

Airwarehouses rely on the pressure of forced ventilation to keep them erect. Once erected and working satisfactorily, bagged produce can be moved in and out of the buildings easily. Each warehouse typically has a capacity of 2000–5000 tonnes. The disadvantage is that appreciable site preparation is required before erection, and a constant power supply is necessary for the fans to keep the structure inflated and erect. Considerable technical skill is also required to manage these structures, which have been used for food aid with varied success.

**Selecting emergency stores**

Temporary stores are preferred where speed of provision is essential, but more permanent stores are easier to manage. The decision tree (Figure 3.3) takes account of the following priorities in order of importance.
Figure 3.3 Decision tree for structure selection
(A) Is the warning of the emergency early or late?

If the warning is early, use the left branch where more permanent structures, either local or imported, are feasible. If the warning is late, the right branch provides details of more temporary storage systems. However, the food store is required only when a flow of relief food supplies is established, and the assessment of urgency should take into account the time needed to achieve this.

(B) Is funding ample or scarce?

Many relief agencies can command appropriate funds, but this criterion is included to keep capital costs in mind. For example, plastic-clad relocatable stores cost five times as much as tarpaulins per tonne capacity. Therefore, in the short term, tarpaulins can be provided for five times the quantity of commodity for the same expenditure.

(C) Is site management good or bad?

If there is poor management, an assumption is made that imported supervision will be needed for store erection. The provision of good management leads to the consideration of difficult-to-manage systems such as cover and plinth and air-supported warehouses.

(D) Are site transport and labour availability good or poor?

Where transport and labour are a constraint, the decision tree leads to the consideration of facilities that speed up the turn-around of trucks. So, for example, drive-through stores or warehouses with canopies over the doors are recommended.

Other factors to be considered include the need for:

- security – such as guards, fence, lights
- protection against extremes of climate
- protection against pests, especially rodents.

In many food relief emergencies the warnings are late, but there is ample funding; on-site management is good, but transport is often poor. In this case the locally made plastic-covered, wooden-frame structure is ideal. If such structures are not readily available locally, imported plastic-clad structures should be used.

Whatever the type of structure preferred, selected by means of Figure 3.3 or otherwise, it is recommended very strongly that in every emergency food storage situation, as an insurance against delays and as a first aid measure, tarpaulins or plastic sheets should be purchased and despatched by air if necessary to cover the initial storage requirement. The procurement of other structures for the total requirement can then proceed normally.
FURTHER INFORMATION

Information from GrainPro Inc., 200 Baker Avenue, Suite 309, Concord, MA 01742, USA, Tel: +1 978 371 7118; Fax: +1 978 371 7411; Email: info@grainpro.com; Website: www.grainpro.com

Information from Rubb Buildings Ltd, Dukesway, Team Valley Trading Estate, Gateshead, Tyne and Wear NE11 0QE, UK, Tel: +44 (0)191 4822211; Fax: +44 (0)191 4822516; Email: info@rubb.co.uk; Website: www.rubb.com


Chapter 4

Effects of moisture, relative humidity and temperature in stored food

INTRODUCTION

An essential objective in food aid storage is to preserve the quality of the food commodities. The climatic factors sunshine, rainfall, humidity and temperature all influence conditions during storage, and may have a direct or indirect effect on the condition of the food.

Table 4.1 shows a very simple classification of climates based on temperature and rainfall. Many of the countries in which food aid commodities are stored are in the hot zone, where deterioration is most rapid and where (in general) the higher the rainfall, the greater the potential for deterioration. Food aid is also supplied to a number of countries in the warm zone, and to a very few in the cool zone where there is a definite winter and summer. Within these zones there are areas at 1500–4000 m above sea level where the climate is modified by the marked effect of altitude on temperature. At high altitudes mean temperatures are reduced, but the daily maximum in tropical regions may still be high.

Moisture, relative humidity and temperature affect food in store indirectly, through their influence on pests and fungi, and directly, through physical and chemical processes. These areas are considered separately below.

SOME DEFINITIONS

Temperature is the measure of how hot something is. It is determined using various types of thermometer, and usually given in degrees Celsius (°C). In most cases a large bulk of stored food will remain at a temperature close to the surrounding air (shade) value.

Relative humidity indicates the amount of water present as vapour in air. It is defined as the ratio of the water vapour pressure of a sample of air to the saturation water vapour pressure at the same temperature, expressed as a percentage. As the saturation vapour pressure increases as the temperature rises, the actual quantity of water per kg air for a given relative humidity is greater at higher temperatures. Even so, organisms – including man – respond primarily to the relative humidity.
The moisture content of a food refers to the amount of water present in it, given as a percentage by weight of the sample. In practice, moisture content should be specified in relation to the test method used to determine it.

The equilibrium relative humidity of a food at a given moisture content represents the relative humidity of the air in equilibrium with the food – when there are steady-state conditions with no net movement of water between air and food. The air between granules of food will usually be at the equilibrium relative humidity (e.r.h.) except during forced ventilation. A food exposed to air with a relative humidity higher than the e.r.h. will gain moisture, and vice versa, although the rate of change will vary according to the food.

The water activity (A\text{w}) of a food is the e.r.h. expressed as a fraction rather than a percentage.

Table 4.1  A simple climate classification for a range of WFP locations

<table>
<thead>
<tr>
<th>Rainfall regime</th>
<th>Low</th>
<th>Seasonal</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>More or less constant dryness</td>
<td>Marked summer rains and winter drought in hot zones (savannah). Winter rains in warm zones with a Mediterranean climate. Rain in spring or summer in the steppes bordering warm-dry climates</td>
<td>Uniformly high rainfall in most months, or high rainfall with one or two pronounced maxima in hot zones</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Annual rainfall (mm)</th>
<th>0–500</th>
<th>500–1500</th>
<th>1000–10 000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature zone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hot: mean temperature of coldest month not less than 18 °C</td>
<td>hot-dry</td>
<td>hot-seasional</td>
<td>hot-wet</td>
</tr>
<tr>
<td></td>
<td>Khartoum, Sudan</td>
<td>Bamako, Mali</td>
<td>Libreville, Gabon</td>
</tr>
<tr>
<td>Warm: mean temperature during coldest month not less than 6 °C</td>
<td>warm-dry</td>
<td>warm-seasional</td>
<td>warm-wet</td>
</tr>
<tr>
<td></td>
<td>Baghdad, Iraq</td>
<td>Algiers, Algeria</td>
<td>Quito, Ecuador (upland climate)</td>
</tr>
<tr>
<td>Cool: during 1–5 months of the year, mean monthly temperature less</td>
<td>cool-dry</td>
<td>cool-seasional</td>
<td>cool-wet</td>
</tr>
<tr>
<td></td>
<td>La Paz, Bolivia (upland climate)</td>
<td>Seoul, Korea</td>
<td>No countries receiving food aid from WFP have a climate of this type</td>
</tr>
</tbody>
</table>
EFFECTS ON BIOLOGICAL DETERIORATION

The organisms that cause deterioration of stored foodstuffs all need a suitable moisture content and a favourable temperature to grow and reproduce. The maintenance of cool and dry conditions in and around food aid commodities will minimize damage from these sources.

Moisture effects

All foods, with the exception of pure oils and fats, contain some water, which may range from about 2% in ‘dry’ foods such as skimmed milk and some biscuits to around 25% for dried fruits.

Most food aid commodities are in granular form, for example, cereals or milk powder. For these commodities it is more meaningful to be aware of e.r.h. or $A_W$, because susceptibility to deterioration is correlated with these factors, not to moisture contents which vary, at any given value of e.r.h. and $A_W$, between different commodities. For example, at 70% e.r.h. most cereal grains have a moisture content in the region of 14%, whereas dried fruit has a much higher moisture content; in contrast, oil-rich foodstuffs have lower moisture contents. However, in practice it is usual to measure moisture content because it is practical to do so with electrical moisture meters.

It is possible to measure e.r.h. directly, but this is very difficult. The e.r.h. can be determined indirectly by measuring the moisture content and finding the corresponding e.r.h. from a moisture sorption isotherm graph for the specific commodity. Isotherms are explained later in this chapter. Most moisture meters indicate the percentage moisture content. This is the conventional measure in commerce, mainly because it relates directly to the weight changes that may occur in storage due to gain or loss of moisture due to seasonal changes in climate.

Micro-organisms such as moulds are unable to multiply when the e.r.h. is below 65%. Insects and mites are most active in the range 60–80%, but some insects are able to breed under drier conditions, for example, *Trogoderma granarium*, *Rhyzopertha dominica* and *Prostephanus truncatus*. Very high e.r.h. values encourage mould-feeding species such as *Carpophilus* spp., *Typhaea stercorea* and *Ahasverus advena*.

Temperature effects

These are more straightforward. The temperature range favourable for the growth of micro-organisms is wide, and extends from a lower limit of –10 °C for cold-hardy mould species to an upper limit exceeding 60 °C for certain heat-resistant bacteria. The range of temperature suitable for insect development is narrower. Most insects are unable to complete their life cycle at temperatures outside the range 10–45 °C, and temperatures below 17 °C reduce insect activity substantially. However, *Sitophilus granarius* and *Oryzaephilus surinamensis* can be important pests under temperate conditions.
Stores in most parts of the tropics and subtropics have temperatures in the range 25–35 °C, so it is necessary to suppress biological activity as far as possible by reducing the moisture content and, therefore, the e.r.h. of stored produce and using other methods, where necessary, to control insects.

Effects on physical and chemical deterioration

All foodstuffs – even when they are not subjected to infestation by insects and micro-organisms – may suffer changes in texture, colour, flavour or nutritive value resulting from the effects of temperature and moisture during prolonged storage. These changes do not necessarily render the food unfit for human consumption, but they may make it less palatable and sometimes unacceptable to the consumer. Labelling of non-perishable packaged foods with a shelf-life (best before or expiry date) is usually based on a loss of quality resulting from physical or chemical changes. Certain temperatures and perhaps humidities of storage are assumed; the date may be misleading if conditions are different.

Physical changes

Changes in storage temperature can alter some foods as a result of a change of physical state in one or more of their components. At high temperatures, the fats in products such as canned meat or dried oily fish may melt. At low temperatures, sugars present in foods such as condensed milk may crystallize from solution, giving a gritty texture to the food.

The absorption of moisture by very hygroscopic foods can also cause undesirable physical changes. Sugar will absorb water from the atmosphere when the relative humidity exceeds 86%, a film of saturated sugar solution forming around each sugar particle. If the relative humidity then falls below 86%, water is lost from this saturated solution and tiny crystals are formed on the surface of each particle. These tend to bind the particles together and the sugar becomes caked in to a hard mass. Salt behaves similarly, but forms the saturated solution at a lower relative humidity (75%). Saturated salt solution is extremely corrosive and can damage the floor and walls of the warehouse. Caking can occur in milk powder which has absorbed moisture from the atmosphere. The increased moisture content allows crystallization of the lactose in the milk powder, and these crystals tend to bind the powder into a very hard mass. The crystallization liberates free water which raises the water activity of the powder, thus increasing the rate of chemical deterioration. The absorption of moisture by dried fruits may also lead to sugar crystallization, but caking does not occur.

Chemical changes

Chemical changes in stored food take place at rates governed by the temperature and moisture content. The effect of temperature is such that a 10 °C rise, within the temperature range likely to be encountered in temperate or tropical conditions, causes an approximately twofold increase in reaction rates. Cool storage retards changes such as fat oxidation, vitamin loss and container corrosion. Foods such as
dried milk benefit from even a small reduction in storage temperature. Keeping such foods cool and dry will usually greatly reduce the rate of development of brown discoloration (browning) and the associated off-flavours.

**Moisture sorption isotherms for foodstuffs**

These show the relationship between moisture content and relative humidity at given temperatures. They indicate the e.r.h. of the air in contact with the foodstuff at a given temperature and for any particular moisture content. Conversely, they show the moisture content that the foodstuff will attain if it is exposed indefinitely to air of a given relative humidity. The moisture sorption isotherms for protein and carbohydrate constituents of foodstuffs are smooth, S-shaped (sigmoid) curves (Figure 4.1). They demonstrate the phenomenon known as hysteresis – one lags behind the other, so the moisture content corresponding to a given e.r.h. may have two values, one for material that is absorbing moisture and the other for material that is giving off, or desorbing, moisture.

As each isotherm relates to a given temperature, the relationship between moisture content and e.r.h. holds only at that temperature. It may be approximately the same within a range of a few degrees of temperature but, with cereal grains for example, the e.r.h. for any given moisture content value will rise by nearly 3% for every 10 °C rise in temperature. For this reason, moisture contents that are considered safe for storage in temperate climates are not necessarily safe for storage at higher temperatures (Figure 4.2). As a rough guideline, moisture contents for grain storage at 25–30 °C should be about 1% lower than for storage at temperatures below 20 °C.

![Figure 4.1 A typical sigmoid (S-shaped) moisture sorption isotherm illustrating hysteresis](image-url)
Equilibrium relative humidity maintained constant at 72%

- Temperature raised to 30 °C → Moisture content decreases to 13.4%
- Temperature lowered to 10 °C → Moisture content increases to 14.6%

Wheat of 14% moisture content

Moisture content maintained constant at 14%

- Temperature raised to 30 °C → Equilibrium relative humidity increases to 75%
- Temperature lowered to 10 °C → Equilibrium relative humidity decreases to 68%

Wheat of 72% equilibrium relative humidity at 20 °C

Figure 4.2 Effect of changes in temperature on the moisture content and equilibrium relative humidity of wheat
The isotherms for any specific foodstuff will depend on its constituents. Thus the sorption isotherm for wheat is similar to that for starch, its main constituent. Dried salt fish, consisting of protein but with a large amount of added salt, has an isotherm showing a marked rise in moisture content at relative humidities around 75%, due to the tendency of salt to form a solution at this humidity. Dried milk powder, containing almost equal amounts of protein and the sugar lactose, will have an isotherm intermediate in shape between those for proteins and non-crystalline sugars, with some of the characteristics of both. The isotherm shape for any given commodity can be predicted with some confidence and provides a guide to the behaviour of the commodity during storage.

Isotherms can be used to determine the moisture content of the stored commodity at its average temperature during storage corresponding to 70% relative humidity. This moisture content is frequently described as the safe storage moisture content. In this condition the commodity is safe from mould attack (Table 4.2).

Table 4.2  Advised maximum moisture contents for safe storage of commodities at temperatures up to 27 °C

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Maximum moisture content % (wet basis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>13.5</td>
</tr>
<tr>
<td>Bulgur wheat</td>
<td>13.5</td>
</tr>
<tr>
<td>Wheat flour</td>
<td>12.0</td>
</tr>
<tr>
<td>Maize</td>
<td>13.0</td>
</tr>
<tr>
<td>Maize meal</td>
<td>11.5</td>
</tr>
<tr>
<td>Rice</td>
<td>12.0</td>
</tr>
<tr>
<td>Sorghum</td>
<td>14.0</td>
</tr>
<tr>
<td>Millet</td>
<td>14.5</td>
</tr>
<tr>
<td>Beans</td>
<td>15.0</td>
</tr>
<tr>
<td>Lentils, split peas</td>
<td>14.0</td>
</tr>
<tr>
<td>Dried fruit</td>
<td></td>
</tr>
<tr>
<td>dates</td>
<td>24.0</td>
</tr>
<tr>
<td>prunes</td>
<td>21.0</td>
</tr>
<tr>
<td>sultanas</td>
<td>20.0</td>
</tr>
<tr>
<td>raisins</td>
<td>25.0</td>
</tr>
<tr>
<td>Dried fish*</td>
<td></td>
</tr>
<tr>
<td>stockfish</td>
<td>14.0</td>
</tr>
<tr>
<td>salt fish</td>
<td>28.0</td>
</tr>
</tbody>
</table>

*Calculated on a salt-free basis.
Values given apply to food in packages; lower moisture contents may be required for bulk.
FURTHER READING


Chapter 5

Measurements of moisture, relative humidity and temperature in stored food

INTRODUCTION

Changes in the moisture content and temperature of exposed foodstuffs can arise as a result of fluctuations in the temperature and relative humidity of the ambient air, especially in commodities stored in small bulks or small stacks. Records of temperature and humidity within stores are useful in assessing their suitability. In some circumstances it may also be necessary to determine the moisture content of foodstuffs, either by standard laboratory methods or, more commonly, by field instruments (moisture meters). This is generally advisable when foodstuffs are taken into store, unless the moisture content is already specified and controlled by impermeable packaging. It will also be necessary at discharge, if weight losses are to be properly assessed.

MEASUREMENT OF MOISTURE CONTENT

Laboratory methods

Oven moisture determinations should follow an international or national standard method wherever possible. Such methods generally involve grinding, then drying a sample of 1–10 g in a ventilated oven (preferably with fan ventilation), or in a vacuum oven, at temperatures ranging from 45–130 °C (Table 5.1). The time required varies according to the method.

Field methods

Resistance meters and capacitance meters: the electrical characteristics of many food commodities vary with the moisture content, degree of compaction and temperature. There are many moisture meters that measure either the electrical resistance or capacitance (Figures 5.1 and 5.2), and most are reasonably accurate and reliable if used carefully and calibrated frequently against a standard laboratory method.

MEASURING RELATIVE HUMIDITY

Wet and dry bulb psychrometer

This commonly consists of two identical mercury-in-glass thermometers, the bulb of one being covered with muslin wetted by distilled water. Movement of air past the thermometer bulbs causes water to evaporate from the wet bulb, resulting in a
decrease in temperature. Under standardized conditions, the difference between the wet and dry bulb readings provides a measure of the relative humidity. The most accurate forms are ventilated by a motorized fan. A sufficiently accurate and more convenient type is the whirling hygrometer (Figure 5.3). This consists of a wooden or metal frame holding the two thermometers, and a reservoir for distilled water. The frame is whirled on a spindle to create an adequate air flow over the thermometer bulbs, and the relative humidity of the air is obtained from the wet and dry bulb readings using a slide rule supplied with the instrument.

The values of wet and dry bulb temperature may also be used, with hygrometric tables, to determine the dewpoint. This is the temperature at which a particular

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cereal and pulses (reference</td>
<td>ISO 711, 1985</td>
<td>BS 4317-2, 1987</td>
<td>45–50 °C, 100 h</td>
</tr>
<tr>
<td>method)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cereals, except maize products</td>
<td>ISO 712, 1998</td>
<td>BS 4317-3, 1999</td>
<td>5 g ground sample, 130–133 °C, 2 h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BS 4317-1, 1981</td>
<td>8 g ground sample, 130–133 °C, 4 h or 25 g whole grain</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>sample, 130 °C, 38 h</td>
</tr>
<tr>
<td>Wheat</td>
<td></td>
<td>ASAE S 352.2, 1997</td>
<td>130 °C, 19 h</td>
</tr>
<tr>
<td>Barley</td>
<td></td>
<td>ASAE S 352.2, 1997</td>
<td>130 °C, 20 h</td>
</tr>
<tr>
<td>Oilseeds</td>
<td>EN ISO 665, 2000</td>
<td>BS 4289-3, 2000</td>
<td>101–105 °C, 3+1 h</td>
</tr>
<tr>
<td>Pulses</td>
<td>ISO 711, 1985</td>
<td>AACC 44-15A</td>
<td>If ground, as for cereals; if whole beans, 103 °C, 72 h</td>
</tr>
<tr>
<td>Milk powders</td>
<td></td>
<td>BS 1743-1968, BS 5272-1975, AOAC 16-192</td>
<td>1 g sample, 103 °C to constant weight; 100 °C vacuum over to constant weight</td>
</tr>
<tr>
<td>Dried fish, dried salt fish</td>
<td></td>
<td></td>
<td>5 g ground sample weighed, mixed with a little water, dried at 100 °C for 4 h</td>
</tr>
<tr>
<td>Cheese, processed</td>
<td></td>
<td>BS 770-2, 1976</td>
<td>3 g ground sample weighed, mixed with 20 g sand and water, dried at 100 °C for 18 h</td>
</tr>
<tr>
<td>Dried fruit</td>
<td>ISO 1026-1982</td>
<td>AOAC 22-013</td>
<td>Azeotropic distillation or vacuum oven, 70 °C, &lt;100 mm, 6 h</td>
</tr>
</tbody>
</table>

ISO: International Organization for Standardization
BS: British Standard
AOAC: Association of Official Analytical Chemists (USA)
AACC: American Association of Cereal Chemists (USA)
ASAE: American Society of Agricultural Engineers (USA)
sample of air would become saturated and start to deposit water as condensation on surfaces or as a mist. The dewpoint is normally lower than the wet bulb temperature, but approaches it as the relative humidity comes close to 100%. Consideration of the dewpoint may be particularly relevant where a surface exposed to warm air can be cooled by some external factor – for example, a ship’s hull cooled by the sea, or a warehouse roof cooled by rain. Foods are then at risk of damage from the condensed water.
Hair hygrometers

A number of natural materials, such as degreased animal hair, alter in length with changes of relative humidity.

A hair hygrometer in which a bundle of hairs is stretched along the inside of a perforated metal stem is shown in Figure 5.4. It can be inserted into bags and left until a steady reading of the humidity in the intergranular air is obtained. All hair hygrometers need to be recalibrated frequently.

Thermohygrographs

Thermohygrographs (Figure 5.5) use the same principle to give a record of relative humidity together with the temperature record obtained by the simple thermograph described below.

METHODS FOR MEASURING TEMPERATURE

A variety of devices are available for use in stores, ranging from simple liquid expansion or bimetallic thermometers to electronic thermocouples and thermistors capable of giving continuous recordings of temperature at a number of points within a store or grain silo.

Liquid expansion thermometers

For the measurement of diurnal air temperature fluctuations within stores, a maximum and minimum thermometer is useful. The thermometer contains small steel bars which rest on the columns of mercury or alcohol, and rise to the maximum and minimum temperatures as the length of the column changes. If the temperature falls, the bars remain at the highest point. Temperatures recorded daily provide a
Figure 5.4  A hair hygrometer

Figure 5.5  A recording thermohygrograph
record of the fluctuations within the store. After each reading, the bars are re-set to rest on top of the column with the aid of a magnet.

Ordinary mercury-in-glass thermometers may also be used to measure air temperature and to check other kinds of thermometers. When suitably protected they may also be inserted into grain to measure temperatures at shallow depths. Alcohol-in-glass thermometers are, however, preferable for this purpose because any contamination that would occur from breakage in use would be less serious.

**Bimetallic thermometers and thermographs**

Bimetallic thermometers with stems about 0.25 m long are useful for spot checks of the temperature within bagged foods. They are generally more robust than mercury-in-glass thermometers, but are less accurate and slower to respond to temperature changes. In the thermograph, a bimetallic strip is linked by levers to a pen which moves over the surface of a recording graph on a circular drum driven by a motor (Figure 5.5). The instrument can be placed within a store, railcar or ship’s hold, and used to obtain a record of temperature changes occurring during a day, a week or a month depending on the type of recording drum. Thermographs need to be checked frequently against a reliable mercury-in-glass thermometer. Thermohygrographs operate on the same principle, but contain a hair hygrometer as well as a bimetallic thermometer. Different-coloured inks are used so that the two traces on the graph paper can be distinguished.

**Thermocouples**

A thermocouple consists of a circuit made from two wires, each of a different metal. When one junction is at a higher temperature than the other, an electromotive force results and this causes a very small current to flow in the circuit. A suitable electronic meter will measure this current, compensate for ambient temperature and give a direct reading of temperature at the sensor junction.

In food storage situations, thermocouples usually consist of a length of copper wire soldered at one end to a similar length of wire made of constantan, an alloy of copper (60%) and nickel (40%). The opposite ends of the wires are attached to the meter and form the reference junction. The soldered ends of the wires, forming the sensor junction, can be inserted into a grain mass or a bag with the aid of a probe. The meters may be battery-powered and portable, or powered by mains electricity for permanent installations.

Thermocouple sensors can be used for spot-checks or to provide a permanent means of measuring temperature at various points. With an automatic switching system and a recording meter, continuous records of temperature can be obtained.
Thermistors

The sensing element is a small bead of semiconductor material, the resistance of which increases with heating. Thermistors can be built into various probes. When provided with a portable battery-operated measuring circuit they are very convenient for field use. They can also be used in silo installations and are readily adapted for continuous recording of temperature.

FURTHER READING


Many of the problems arising during storage and transportation of food aid commodities are related to climatic conditions. An assessment of the potential for deterioration due to climate is sometimes made by reference to the deterioration index, which is derived from the mean monthly values for temperature and humidity. Table 6.1 shows the relationship between this index and the classes of climate described earlier (Chapter 4), and indicates the zones in which storage problems are most likely to arise. However, the index does little more than express the fact that commodities can be expected to deteriorate more quickly in hotter and more humid climates than where it is cooler and less humid. It obscures the fact that durable commodities can be stored for quite long periods, with relatively little deterioration even in hot humid climates, if the storage structures have been well designed and are well managed.

The deterioration index is calculated from $I = (H - 65/100) \times V$, where $I$ = deterioration index in millibars of water vapour pressure; $H$ = mean percentage monthly relative humidity (mean of day and night); and $V$ = saturated water vapour pressure in millibars at the mean monthly temperature.

It is the microclimate within a store, rather than the external climate, that is the major factor affecting the rate of deterioration of the stored foodstuffs. A more reliable

<table>
<thead>
<tr>
<th>Climate class</th>
<th>Deterioration index (millibars of water vapour pressure)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>January</td>
</tr>
<tr>
<td>Hot-dry</td>
<td>0–2</td>
</tr>
<tr>
<td>Hot-seasonal</td>
<td>0–2</td>
</tr>
<tr>
<td>Hot-wet</td>
<td>5–10</td>
</tr>
<tr>
<td>Warm-wet</td>
<td>0–2</td>
</tr>
<tr>
<td>Warm-seasonal</td>
<td>2–5</td>
</tr>
<tr>
<td>Warm-wet</td>
<td>2–5</td>
</tr>
<tr>
<td>Cool-dry</td>
<td>0–2</td>
</tr>
<tr>
<td>Cool-seasonal</td>
<td>0–2</td>
</tr>
</tbody>
</table>

Deterioration potential: low, $I = 0–2$; moderate, $I = 2–5$; high, $I = 5–10$. 
assessment of the potential for deterioration is possible only through a study of the microclimate of the store, including the temperature and humidity within large stacks or bulks of foodstuffs.

Air temperatures within stores are affected by the ambient air temperature, solar radiation (which is most pronounced in clear weather but also present when it is cloudy), and the cooling of the store fabric (especially at night in clear weather).

Depending on the materials used for store construction, daily temperature fluctuations within the store can be more or less than those outside. In extreme situations, for example, when food aid commodities are stored under exposed tarpaulins or in closed rail cars, the temperature in the commodity on sunny days can be up to 20 °C above the ambient air temperature.

Temperatures deep within a large stack or bulk of foodstuff do not respond to daily fluctuations in the ambient temperature, but will follow seasonal temperature changes with a substantial time delay. The larger the stack or bulk, the greater the time delay.

The relative humidity in well sealed stores tends towards the equilibrium relative humidity of the stored food, especially if it largely fills the store and is not packed in moisture-proof containers. In a well ventilated store, the relative humidity will correspond closely to that of the air outside. The value of ventilation in maintaining the condition of stored foodstuffs in permeable containers depends mainly on whether the outside air is drier or wetter than the intergranular air in the commodity. In stores where foodstuffs are subjected to large and rapid changes of temperature and humidity, condensation of moisture on the surfaces of the store and its contents may occur. This can cause localized increases of moisture content in the stocks and consequent mould growth or even the germination of grains.

A good store is one that minimizes in-store temperature fluctuations and permits controlled ventilation.

**CONDENSATION**

When warm air, at high relative humidity, is cooled it will have a lower capacity for retaining water and its relative humidity will increase. If it reaches saturation point or dewpoint (100% RH), then liquid water can form as condensation.

Condensation frequently occurs in sealed metal structures which are subject to considerable cooling at night when moisture, released from the stored foodstuffs during the day, condenses on the store fabric. Any consequent wetting of stored foodstuffs can lead to mould growth.
VENTILATION OF STORAGE BUILDINGS

It is important for safe storage that the temperature fluctuations within a store should be kept to a minimum and that conditions of high relative humidity, conducive to condensation, do not occur. On occasions, therefore, it may be necessary to ventilate a store with the object of reducing air temperature or removing moisture-laden air. The success of ventilation depends not only on the prevailing climate, but also on the design of the storage building and how the commodities have been stacked and arranged.

Ventilation must be practised with caution in hot-wet or warm-wet climates. The introduction of moisture-laden air will inevitably give rise to absorption of moisture by hygroscopic produce. However, in such climates daily and seasonal temperature changes are small, so there is often little to be gained by ventilation.

In hot-seasonal, warm-seasonal and cool-seasonal climates, ventilation might be beneficial at certain times of the year when conditions are hot and dry. At other times of year, the external air is moisture-laden and should be excluded. Under these circumstances a system of controllable ventilation is needed so that stores can be ventilated only at the appropriate times. Buildings with arrangements for permanent year-round ventilation in the form of openings in the eaves are quite unsuited to this type of climate.

In hot-dry, warm-dry and cool-dry climates, ventilation during the day can be practised nearly all year round, but at night it might be helpful to prevent excessive heat loss so as to reduce temperature fluctuations. In these climates, controllable ventilation is desirable. However, if this cannot be arranged, permanent ventilation is an acceptable, but second-best, alternative.

CLIMATIC HAZARDS DURING TRANSPORTATION

Ships’ holds, freight containers, rail cars and closed road vehicles can be regarded as moving stores which may pass through a variety of climates in a comparatively short period. A number of special problems are likely to arise in such circumstances. There are only limited records of microclimatic conditions in railway boxcars or road vehicles which are relevant to the types of commodity supplied as food aid. However, technology now exists to use devices such as time-temperature integrators, data loggers and electronic chip monitors to generate the necessary data.

Ships’ holds

The temperatures of ships’ cargoes change very slowly during a voyage, and tend to remain at or close to the original temperature at the time of loading. On the other hand, the steel structure of the ship and the ventilating air admitted to the holds will have a temperature very close to that of the surrounding sea and air. Figure 6.1 illustrates the relationship between the temperature of a grain cargo, the temperature of the air in the hold, and the temperature of ambient air during a voyage from North
America to West Africa. It is the difference between the temperature of the cargo and temperature of the air or the ship’s steelwork that can cause condensation within the hold. Condensation in ship’s holds is usually described in two categories.

- Cargo sweat is the term used for the consequences of condensation taking place directly on the cargo. It is brought about by loading the cargo into the ship at a low temperature and subsequently exposing it to warm moist air. A typical example is the shipping of food aid commodities in winter from a temperate climate to the tropics. As the vessel sails into the warmer regions the steel hull of the ship, in contact with the warm water and exposed to the higher ambient temperature and the radiant heat of the sun, will warm up. However, the temperature of the cargo is unlikely to change significantly, especially if it is carried in bulk or is tightly stowed. Under these conditions the temperature of the cargo may be below the dewpoint of the atmosphere, and moisture will condense directly onto it from the ventilating air during the voyage or on arrival at the tropical port, while the ship’s steelwork remains dry.

- Ship’s sweat is the term used to describe condensation on the cold ship’s steelwork of moisture originating from the cargo. Ship’s sweat is severe when a hygroscopic moisture-containing cargo, loaded into a ship’s hold at a high temperature (in a tropical port, for example) is carried into a region where the ambient and sea temperature fall quickly. The steelwork of the ship will cool quickly but the cargo will not, and it is this difference in temperature that may bring about the ‘sweating’. When the steelwork is cooled to below the dewpoint of the air in equilibrium with the cargo, condensation may form on the underside of the deck and on the cool sides of the hold, and this condensed water may then drip onto the cargo.
The differences in temperature created by a voyage through various climatic zones can be further aggravated by temperature differences created by conditions within the ship. For example, a cargo stowed near the sides or bottom of the ship, or adjacent to a refrigerated compartment, is likely to be cooled. More serious perhaps is the warming of a cargo by heat from the engine room bulkhead, the propeller shaft, or the heating elements of fuel tanks. If such heating occurs the cargo may never cool sufficiently despite the operation of the ventilation system, and worse still it may cause the temperature of the cargo to rise to hazardous levels.

A further cause of high temperature within cargoes of durable commodities is ‘spontaneous heating’ due to the activities of insects and micro-organisms.

In Figure 6.2 some of the areas within a ship where warm or cool conditions are likely to prevail are shown, together with points where food residues may lodge and become the focus of insect infestation.

In conventional cargoes (bags, cartons, drums, etc.), the temperature effects can be reduced by keeping the commodities away from direct contact with warm or cool surfaces by means of wooden dunnage or fixed cargo battens. They can also be avoided by stowing non-hygroscopic cargoes in the hottest and coolest areas of the holds. Modern bulk carriers are usually designed so that the temperature effects – from the engine room bulkhead, for example – are likely to be minimal.

Older ships have cowl ventilators which take in or discharge air from the holds and provide a natural ventilation system, although in rough weather the ventilators are closed to prevent sea spray entering the holds. Modern vessels are equipped with forced ventilation systems, and the fans can be operated in any conditions to provide rapid changes of the hold air when necessary.

**Figure 6.2** Areas within a ship where warm or cool conditions are likely to prevail
It is generally assumed that the risk of condensation in ships’ holds can be reduced by ventilation which either cools or warms the cargo and removes moisture. However, cargo ventilation presents complex problems, and decisions as to whether or not to ventilate will depend on the nature of the cargo, its condition, and the prevailing climatic conditions during the voyage.

Such decisions are sometimes based on the measurement of the dewpoints of the air inside and outside the hold. It will normally be safe to ventilate if the dewpoint of the external air is lower than that inside the hold. However, even under these conditions, there might be occasions when it is unwise to ventilate. For example, during a voyage from a temperate to a tropical region the ship’s cargo will warm only very slowly and excessive ventilation might result in condensation forming on the exposed cargo surfaces.

The dewpoint inside a ship’s hold might be high when a warm hygroscopic cargo with a relatively high moisture content is carried from a tropical to a temperate region. Ventilating with air of a lower dewpoint will tend to remove moisture from the hold, but the surface of the cargo might be cooled quickly if the temperature of the external air is much lower than that of the cargo. Under these conditions warm moist air rising from the warm cargo below could condense in the cooler surface layers and cause spoilage.

The British Standards Institution’s publication BS 4672-1971 provides some guidance on cargo ventilation, but there is often disagreement between experts on both the general aspects of ventilation and on the advisability of ventilation in specific circumstances. It is not surprising, therefore, to find that instances of ships’ sweat and cargo sweat still occur despite the use of modern ventilation systems and the vigilance of cargo officers.

**Shipping containers**

Problems of biodeterioration associated with the use of metal containers for the sea carriage of hygroscopic cargoes such as food commodities were recognized by the shipping trade soon after containers were introduced on a commercial scale in the 1960s and 1970s.

In the 1980s, trade organizations recommended that standard, non-ventilated containers should be used only for the carriage of commodities with low or negligible moisture contents, or for hygroscopic cargoes such as bagged grain and some processed grain, on very short voyages. However, a wide range of food commodities can be carried successfully in ventilated containers provided that established, inherent commodity standards are met, and that container design and usage permit optimal ventilation performance.

In the many types of ventilated container in use, air exchange is initially governed by the type, size and positioning of the air vents. When these are optimally arranged, up to four air changes per hour are achievable. Within the container, effective air
changes can only take place throughout the interior if airflow is unobstructed around the sides and over and beneath the cargo. This can be achieved by leaving an appropriate headspace above the cargo; using dunnage, or preferably regular pallets beneath the cargo; and either introducing a physical separator between cargo and container wall to permit airflow, or leaving a discrete distance at loading between cargo and container wall to achieve the same effect. A commonly used physical separator is an inner skin of plywood or other material which is a poor conductor of heat which will reduce the risk of damage to the commodity should condensation occur within the container.

The greatest risk to the integrity of hygroscopic cargoes is posed by rapid cooling of the container structure when ambient temperatures fall. Therefore, such containers should ideally be stowed below deck in order to retard the rate of cooling. Purpose-built container ships fitted with mechanical ventilation are best suited for the carriage of such commodities, as the rate at which cooling air is introduced to the container holds and thus the occurrence of internal condensation can be (at least partially) controlled.

Design modifications to ventilated containers, aimed at minimizing internal condensation, may unintentionally introduce insect harbourage and render the container more difficult to clean, thus encouraging residual infestation. Container operators should be aware of this risk and conversant with the principles and operation of fumigation as a routine disinfestation measure.

**FURTHER READING**


The aim of food aid logistics operations is frequently to assist local governments or other organizations to deliver to beneficiaries the required amounts of good quality food in as timely, efficient and economic a way as possible. To achieve this, an often elaborate system of transport, storage, handling and distribution will need to be established, as food aid commodities typically travel long distances from the point of import or procurement to the final distribution centre.

A typical storage and distribution plan is shown in Figure 7.1, where four main categories of transport route can be identified:

- **long-distance** – intercontinental and transcontinental routes for the importation of large quantities of foodstuffs
- **medium-distance** – inter-regional and intra-regional road and rail routes for the distribution of commodities
- **short-distance** – from national stores to distribution points such as regional or village stores
- **very short-distance** – from distribution points to beneficiaries’ home or place of work.

Throughout the system there will be opportunities for foodstuffs to be damaged or lost. The transport environment has a direct effect on the quality of food commodities, hence careful selection of methods of transport and handling will be necessary if losses are to be minimized. The food aid agency may have responsibility for, and even management of, transport over the first three categories of route, although responsibility for the final stage in the distribution will commonly rest with the beneficiaries themselves. No matter which organization is responsible for transportation and handling, it is important that the quality of the food aid is not compromised.

**TRANSPORTATION IN BULK OR BAGS**

Certain commodities, such as cereals and pulses, are commonly imported in bulk. However, at some point they will have to be put into bags to facilitate handling and distribution. The point at which this can take place will depend on the facilities for bulk handling and storage within the country. Food aid grain delivered in bulk is usually bagged off at the receiving port, but it may be possible to transfer the grain
Figure 7.1 A typical storage and distribution plan
in bulk by inland waterways, road or rail, or to inland storage sites where it subsequently can be put into bags. The increased use of shipping containers has led to an increase in the incidence of containerized bagged grain.

OPTIONS FOR TRANSPORTING FOOD AID

Transport by water

The bulk grain carrier, with a capacity of the order of 15 000 to 30 000 tonnes, generally ensures a quick delivery while providing good economies of scale. However, these vessels are usually limited to deep-water berths, although where such berths are not immediately available, the cargo may sometimes be discharged into lighters or barges using mobile pneumatic handling equipment (vacuvators) placed on the deck of the ‘mother ship’. In order for the vessel to achieve a fast turn-round time it is essential to have good bulk discharge, storage and distribution facilities.

Cost efficiencies accrue from the use of cargo consolidation. This is the procedure whereby several small consignments are consolidated into fewer but larger shipments. On arrival at the port of discharge, the consignment is subdivided for country distribution. This arrangement is particularly well suited to food aid grain being shipped for subsequent distribution by a number of local or international non-governmental organizations. It is widely accepted that consolidated cargoes, being larger and therefore benefiting from economies of scale, incur reduced administrative, freight and service costs.

Mixed cargo or coaster vessels, with capacities ranging from around 5000 to 15 000 tonnes, will be slower to discharge, especially where bagged cargo is not pre-slung. An efficient rate of discharge will depend on the availability of labour and transport to transfer the commodities to store or vehicle.

If the cargo is discharged onto the quay or into a port transit shed, there may be a risk of damage and loss from unfavourable climatic conditions, spillage from damaged containers, pest infestation and pilferage. These difficulties will be exacerbated in congested ports where movements are often delayed.

River barges provide a useful, relatively cheap and secure method of delivery for commodities in units of between 200 and 500 tonnes on navigable inland waterways.

Transport by land

Rail transport is ideal for long-haul transport of food aid commodities. Unit loads may vary from 20 to 60 tonnes, but the total capacity of a goods train may be in excess of 1000 tonnes. Timely delivery is usually assured, but distribution may be slow at times if the track is in need of repair or the network is overloaded due to shortages of rolling stock and locomotives. Security is generally good with closed rail cars, especially when the doors are welded closed. However, security difficulties can arise when open rail cars move slowly up inclines or are stationary in railway sidings.
The operating costs (per tonne/km) of large trucks transporting loads of 25–35 tonnes by road can be minimized if trucks are fully laden. Large trucks operate best over long distances on major roads; they can be very damaging to non-metalled roads. Their operators are often reluctant to permit them to be used on roads with poor surfaces because of the increased risk of damage to the vehicles. As with rail transport, closed trucks will provide a greater degree of security than open ones.

Small trucks of up to 25 tonnes (usually 7–10 tonnes) are useful as feeder vehicles, for example, in transferring commodities to distribution points. They are able to operate on poor roads, at least in the dry season, and into areas denied to larger vehicles. However, under these conditions there is a higher risk of breakdown and delay. Hence effective monitoring may be difficult to achieve, and security is at risk.

**Transport by air**

Air freight is very expensive and should be used only as a measure of last resort for delivery of food commodities to isolated disaster areas. The size of individual loads will be limited, although it may be possible to schedule several flights per day, weather and daylight permitting. Deliveries by air usually require either prepared airstrips suitable for the type of aircraft used, or special packaging of commodities and experienced crews for air drops. Specialist advice will be needed in selecting the most suitable aircraft for particular circumstances and in co-ordinating flights.

**ASSESSMENT OF TRANSPORT SUITABILITY FOR THE CARRIAGE OF FOODSTUFFS**

The losses that arise during transportation and handling are primarily due to damage to packaging resulting in spillage; water penetration and consequent mould damage; deterioration due to micro-climatic factors; pest infestation; contamination; and theft. Transport requirements will be selected mostly according to the quantity and type of commodity to be moved, and the logistics plan will aim to maximize the efficiency of journeys and vehicle loads. However, the availability of transport, and seasonal delivery problems such as floods and impassable roads, will influence the final choice.

Any mode of transport can be regarded as a form of moving food store and should, therefore, be secure, dry, clean, free from pest infestation, and able to provide protection against adverse climatic conditions. All forms of transport should be inspected for these factors before use. It will also be necessary to ascertain whether the vessels or vehicles concerned have the appropriate licence and water-, road- or rail-worthiness certificate. They may not be used without such documentation.

In instances where transport is subcontracted, the appropriate contract terms and conditions will normally specify the responsibilities of the contractor with respect to documentation, damage, losses, and fitness of vehicles to carry foodstuffs.
Ships

The loading of ships’ holds cannot begin until formal notice of readiness has been given by the ship owners or the master of the vessel. At this time the holds must be in a fit state to receive the agreed cargo. For international shipments, it is usual for the holds to be inspected by surveyors acting on behalf of the shippers and/or the cargo. Special arrangements may have to be made for the inspection of coastal or inland waterway vessels.

The holds must be sound and dry, and free from pest infestation. Grain and other infestable residues, which may provide a focus for insect infestation, can accumulate on the girders supporting the decks and hatches, in pipe casings, on ledges where steel plates overlap, behind flaking rust or paint, and between wooden planks lining holds or bulkheads. General cargo vessels and coasters, that occasionally carry grain in bulk, may be fitted with semi-permanent wooden partitions, or shifting boards, which prevent excessive movement of the grain in heavy seas; the gaps between boards and the supports may harbour an insect infestation.

Dunnage, used to support or separate cargoes, and consisting of a variety of materials including bamboo matting, timber, pallets, tarpaulins and plastic sheeting, may harbour infestation and should, therefore, be included in the inspection.

Road and rail trucks

A prime requirement in some countries is that road vehicles and rail trucks should provide proper security during transit. This means, in effect, that the truck should be solidly built with lockable doors, hatches or other access points. Open-topped trucks cannot meet this requirement, but are commonly used as there may be no alternative. Special arrangements may be needed to ensure the security of the goods in transit.

The floors and walls of trucks should be in a state of good repair and have smooth surfaces. In particular, there should be no holes or gaps in the floors through which loose produce may be lost, and there should be no projections such as hooks or nails that might snag packaging and cause spillage. The roof of closed trucks should be waterproof, or waterproof covers in good repair should be provided. Doors, hatches, tailgates, etc., should also prevent the entry of rainwater.

No truck should be accepted for the transportation of foodstuffs unless it is absolutely clean, dry and free from pest infestation. Special care should be taken to avoid loading foodstuffs into trucks that have previously carried commodities which will stain or taint the food.

If it is necessary for the road truck driver to carry personal belongings, reserve fuel, oil, or spare parts on long journeys, such items must be kept completely separate from the main load in order to prevent contamination or damage.
**Freight containers**

Freight containers are specially designed transport units that facilitate the carriage of commodities by one or more modes of transport. There are now many different designs of container, but the standard unit traditionally consists of a fully enclosed rigid box, fitted with a pair of hinged doors at one end.

In determining their suitability for the carriage of foodstuffs, containers should be judged in the same way as closed road or rail trucks. However, in international movements, containerized commodities may be subjected to hazardous climatic conditions in the same way as ships’ cargoes (Chapter 6).

Design modifications to facilitate ventilation can present a challenge to successful fumigation in the container. However, successful fumigation can be achieved only if the container can be fully sealed for the duration of the fumigation. The ventilation must be restored as soon as possible after completion of the fumigation.

At present, only a small percentage of bagged grain is containerized, but this proportion is likely to increase because of the economic benefits that accrue from containerization. Food aid agencies will need to be alert to the possibility of shipments being damaged by fungi resulting from condensation. The problem will be greatest during extended voyages.

**GRAIN QUALITY AND TRANSPORTATION**

Considerable quantities of food aid cereals and pulses are shipped to the tropics from temperate regions and, while the majority of these shipments present few problems, there have been instances of serious losses. These losses can take place during the voyage, during the first few weeks after discharge, or even several months following import at the tropical port.

These problems arise because the quality standards used, although internationally recognized and acceptable for normal commercial transactions (mainly within the temperate regions), are less suited to tropical storage. They are also related to the climatic hazards in transportation discussed in Chapter 6.

The procurement quality specifications typically set maximum limits on the levels of foreign material, or impurities such as broken grains, dust, chaff, straw and weed seeds and, while these limits are commercially acceptable, they may have a serious negative effect on the keeping quality or shelf-life of grain under tropical conditions. Procurement staff need to be aware of the quality standards that are required for the safe transport and storage of the food aid commodity, depending on the means and duration of transport and the conditions in the destination country. Whenever mechanical grain handling equipment is used, it is common for concentrations of foreign material to be deposited at the end of a run. Consequently, dense pockets of foreign material may build up in parts of the bulk and these may result in localized
patches of high moisture content or provide a focus for the rapid development of insect infestation. Every time grain moves through a mechanical or pneumatic handling machine the percentage of brokens will increase.

Potentially more serious is the loss of grain due to mould growth and the associated development of mycotoxins. This may arise if the quality standard at the time of procurement specifies a maximum moisture content which is too high for subsequent safe storage under tropical conditions. It can even occur when the overall average moisture content is acceptable, but the average figure disguises wide variations within the consignment – some parts of the cargo are much drier than the average and other parts much wetter than the average.

The deterioration occurs because of a change in the equilibrium relative humidity (e.r.h.) of the grain, which results from the large differences in temperature between the ports of loading and discharge. The grain moisture, temperature and relative humidity relationships are discussed more fully in Chapter 4. However, each type of grain has an upper limit of moisture content for ‘safe’ storage, and this is one which produces an e.r.h. of 70%. The effect of temperature is critical. If the grain moisture content remains constant, then for every 10 °C rise in temperature there will be a rise in the e.r.h. of about 3%.

Consider the example of a winter shipment of maize from North America to West Africa. The maize at export may have a moisture content of about 15%. At 0 °C the e.r.h. would be at or just below 70% and thus marginally safe, but the grain will keep satisfactorily before shipment because the temperature is low enough to prevent mould growth. During the voyage some changes in the grain temperature may occur, but these are rarely large enough to cause significant deterioration. Similarly, the moisture content changes tend to be small.

When the maize is discharged in West Africa, the grain can be expected to warm up quickly with no, or very little, change in the moisture content. At a temperature of 25 °C the e.r.h. will increase to 77% and so the grain will be vulnerable to mould development over a period of weeks or months. Such damage has been reported in grain shipped both in bulk and in bags, and increasingly in bagged grain shipped in containers.

Recent advances in technology have provided much more effective means of monitoring the storage environment during shipment. These include time-temperature integrators, data loggers, electronic chips and smart labels, all of which have potential as management tools.

**FURTHER READING**


INTRODUCTION

Adequate packaging can make a major contribution to the reduction of loss and deterioration in transit and in storage. This contribution is particularly significant for storage in tropical areas of the world, where climatic conditions make food deterioration a greater hazard.

Properly specified packaging is designed not only to suit the product, but also to take into account the length of time required for storage and distribution, and the prevalent conditions. Where packaged products specified for commercial handling in a temperate climate are diverted as food aid for tropical regions, packaging inadequacies alone may account for considerable food losses.

The main functions of packaging are:

- containment – so that a quantity of the commodity can be handled in one unit
- protection – so that the commodity should reach the consumer in an acceptable condition
- information – so that the type of foodstuff, manufacturing batch, weight, source and destination, and method of use can be indicated.

In addition, packaging can also add to the acceptability of the commodity. For food aid commodities, this relates especially to ease of opening and dispensing, and the suitability of the unit size. It is very difficult to design a perfect package that is not unacceptably costly, and compromise specifications are usually necessary.

A primary package is in direct contact with the food; a number of primary packages may be enclosed in a secondary package for transport.

The hazards affecting foodstuffs in transit and storage are shown in Figure 8.1. Some are unavoidable, and make physical protection with packaging essential. Others are introduced by working practices. The main mechanical hazards during handling and transport are detailed further in Table 8.1. Damage will be reduced by the choice of an appropriate package specification, paying particular attention to the important factors listed in the table. However, there is a limit to what can be achieved by
packaging, and improvements in working practices may be more economic than packaging the commodity to resist their effects.

**BASIC PACKAGING MATERIALS**

**Paper and fibreboard**

Paper is composed of layered cellulosic fibres held together by physical adhesion and by weak chemical bonds. It is an inexpensive packaging material, but has low tear strength and is highly water absorptive. When wet, it becomes weaker in tensile strength and in stiffness.

Solid and corrugated fibreboards are heavier and more rigid than paper although made from the same raw materials. They are similarly affected by moisture.

**Woven fibres**

Natural and synthetic fibres can be woven into materials suitable for food packaging. Such materials, although characterized by the nature of the constituent fibre, have certain common characteristics. They are very flexible, to some extent resistant to tearing stresses, and permeable to water and water vapour.

Jute is the natural fibre most used for food aid sacks and bale wraps, although cotton is used for some commodities. Both have high inter-fibre friction but are liable to rot if they are wetted. Synthetic sacking materials, made from woven plastic tapes
Table 8.1 Types of damage and their effect on food containers

<table>
<thead>
<tr>
<th>Type of damage</th>
<th>Container</th>
<th>Result</th>
<th>Important factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact damage through dropping</td>
<td>Sacks – woven and paper</td>
<td>Splitting of seams and material causing leaking and spillage loss</td>
<td>Seam strength</td>
</tr>
<tr>
<td></td>
<td>Fibreboard boxes</td>
<td>Splitting of seams, opening of flaps causing loss of containment function, distortion of shape reducing stacking ability</td>
<td>Bursting strength; closure method</td>
</tr>
<tr>
<td></td>
<td>Wooden cases</td>
<td>Fracture of joints, loss of containment function</td>
<td>Fastenings; wood toughness</td>
</tr>
<tr>
<td></td>
<td>Cans and drums</td>
<td>Denting, rim damage; splitting of seams and closures causing loss of containment and spoilage of contents</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Plastic bottles</td>
<td>Splitting or shattering causes loss of contents</td>
<td>Material grade; wall thickness</td>
</tr>
<tr>
<td>Compression damage through high stacking</td>
<td>Fibreboard boxes</td>
<td>Distortion of shape, seam splitting causing loss of containment and splitting of inner cartons, bags and wrappings</td>
<td>Box compression strength</td>
</tr>
<tr>
<td>Vibration</td>
<td>Plastic bottles</td>
<td>Distortion, collapse and sometimes splitting, causing loss of contents</td>
<td>Design, material, wall thickness</td>
</tr>
<tr>
<td></td>
<td>Woven sacks; corrugated fibreboard cases</td>
<td>Sifting out of contents; become compressed and lose their cushioning qualities; contents more prone to impact damage</td>
<td>Closeness of weave; box compression strength</td>
</tr>
<tr>
<td>Snagging, tearing, dropping, hook damage</td>
<td>Sacks – woven and paper</td>
<td>Loss of containment function, spillage (more severe with paper sacks)</td>
<td>Tear strength</td>
</tr>
<tr>
<td></td>
<td>Tins, drums, plastic bottles</td>
<td>Puncture, loss of contents</td>
<td>Wall thickness</td>
</tr>
</tbody>
</table>

(polypropylene and polyethylene), are increasingly used. They provide some resistance to wetting of the contents and do not rot. The plastic materials are liable to lose strength and become brittle through exposure to sunlight. Woven plastic sacks used by donors will normally incorporate protective additives that allow safe outdoor exposure for a limited period, up to perhaps 3 months, but outdoor stacking should be avoided as far as possible. These sacks are also slippery, so that stacking is more difficult unless a friction coating is applied to the surface.
Wood

Wood is a strong packaging material and is used for the construction of many types of crates and boxes. Its advantages stem from its rigid fibrous structure and the relatively slight effect of ambient climatic conditions on its rigidity. However, wood is less homogeneous than manufactured materials and, consequently, performance is variable.

Films and foils

Many plastic films are available, differing in moisture and gas permeability, strength, extensibility and other properties. Used as a single unsupported and uncoated film, only polyethylene film is significant in food aid packaging; the performance can be adjusted by selecting a suitable thickness of film. An important property of polyethylene is its heat-sealability, which allows fully sealed packages to be produced easily and reliably. Some other films give greater resistance to water vapour and oxygen transmission. Polyester (polyethylene terephthalate or PET) is the most important of these for food aid; its properties may be further improved by coatings of other polymers or vacuum-deposited metal.

These higher barrier films are used as components of flexible laminates made of two or more layers. The inner layer must enable heat-sealing, and is usually polyethylene. Aluminium foil is an excellent barrier to water vapour, gases and odours. It is used as a component of flexible laminates, but owing to its high cost is tending to be replaced by plastic-based materials.

Important characteristics of flexible packaging materials used in food packaging are given in Table 8.2.

Sheet metal

Metals are rigid and impervious, and can provide excellent resistance to all the hazards of transit and storage. Plain steel sheet of appropriate thickness is used to make drums and pails; the surface in contact with the food is, if necessary, lacquered to prevent corrosion, and the exterior surface of the container is protected by paint. Tin-plate consists of a thin sheet of low-carbon steel, coated on both sides with a very thin layer of tin, which provides some protection, although lacquer may also be applied. ‘Tin-free steel’ is similar steel sheet with an inorganic coating replacing the tin, and is always lacquered on the surface in contact with the food. Sheet aluminium is used for some small food cans. It is less rigid than steel, but less susceptible to corrosion.

Moulded plastics

Plastic materials are used in food aid packaging for vegetable oil. Formerly containers were made from polyvinylchloride (PVC), but this has now been largely replaced by polyester, which is tough, fairly rigid and chemically inert. Oil drums in the 5–25 l range are usually of either tin-plate or high-density polyethylene (HDPE). Closure components for both metal and plastic containers are made from
polypropylene, and polyethylene of low or high density, according to the specific properties required.

**TYPES OF CONTAINER**

**Woven sacks and bales (jute, cotton and plastic)**

Woven sacks are used principally for cereal grains and pulses, with net weight usually of 25–50 kg but in some instances up to 100 kg. The strength of the sack, and the seam and closure stitching, must be appropriate to the weight. Jute sacks may be closed by hand- or machine-stitching, while woven plastic sacks should be closed only by machine.

Smaller cotton bags are also used as primary packages, sometimes with a jute sack as a secondary package for transport.

Bales and bundles are used to a limited extent. In these, fabrics are sewn around a bundle of the commodity (especially dried fish). For bales, the foodstuff is compressed and steel wire or plastic banding is used to assist containment. Bundles are not compressed, and may use a woven palm mat as an inner wrap.

### Table 8.2 Properties of flexible packaging materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Typical thickness (µm)</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper</td>
<td>100</td>
<td>Strength, stiffness, opacity, printability</td>
</tr>
<tr>
<td>Aluminium foil</td>
<td>9</td>
<td>Negligible permeability to water vapour, gases and odours; greaseproof, opacity, bright appearance; dimensional stability, dead-folding characteristics</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>50–100</td>
<td>Durability; heat sealable, low permeability to water vapour, good chemical resistance, good low-temperature performance</td>
</tr>
<tr>
<td>Polyester (polyethylene terephthalate)</td>
<td>12</td>
<td>Strength, durability, dimensional stability; low permeability to gases, odours and greases; requires coating or laminating for sealing</td>
</tr>
<tr>
<td>Polypropylene (oriented)</td>
<td>12</td>
<td>Durability, strength, low permeability to gases and water vapour; requires coating or laminating for sealing</td>
</tr>
<tr>
<td>Metallized polyester</td>
<td>12</td>
<td>As for non-metallized films, with lower polypropylene permeability to gases and water vapour; bright appearance</td>
</tr>
<tr>
<td>Polyvinylidene dichloride copolymer (PVDC) co-extrusion (e.g. Saran wrap)</td>
<td>80</td>
<td>Composite films resembling polyethylene in general properties but with low permeability to gases</td>
</tr>
</tbody>
</table>
Woven sacks and bales give no protection to the foodstuff; a liner bag of polyethylene film can be used in a sack if protection against moisture is needed for a commodity such as sugar or salt.

**Multi-wall paper sacks**

Paper sacks used for food aid have four to six plies, but are nevertheless rather more vulnerable than woven sacks to journey hazards. For special circumstances, a woven plastic ply may be incorporated, giving much improved strength. Package weights are usually lower (20–30 kg). Waterproof plies, incorporating bitumen, waxes or plastic coatings, are used to help retain sack strength when wetted, but for adequate protection of the contents against water vapour a separate plastic film liner of sufficient thickness is needed.

Sack closure methods vary. Hot-melt glued, and sewn and taped closures give the best protection against moisture absorption, insect attack and sifting of the contents. Plastic film liners may be heat-sealed in the same operation. Moisture absorption not only reduces the strength of paper sacks, but may cause glued seams or sealing tapes to fail. The advantages and disadvantages of paper sacks are detailed in Table 8.3.

**Fibreboard boxes**

Solid and corrugated fibreboard boxes (cartons) are widely used for packaging of all types of merchandise. For foodstuffs they are normally used as secondary packaging, although with a liner of plastic film or waxed paper, a fibreboard box may be the primary package for dried fruit. The most common packages are within the weight range 3–25 kg. Package strength depends on the method of construction and the materials used; the stacking strength may be aided by the firmness of the contents. Fibreboard boxes are inexpensive and, when empty, take up little storage space because they can be stacked flat. They lack strength in wet or humid conditions, although special treatments such as waxing may give some improvement. Boxes may be closed using glue, adhesive tape, staples, or combinations of these.

**Wooden cases and plywood chests**

Wooden cases are now rarely used for food aid, but certain donors pack dried salt fish directly into wooden cases. The case provides little protection against moisture uptake. The transport performance of a wooden case depends largely on the effectiveness of the method used to hold together the component parts.

**Food cans**

Cans used for meat, fish and cheese vary in capacity from about 100 g to 1.5 kg. For these products the can is an integral part of the preservation process, and any fault in the can will bring the safety of the food into question. Defects are most likely to occur at the seam joint between the body of the can and the end caps. The seam is formed by interlocking a hook on the end of the body wall with a hook on the end of
<table>
<thead>
<tr>
<th>Sack type</th>
<th>Protection against</th>
<th>Containment of fine granular produce</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tearing and snagging</td>
<td>Impact</td>
<td>Moisture absorption</td>
</tr>
<tr>
<td>Jute</td>
<td>Good</td>
<td>Good</td>
<td>None</td>
</tr>
<tr>
<td>Cotton</td>
<td>Fair</td>
<td>Fair</td>
<td>None</td>
</tr>
<tr>
<td>Woven plastic</td>
<td>Fair-good</td>
<td>Good</td>
<td>None</td>
</tr>
<tr>
<td>Paper</td>
<td>Poor</td>
<td>Fair-poor</td>
<td>Good, WFP multi-wall have plastic liners</td>
</tr>
</tbody>
</table>
the cap. Any damage to either of these hooks during the manufacturing process can result in defects that compromise the integrity of the can.

All types of can used by the canning industry are subject to impact damage, which may open the seams or cause a loss of vacuum.

Corrosion may also cause failure of cans, from both the inside and outside. Some food products are particularly aggressive in attacking the can, leading either to swelling (through production of hydrogen) or to perforation. Exterior corrosion results especially from wetting by salt water.

**Tin-plate containers**

Drums in the 5–25 l range are usually of either tin-plate or HDPE. There is some use of tin-plate cans (round or rectangular) with plain seamed ends, requiring puncturing to remove the contents. Tin-plate containers with a capacity varying from 1 to 20 kg are employed for certain dehydrated foods such as dried milk and egg, and also for vegetable oils. In general, these containers are constructed in much the same way as the tin-plate food can, but special opening or pouring devices may be incorporated for liquids. Tin-plate containers are usually packed for transport in fibreboard boxes.

Solid fats such as ghee have a melting point not far removed from ambient. For large-scale packages they are likely to be treated as oils. Sealed tins are commonly used when high ambient temperatures could be encountered and the availability of refrigeration cannot be assured.

**Steel drums**

Mild steel drums are suitable for capacities of 25–200 l. Steel drums are used for food aid shipments of vegetable oils and fats. They provide effective protection and are usually sufficiently robust to withstand rough handling. Their size makes manual handling difficult, and may lead to problems at the point of distribution. Re-packing of the contents into small containers is often necessary. If possible, this should be avoided by requesting shipment in small containers.

**Plastic containers**

Owing to their low surface tension, liquid oils can penetrate through very small gaps; package closures must be carefully chosen if the product is to be contained without any seepage. Packages should also preferably restrict the access of oxygen and light to avoid promoting oxidative rancidity. Plastic bottles and jerry cans up to 10 l capacity are used for vegetable oils. The containers are made by blow-moulding and are seamless; consequently they cannot leak (except at the closure) unless ruptured. Resistance of the containers to transport damage can be high, but poorly designed containers can have thin regions in the walls causing weakness. Suppliers’ attention should be drawn to the need for closures which will remain leak proof during

Food packaging
transport through varying climates; a sealed membrane over the container neck is helpful in preventing leakage and also provides evidence of security. The containers are usually transported in fibreboard boxes, which should provide the required stacking strength.

**SALVAGE, REPAIR AND RE-PACKAGING**

Containers damaged by rough handling during storage or transit may have to be rejected, but it may be possible to salvage the contents by repair or re-packaging. Whatever the situation, badly damaged containers, particularly those showing obvious signs of loss or leakage of the contents, should be isolated as soon as possible from the rest of the consignment. It may be helpful at this point to take photographs to assist insurance claims and to advise donors. The fitness of the contents for consumption must then be established. If this cannot be done immediately then repairs or re-packing should be done to prevent further loss or deterioration of foodstuffs that may be good. Once fitness has been established, these foodstuffs should be used before similar foodstuffs contained in undamaged packages.

**REPAIR OR RE-PACKAGING FOR DIFFERENT TYPES OF CONTAINER**

**Sacks and liners**

- Natural fibre sacks of jute or cotton can be repaired by sewing or darning or, if necessary, by stitching on patches of the same or similar material.
- Woven plastic sacks cannot be effectively repaired by sewing, and the contents should be re-bagged.
- With paper sacks or plastic film liners, once they have been holed or torn, little can be done other than to re-package.

Wherever possible, spare sacks or liners should be available for re-packaging. A few oversized sacks that will fit over damaged sacks may also be useful.

**Fibreboard boxes**

Boxes that come open, or are torn and liable to lose their contents, may be re-closed with adhesive tape. With extensive damage, or where further journey or storage hazards are likely to be severe, the use of new or undamaged containers for re-packaging is the best solution. Spare containers should be made available wherever they are likely to be needed.

**Metal containers (tins, pails, drums)**

Once a container of this type has been ruptured, there is little that can be done to repair it. With the thin metal tins used for edible oils, failure is usually a result of damage to a seam or the closure. Oil leakage stains the outer fibreboard box and this
can give an impression of greater loss than has actually occurred. Damage to tins of dry foods will be less obvious.

Steel drums are most likely to fail by puncture damage, either by falling onto a sharp point or through deliberate intervention.

Edible oils can be transferred from damaged to sound containers. Dry foods, if uncontaminated, may be temporarily re-packed in plastic bags, but should be used quickly.

Canned meat, fish and cheese must be regarded as unfit for consumption if the can is ruptured.

**Wooden cases and chests**

Damaged wooden containers can often be satisfactorily repaired provided the damage is not too extensive. Re-nailing or replacing damaged areas with new sections is usually possible. Metal wire or banding may also be useful for strengthening damaged or weakened wooden containers. Two things must be remembered: new or replaced nails should be driven into sound wood, not into the original nail holes; and care is necessary to avoid damage to the contents of the box and any lining material.

**RE-PACKAGING FOR DISTRIBUTION**

In some circumstances it will be feasible and desirable to re-pack foods into convenient quantities for distribution. Simple procedures will be necessary, unless it is possible to obtain the services of an established food-processing factory.

For dry foodstuffs, polyethylene bags are suitable for quantities up to approximately 5 kg. The bottom-weld style of bag is stronger; film thickness should be at least 38 µm for packages up to 1 kg increasing to 75 µm for 5 kg. Plastic bags are best closed by heat-sealing if electric power and a suitable sealer are available. The preferred type of sealer is an impulse sealer, which gives the most reliable seals but is expensive. Hot knife, hot bar and electric hand-iron methods require more skill and yield weaker seals. Although polyethylene can be heat-sealed without electricity, such methods are not recommended. Bags may also be closed by bunching the mouth and tying a knot, or applying a wire tie, adhesive tape or ring staple. The food is most conveniently dispensed by volume, using a suitable cup or tin as a measure, with the weight being checked and adjusted afterwards if scales are available. Scoops for handling the food and wide-necked funnels for bag filling are helpful.

Dry foods distributed in larger quantities are likely to be whole cereals or flour, for which jute or woven plastic sacks are satisfactory. It is probable that the sacks will have to be of any available size and under-filled. Only a temporary closure, with a string tie, will be required.
Re-packaging vegetable oil into quantities for issue requires screw-capped tins, glass bottles or plastic containers. These containers are expensive and it is desirable that they are used several times; this raises a problem as to whether the distributing agency or the recipient should have responsibility for cleaning the container. A measuring vessel and a narrow-necked funnel should be available.

**FURTHER READING**


Chapter 9

Inspection and sampling

Inspection in relation to food storage management will involve a detailed examination of all or part of the consignment of stored commodities, the methods of handling and transport, the storage building, and the standards of storekeeping and pest control. Examination of the commodities themselves may or may not include the taking and analysis of samples.

The overall objective of inspection is to provide information as a basis for management action and future planning to ensure that deterioration and loss of stored commodities are kept to a minimum.

Inspection and sampling work calls for the exercise of judgement by staff, based on their experience and a thorough knowledge of the nature and characteristics of the commodities and the conditions under which they are to be stored. The past treatment of a commodity, the expected storage period, and its future destination or use may all influence the methods of inspection and sampling adopted, as well as any consequent recommended action.

Summary guidelines for storage inspection are provided at the end of this chapter.

INSPECTION OF STORAGE BUILDINGS

The quality of food commodities can be adversely affected, either directly or indirectly, by the design, condition or location of any building in which it is stored. Security of stocks from theft or other forms of loss, and the health and safety of persons in or near the building, may also be affected. It is, therefore, important that buildings are regularly inspected to ensure standards are maintained. The main requirements of a storage building are discussed in Chapter 3.

Inspection of transport

Any form of transport is a potential source of infestation, contamination, spoilage or loss, so inspection is necessary if exposure of food commodities to such hazards is to be minimized. A more detailed discussion of the assessment of the suitability of various methods of transport for the carriage of foodstuffs is given in Chapter 7.
Inspection of commodities in store

Inspection of commodities should begin as soon as they arrive at the warehouse. Look for signs of damage to containers or packaging. Look for evidence of insect or rodent damage or activity. Look for signs of fungal discoloration or caking. Pour out some oil, and smell or taste it for off-flavours and rancidity. Smell or taste dried powders for off-flavours, rancidity or putridity. Open canned food to see if it is rancid or putrid. If it is just over-cooked it is safe to eat, but should be distributed quickly.

The basic equipment required for sampling comprises a notebook, torch, knife and sampling spear (Figure 9.1). Sample bags, labels, sieves and a hand lens are also useful. Effective inspection depends on access to all parts of the store. For stacked commodities there is a need for sufficient space around the stack to examine the sides and the top surface. The best time to inspect a commodity is when it is being moved into or out of the warehouse, silo, ship or truck, because all parts of each lot can be examined. However, routine inspections of commodities in store are needed.

Figure 9.1  Sampling spears (not to scale): (a) cylindrical, (b) tapered, (c) compartmented
to detect any early signs of deterioration. In the tropics, one of the major causes of loss is insect infestation. The following description of inspection methods concentrates on the detection of insects, but the principles are basically the same for inspections for other forms of qualitative deterioration.

**RECORDING INSECT INFESTATION**

A form of shorthand notation is needed to record the results of inspections, and the following categories (based on those used by the UK Department of Environment, Food and Rural Affairs) may be useful:

- **clear or none** (C) no insects found in the course of a prolonged search
- **few or light** (F) small numbers of insects occurring irregularly
- **medium** (M) insects obvious, occurring regularly (sometimes in small aggregations)
- **heavy** (H) insects immediately obvious – large numbers crawling over the outside of the stack
- **very heavy** (VH) insects so numerous and active that a rustling sound can be heard inside the stack; a carpet of insects or cast skins is often present on the floor round the base or on top of the stack.

In describing the insects found, the generic name and specific name (see Chapter 12) should be given if they are known with confidence. Otherwise only general names, such as beetles or moths, should be given, and if possible, specimens should be collected for identification by a specialist.

**DETECTING INSECT INFESTATION**

Insect pests of durable food commodities are mostly small, dull-coloured and cryptic in behaviour. Only when they are present in large numbers or have moved away from the commodity, perhaps because of a physical disturbance, are they easily noticeable.

A torch or lamp which provides a powerful beam of light is essential when looking for insects in a dark store. Insects are often induced to move and show themselves when suddenly exposed to bright light, so illumination of the sides of a stack or the spaces between bags will usually reveal insects if they are present. Some insects may react to such illumination by ‘freezing’ or feigning death and may not be noticed. Therefore, if at first no insects are seen, other methods of detection should be tried. Physical disturbance, such as sweeping likely resting places with the hand or turning the ears of bags, may reveal larvae, pupae or adult insects. The stitched overlap of the mouth of the bag should be examined carefully.

The next step should be to move some of the bags in the top layers of the stack, as this often reveals free-living insects moving in previously completely dark or hidden...
places. Also, if the bags are moved vigorously enough insects will move out of the bags regardless of light intensity.

During the course of the inspection, supplementary evidence of infestation should be sought. Residual insect infestations are likely to be found in cracks and crevices in the building structure and in any piles of spillage or sweepings lying around the store. Disturbing suspect material is usually sufficient to reveal insects, but samples should be sieved if infestation is not obvious. Other evidence of infestation includes webbing or cast larval skins on the commodity or the fabric of the building.

In dimly lit stores, adult insects are likely to be found on floors, walls and superstructures. Moth larvae may be found wandering away from infested produce and settling in corners or crevices to pupate. Anything that looks like a mass of spiders’ webbing should be investigated, as it may consist of cocooned moth pupae. Termites (white ants) can be a menace in untreated stores. Their presence is indicated by their earth-covered pathways on floors, walls, dunnage, or even the stored commodity itself.

**ORGANIZING A SAMPLING EXERCISE**

Sampling is usually done because a problem has been identified with the commodity. Given the nature of food aid, there may be several parties interested in the consignment, its condition and end use. As well as food aid agency staff, stakeholders can include government ministries (agriculture and health), shipping agents, testing laboratories, insurers, cargo superintendents and port authorities.

All these parties will have different agendas, and different opinions as to the fitness of the commodity and its fate. As the results of any testing of samples may be contentious, it is in the interest of the food aid agency to ensure the sampling exercise takes place with the full understanding and agreement of all interested parties, and in their presence, so that accusations of bias at a later date can be avoided. Thus it is recommended that a clear plan of action be agreed for:

- the separation of cargo into damaged and acceptable lots, if appropriate
- the method of sampling of these lots
- the type of analysis that should be undertaken

It may be necessary to oversample so that the same large sample can be subdivided and shared between the stakeholders. This ensures that analyses are done on the same sample, reducing a potential source of error and contention.

- Parties must fully understand and agree what constitutes damaged and acceptable commodity.
- Damaged and acceptable commodity must be placed in distinctly separate and manageable stacks. If space permits, several small stacks of around 500 tonnes (or smaller in the case of damaged grain) are preferable to a few large stacks.
Stacking of commodities on pallets will allow rapid ventilation and reduce the rate of any deterioration due to mould.

- Stacks must be properly identified or labelled to ensure the results of analysis of samples collected can be matched to the grain from which they were drawn.
- Sampling should be undertaken according to an agreed and acceptable sampling plan. Representative samples should be drawn from each stack. The number and size of the samples must be determined by the type of analysis to be undertaken – samples for mycotoxin analysis will be much larger than those for routine quality assessment; for example, for cereals at least 10 kg is needed for mycotoxins, whereas 1–2 kg is sufficient for insects.
- Samples must be properly identified and clearly labelled with details of the cargo, warehouse and stack number, the date of sampling, the name of the sampler and the analysis required.

An example of a sampling plan is given in Annex 1.

**PRINCIPLES OF REPRESENTATIVE SAMPLING**

Food aid commodities are rarely completely uniform in quality, even when they are in acceptable condition. If a consignment is subjected to poor handling or storage, some parts of it may differ significantly in character to the remainder – for example, the distribution of insects, moulds or mycotoxins will usually be uneven. Consequently, the only sure way of obtaining full and accurate information about the commodity would be to carry out a complete examination. This may be possible if the quantity involved is small, or during operations when the commodity is being moved into or out of a warehouse, or a stack is being broken down for other reasons. However, information is usually obtained from examination of a number of samples, and these samples should be representative of the whole lot if valid conclusions on the condition of the whole lot are to be reached. Samples taken from only part of the lot will represent only those parts from which they were taken. Thus, if the consignment consists of 10 000 bags but the sample is drawn only from 10 bags (rather than 100; Table 9.1), then any results will apply only to those bags, not to the whole consignment.

The results of sample analyses can be expressed in precise terms. However, precise results will be of little practical value, and may even be misleading if the samples are collected without taking account of possible non-uniform or non-random distribution of quality factors such as insects, moulds and damaged grains. Certain principles of representative sampling must, therefore, be observed if the various components of the consignment are to be proportionally included in the samples.

1. The consignment should be divided into primary units of equal size or status, any or all of which may be sampled. In the case of packaged commodities, individual bags, boxes, cartons etc., can be regarded as primary units from which samples are taken. For commodities in bulk, the primary unit may be expressed in terms of weight (if the commodity is being moved) or volume (when it is static, for example, truck, bin, etc.).
2. All primary units should have an equal opportunity of being sampled. This is possible only during the construction or dismantling of stacks, the loading or unloading of trucks, ships etc., or when a bulk commodity is being moved. It is not possible to obtain samples that are completely representative of a whole consignment if it is in a stack, bin or bulk.

3. The method of selecting primary units for sampling should permit a sufficient number to be selected so as to be representative of the consignment, and should be free from bias. In the case of bulk commodities that are being moved, at least one primary sample can be taken from each primary unit. This will not be possible with consignments of packaged commodities, so a scheme for selecting a proportion of the primary units must be used. The minimum number of primary units needed to represent a batch can be determined statistically and depends on the total number of units in the batch. Table 9.1 is based on recommendations of the International Organization for Standardization (ISO), and indicates the number of units to be sampled in batches of different sizes. Once the required number of primary sampling units has been determined, the actual units must be selected, ideally at random. Strictly speaking, a regular pattern of selection, for example, taking every tenth unit, should not be adopted as this does not conform to the principles of representative sampling. However, it is often extremely difficult to establish a truly random system, and under practical conditions a regular pattern of selection will be acceptable.

### Table 9.1 Minimum number of bags (primary units) to be sampled for different problems

<table>
<thead>
<tr>
<th>Total number of bags</th>
<th>Insects and moisture content</th>
<th>Fungi and bacteria</th>
<th>Mycotoxins</th>
</tr>
</thead>
<tbody>
<tr>
<td>4–20</td>
<td>4</td>
<td></td>
<td>Every unit</td>
</tr>
<tr>
<td>Up to 10</td>
<td>Every unit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11–100</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21–60</td>
<td>6</td>
<td></td>
<td>Every unit</td>
</tr>
<tr>
<td>61–100</td>
<td>9</td>
<td></td>
<td>Every unit</td>
</tr>
<tr>
<td>&gt;100</td>
<td>Square root</td>
<td></td>
<td></td>
</tr>
<tr>
<td>101–400</td>
<td>Square root</td>
<td>16</td>
<td>100</td>
</tr>
<tr>
<td>&gt;400</td>
<td>Square root</td>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td>1000</td>
<td>32 (square root)</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>10 000</td>
<td>100 (square root)</td>
<td>1001</td>
<td>1001</td>
</tr>
<tr>
<td>20 000</td>
<td>142 (square root)</td>
<td>200 (i.e. 2 x 100)*</td>
<td>200 (i.e. 2 x 100)*</td>
</tr>
<tr>
<td>30 000</td>
<td>174 (square root)</td>
<td>300 (i.e. 3 x 100)*</td>
<td>300 (i.e. 3 x 100)*</td>
</tr>
<tr>
<td>50 000</td>
<td>224 (square root)</td>
<td>500 (i.e. 5 x 100)*</td>
<td>500 (i.e. 5 x 100)*</td>
</tr>
<tr>
<td>100 000</td>
<td>317 (square root)</td>
<td>1000 (i.e. 10 x 100)*</td>
<td>1000 (i.e. 10 x 100)*</td>
</tr>
</tbody>
</table>

*When large stacks (>1000 tonnes) are to be sampled, divide the stacks into lots of about 500 tonnes (= 10 000 x 50 kg bags) and take 100 samples from every lot.
4. Primary samples should be extracted from primary units in such a manner, and to be of such a size, as to be representative of the consignment. Some sampling equipment and methods are more efficient than others in obtaining representative samples. When devising a sampling scheme it is expedient to select only the most efficient of those methods that can be used. Primary samples should not be too small, otherwise there is a risk that they will not include the less frequent components of the commodity and other components will be disproportionately represented. Primary samples are the initial samples obtained from the primary unit, and for the determination of quality, it is the primary samples that are usually mixed together to form the bulk sample. This may be subdivided or reduced to the required number of submitted, final lot or laboratory samples. In the laboratory, the submitted sample may be further divided or reduced to one or more working samples. Sometimes duplicate samples may be set aside as file or reference samples which may be analysed at a later date if there is a dispute over the first set of results.

**Sample size**

Different sampling protocols are needed for different commodities, and for different problems, to ensure the sample taken is representative of the lot. Thus submitted samples for free-flowing and finely divided commodities (cereal grains, pulses and blended foods) should be not less than 1 kg. For commodities that are not free-flowing (such as dried fish), the submitted sample should be not less than one item (such as one piece of fish) if each item weighs more than 1 kg.

It is important to note that, while the principles of representative sampling can be used to establish a basic sampling scheme for a wide range of commodities, there are occasions when more specialized schemes are needed, for example, when samples are required for mycotoxin analysis or when canned goods are to be sampled. On such occasions there may be a requirement to increase both the number and size of the primary and/or submitted samples. Thus submitted or final lot samples for cereals and blended foods should be 10 kg if mycotoxin, fungal or bacterial analysis is required, with 1–2 kg being sufficient for insects, moisture content and general quality parameters.

**NON-REPRESENTATIVE SAMPLING**

Best practice requires that samples should usually be representative of the whole lot, but there may be occasions when non-representative sampling is relevant. For example, a store roof may leak, so information on spoilage of the commodities directly under the leak may be sufficient, without needing to sample the rest of the lot. Likewise, food in containers may deteriorate if the container is damaged, so sampling could be confined to the affected container, there being no reason to take samples from the commodities in undamaged containers.

This type of sampling is known as judgement or purposeful sampling.
SAMPLING STORED COMMODITIES

Most food aid commodities are stored in bags. The number of bags to be sampled depends on the nature of the problem; the type of commodity; its amount; the amount that can be sampled (can the stack be broken down so that internal bags can be reached?); and the age of the stack (if newly built, bags on the faces can be assumed to be in the same condition as those inside, but if the stack is old the condition of external and internal bags may be very different). In general terms, fewer samples are required if insects and fungi are the major problems, but more samples should be taken if mycotoxin contamination is suspected (Table 9.1). There are no hard-and-fast rules for sampling methods that cover all commodities under all conditions. The data in Table 9.1 should be used as guidelines only.

Although a general inspection in a warehouse may provide useful information about the nature and distribution of an insect infestation on and near a stored commodity, it cannot yield details about the infestation within the commodity itself.

A knowledge of the history of the consignment can help considerably in determining how best to sample for insect infestations. Well kept records and stack cards will provide the best source of information. If it is known that the consignment was free from infestation when it was taken into store, or that it had been fumigated recently, it can reasonably be assumed that any live insects subsequently entering the store or cross-infesting the commodity will be located in the outermost layers of stacks or in the top 100 mm of a bulk of grain. Sampling can, therefore, be restricted to these superficial areas.

If the history of the consignment is unknown, it may be necessary to conduct a more extensive examination involving the collection of samples from inner parts of the stack or bulk. This is relatively easy in the case of bulk commodities, as a probe sampler can be used to draw samples from parts below the surface. However, sampling deep within a stack of a bagged commodity involves moving bags and is satisfactorily achieved only when the stack is completely dismantled. If this is not practicable or desirable, a compromise of sampling bags in the top two to three layers has to be accepted.

Sieving methods

Free-living insects can be extracted from samples of granular material by using either a sack sieve or hand-held sieves. However, in order to obtain maximum extraction of insects, it is important that the sieve has a screen of the right specification and that it is properly used. As a general rule, fine sieves for determining foreign matter are suitable for extracting insects from samples of large-grain commodities such as maize. Appropriately fine woven wire screens may be used for separating insects from flour or similar commodities. Different authorities specify different sieve sizes, sometimes for the same commodity, as shown in Table 9.2.
The most accurate estimates of free-living insect populations in granular commodities are obtained by sieving the contents of whole sacks. Sack sieves commonly have a sloping screen about 1 m wide and 2 m long under which a tray is fitted to collect the insects and foreign material extracted. The sample is dumped on the top end of the screen and worked by hand towards the bottom end, where it is guided into a sack (Figure 9.2).

### SAMPLING EQUIPMENT

#### Bagged commodities

Commodities stored in bags can be sampled using a sample spear (probe or trier), but it must be remembered that spear sampling does not conform to the principles of representative sampling. Sampling spears are basically pointed hollow tubes with a hole on one side. To use the spear effectively it is important to insert it into the sack with the hole underneath. Then when the spear is fully inserted into the sack, it is rotated until the hole is on the top. It can then be withdrawn carrying the sample with it. Figure 9.3 illustrates how this technique draws a sample from a cross-section of the contents of the sack, rather than just sampling the contents inside the sack material as it would if the spear were to be inserted with the hole uppermost.

A disadvantage of spear sampling is that the sample represents only one part of the contents of the sack. One sample is taken from each sack. However, Figure 9.4a illustrates that there are many possible sampling positions that would underrepresent a large area of defective grains in a sack. Figure 9.4b illustrates how the spear might be inserted into a small area of defective grains and thereby overrepresent the problem with regard to the contents.
Some designs of double-tube sampling spear may also be used to obtain samples from bags (Figure 9.5). This is better than the simple bag spear, as it collects samples from several points within the bag, but it is still a somewhat haphazard method of sampling. The only way a truly representative sample can be obtained from bags is to empty the contents and reduce the quantity using a suitable method of sample reduction or division, such as coning and quartering or a sample divider.
Commodities in bulk

If a truly representative sample is to be collected from commodities stored in bulk such as grain, this can be achieved only by drawing samples as the grain is moved into or out of store. If the grain cannot be moved, samples must be drawn using deep grain probes (Figure 9.6) and an effort should be made to reach every part of the bulk. A scheme for sampling bulks based on ISO recommendations is shown in Figure 9.7. A large bulk sample should be collected and then reduced to obtain a submitted sample of manageable size.

SAMPLE DIVISION

Coning and quartering

This is the simplest and cheapest acceptable method of reducing the size of a sample while ensuring the final sample is still representative of the original batch from which
Inspection and sampling

Excessive amounts can be missed. Small amounts can give an over-estimation of what is actually present.

Figure 9.4  Disadvantages of spear sampling

Vertical insertion  Horizontal insertion

Figure 9.5  Using a double-tube bag spear
it was obtained. It can be used for relatively large batches of granular commodities, for example, one or two bags of grain, or for samples submitted to a laboratory.

The sample to be reduced should be poured onto a flat surface where it will naturally assume the shape of a cone. The top of the cone should then be levelled, and the bulk divided into quarters using a flat piece of wood or specially prepared quartering irons. The opposite quarters should be combined and mixed to give the reduced sample. If this is still too large, the reduced sample can be further subdivided in the same way (Figure 9.8).
Inspection and sampling

Figure 9.7 Minimum sampling positions for road and rail trucks and small bulks of grain: (a) up to 15 tonnes, (b) 15–30 tonnes, (c) 30–50 tonnes

(a) Trucks and bulks up to 15 tonnes

(b) Trucks and bulks up to 15–30 tonnes

(c) Trucks and bulks up to 30–50 tonnes

Figure 9.8 Coning and quartering

Grain mixed and coned

Cone flattened for quartering

First division

Second division

Opposite quarters taken for mixing and forming

The reduced sample

Figure 9.8 Coning and quartering
Riffle (multiple-slot or box) divider

The riffle divider (Figure 9.9) is the simplest of the sample dividers recommended by the ISO. It comprises a funnel arrangement and three sample boxes, each identical in size. The rectangular-mouthed funnels are arranged side-by-side so that alternate funnels lead to opposite sides. The funnel assembly is fitted inside a box which is open at the bottom. It is designed so that the funnel assembly box sits on any two sample boxes, while the third is used to pour a sample through the hopper.

Boerner divider

This is a gravity-fed divider, also recommended by the ISO (Figure 9.10). The sample is fed from a hopper down the outside of a smooth cone divided at its base into 36 streams which are recombined into two outlets, giving two equal samples. As with the riffle divider, samples can be divided sequentially to give subsamples of 1/2, 1/4, 1/8, etc.

Motorized divider

Various designs are available, but are more expensive than the riffle or Boerner dividers. The Gamet divider (Figure 9.11) is electrically operated; a sample fed from the hopper falls onto a revolving disc from which it is flung into a chamber dividing into two or more outlets.
Figure 9.10  Boerner divider

Figure 9.11  Motorized divider
SAMPLING PLANS FOR CANNED FOODS

There are basically two sampling plans.

Cooking oil and dried products

Select a few cartons (six from a very small lot; up to 25 for a very large lot). Examine one can from each carton. Check the contents for acceptability. Take action only if something is obviously wrong.

All other commodities

No sampling plan can be infallible. If there is only one bad can in a lot of 10 000, 49 out of 50 samples of 200 cans will fail to include it. Even if there are 115 bad cans among 10 000, there is still a 10% chance that a sample of 200 cans will all be good. Sampling schedules are designed to give a balance between the number of items to be inspected and the risk involved in accepting (or distributing) one defective item. Any schedule is therefore a compromise. A schedule that has a number of steps is usually better than one with only one step (Figure 9.12) although, on paper, it may seem more complicated. The following schedule is recommended for examination of shipments of cans of meat, fish and cheese products.

Step 1  Obtaining the sample

1(a)  Determine the number of cans for inspection (round up intermediate sizes to the next larger lot size)

<table>
<thead>
<tr>
<th>Cans in lot</th>
<th>Number for inspection</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 000</td>
<td>200</td>
</tr>
<tr>
<td>20 000</td>
<td>250</td>
</tr>
<tr>
<td>40 000</td>
<td>300</td>
</tr>
<tr>
<td>60 000</td>
<td>350</td>
</tr>
<tr>
<td>100 000 or more</td>
<td>400</td>
</tr>
</tbody>
</table>

1(b)  Ascertain the number of cans to be selected from each carton to be opened

<table>
<thead>
<tr>
<th>Cans in carton</th>
<th>Maximum number from each carton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 12</td>
<td>All</td>
</tr>
<tr>
<td>12–24</td>
<td>10</td>
</tr>
<tr>
<td>Over 24</td>
<td>16</td>
</tr>
</tbody>
</table>
1(c) By dividing (1a/1b), determine to the nearest whole number the number of cartons to be opened, selecting the cartons to be opened as randomly as possible.

*Example:* A shipment arrives of cartons each containing 24 cans. The bill of lading identifies two lots, one of 1476 cartons, the other of 524 cartons.

<table>
<thead>
<tr>
<th></th>
<th>Lot 1</th>
<th>Lot 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of cartons in lot</td>
<td>1476</td>
<td>524</td>
</tr>
<tr>
<td>Number of cans in each carton</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>Number of cans in lot</td>
<td>35 424</td>
<td>12 576</td>
</tr>
<tr>
<td>Next higher number (in 1a)</td>
<td>40 000</td>
<td>20 000</td>
</tr>
<tr>
<td>Sample size (cans)</td>
<td>300</td>
<td>250</td>
</tr>
<tr>
<td>Number of cans from each carton</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Number of cartons to be opened</td>
<td>30</td>
<td>25</td>
</tr>
</tbody>
</table>

**Step 2  Defects**

There are two levels of defect that should be recorded.

2(a) Very serious defects

- visible seam defects (the seam is where the ends of the tin-plate are overlapped and pressed together on the side and around the ends)
- perforations (tiny holes) apparently due to abrasions, or internal or external corrosion.

2(b) Serious defects

- swollen cans, other than apparently due to temperature, altitude, denting or overfilling
- can perforation, apparently due to non-abrasive external damage
- severe corrosion or abrasion, suggesting that perforation is a possibility in unsampled cans.

**Step 3  First inspection**

3(a) No defects

Open a few cans to look at and smell the contents. If apparently good, pass the lot for distribution or for storage. If the contents smell good but appear overcooked, distribute as quickly as possible.

3(b) One very serious defect, or one or two serious defects

Resample (see Step 4, below).
3(c) Two very serious defects or three serious defects
Securely impound the lot. Refer some suspect cans (and some apparently good cans) for expert opinion and disposal instructions.

In the case of swollen cans of cheese, keep the lot as cool as possible to minimize losses.

**Step 4 Second inspection (using double the number of cans in the original sample)**

Do not include the sample from the first inspection.

4(a) No very serious defect or up to 1% serious defects
Sort the remainder of the lot, discarding defective cans.

4(b) Over 1% serious defects or one other very serious defect
As in 3(c) above.

Figure 9.12 summarizes the instructions for inspection as described in Steps 3 and 4.

No sampling schedule can cover all eventualities. In the last resort, all the available relevant information must be used in deciding what to do with a shipment. Where a lot is impounded, precautions must be taken to guard against unauthorized removal of possibly dangerous cans prior to their destruction.

**PACKAGING, LABELLING AND TRANSPORTATION OF SAMPLES**

**Samples for quality determination**

Samples must be packed according to the required analysis. Cotton bags or heavy-gauge polythene bags are acceptable for samples for general quality assessment and for mycotoxin analysis.

**Samples for moisture content determination**

These should be packed in moisture-tight containers. Glass jars with screw caps and rubber seals may be used with adequate packing, but unbreakable containers are preferable, such as screw-cap polythene bottles, well sealed polythene bags or screw-cap metal containers. The container should, whenever possible, be filled completely to minimize the risk of interchange of moisture between the commodity and air in the free space, and to prevent damage to the sample caused by movement during transportation. A sample of around 250 g will suffice for the moisture determination, and this can be extracted from the main sample and packed and labelled separately.
These are often dispatched in polythene bags, but ideally should be packed in closely woven bags of unglazed, unbleached cotton or similar material. If there are several samples to be transported over some distance, some form of additional packaging will be needed to protect the sample and the primary packing material.

**Labelling and transportation**

All samples must be carefully labelled at the time of packaging so they can be readily identified whenever they are subsequently handled. The following information should always be recorded:

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**Figure 9.12  Flow diagram for action on can inspection**
Inspection and sampling

- commodity
- origin of the sample
- how, when and where it was collected
- the purpose for which it was collected.

If possible, the required information should be written indelibly on the outside of the sample container. Alternatively, adhesive or tie-on labels may be used, although such labels need to be strong and securely fixed. It is advisable to include a duplicate label, enclosed in a sealed polythene bag, inside the container with the sample itself. During transportation, individual samples should be separated from one another with suitable packing, insulating and shock-absorbing material. A strong, compartmented box would be ideal. Samples of different commodities should be packed in different containers to avoid cross-contamination or cross-infestation. All cartons containing samples should be well secured and protected from exposure to direct sunshine, sources of extreme heat, and any form of wetting.

Samples for mould, mycotoxins and other contaminant determination

The usefulness of analytical tests for moulds, mycotoxins and other contaminants depends primarily on the effectiveness of the sampling procedures used. If such tests are required, advice on sampling should be sought from the laboratory that is to undertake the analysis. However, the following guidelines can be given for sampling for mycological analyses.

It is important, for interpretation purposes, that samples submitted are accompanied by as much information as possible about the commodity from which they were drawn. For example, include information on details of the duration and conditions of storage, whether the commodity had been subjected to wetting, the moisture content and temperature measurements at the time of sample collection, and any similar records taken during storage.

A report of observations on the condition of the commodity should also be submitted. Areas of stacks showing signs of visible mould growth should be mapped and described, for example, mould growth at the surface or centre of the stack, whether mycelium or sporing heads are present, colour of the moulds, and the extent of discoloration of individual grains (see Chapter 10).

Problems in sampling for moulds and mycotoxins occur because of the uneven distribution of mould growth and hence mycotoxin production. Mycotoxin contamination may be concentrated in a relatively small percentage of grains, which may contain very high levels of toxins. The sampling scheme must, therefore, be more intensive than that used for detection of insects or general quality control.

The minimum numbers of samples required are given in Table 9.1.
Transportation of samples for mycological analysis

In transporting samples to the laboratory, care must be taken to prevent further mould growth and mycotoxin formation. Samples should be transferred to the laboratory as quickly as possible. If samples are wet, they should first be dried to a safe moisture content, for example 13–13.5% for maize (see Chapter 4). Samples should be kept cool, and if there is likely to be a delay in sending them to the laboratory they should be stored under refrigeration. The use of plastic bags for refrigerated storage should be avoided.

SUMMARY GUIDELINES FOR STORAGE INSPECTION

Warehouse site

- Site generally clean and tidy; suitable arrangements provided for disposal/destruction of rubbish.
- Roads and hardstandings in good repair.
- Vegetation under control.
- Areas adjacent to warehouse clear of vegetation, refuse, equipment and machinery.
- No evidence of rodent activity, e.g. burrows, droppings, tracks.
- Drainage and flood water disposal satisfactory.

Warehouse structure – external

- Walls structurally sound.
- Roof in good repair.
- Windows and ventilators in good repair and screened to prevent access by birds and rodents.
- Doors sound, well fitting and secure.
- Rodent barriers, if provided, in good condition.
- Rainwater guttering and drainpipes secure, functioning and screened against rodents.
- Eaves and guttering free of birds' nesting material.
- Service duct entries (water, electricity, telephone) screened against birds and rodents.

Warehouse structure – internal

- Walls structurally sound, clean and smooth as possible.
- Roof in good repair.
- Windows and ventilators in good repair and screened to prevent access by birds and rodents.
• Doors sound, well fitting and secure.
• Rodent barriers, if provided, in good condition.
• Internal drainage pipes functional and in good repair.
• Ledges on beams and walls clear of debris.
• Concrete floors smooth and crack-free; holes and gaps in wooded floors repaired or filled; earth floors well compacted to prevent rodents burrowing.
• Gaps at wall/floor angle filled to prevent rodent access.
• Lighting adequate and functioning.

**Standard of warehouse keeping and hygiene**

**Handling**

• Sack trolleys in use where provided; bags carried not dragged.
• Bags handled properly to avoid weakening or damage by tearing or splitting; excessive use of bag hooks avoided.

**Stacking**

• Gangways between stack and wall, and between stack and roof supports, at least 1 m wide.
• Gangways between stacks at least 2 m wide.
• Where vehicle entry is permitted, main gangways wide enough to allow loading and unloading.
• Stack boundary lines marked on floors and stacks built within them.
• Stacks built firmly and bonded to prevent collapse.
• Stacks built to reasonable heights to facilitate handling and prevent crushing of commodities in lower layers.
• Dunnage in good condition and disinfested before use.

**Commodities**

• Individual commodities stacked separately.
• Food stocks well separated from non-food stocks.
• Damaged stocks or stocks awaiting disposal segregated from main stocks.
• Packaging in good condition, showing no signs of damage by pests (insects, rodents, birds, fungi) or physical damage such as crushing, spillage, leakage, wetting or staining.
• Stack cards in prominent position and maintained.
Pest control

- Insect and rodent control equipment provided and fully functional.
- Pesticides and application equipment kept locked in separate store.
- Insect control regime maintained.

Safety and hygiene

- Fire extinguishers in position and maintained ready for use.
- Sanitary facilities provided for staff.
- Cleaning materials provided.

FURTHER READING


www.envirologix.com/artman/publish/article_60.shtml
Food aid is probably more prone to deterioration than food sold through mainstream, commercial channels. Movement, handling and storage under adverse conditions pose a threat. In addition, the quality of food offered as aid may not be ideal at the time of despatch, as stocks may have been stored for some time in the country of production.

Quality assurance assumes major significance where commodities have to be moved for great distances overland. If the consignment becomes unfit for consumption, it can take many months to replace. In emergencies, such a delay arising from the long lead time could have serious consequences for the beneficiaries. Furthermore, substantial costs may be incurred for the destruction or other disposal of condemned stock. If much-needed consignments become spoiled, a politically sensitive situation could arise which may detract from the effectiveness of the food aid operation.

For these reasons it is important that, if quality problems occur, action is taken quickly to correctly identify and redress the situation, and arrive at scientifically valid conclusions that justify release, disposal or alternative uses for the food. Before this can happen, store managers need to know what tests are appropriate for different commodities under different conditions, given the safety and quality considerations of aid supplied as food for human consumption.

STANDARDS, GUIDELINES AND SPECIFICATIONS

There are three recognized categories of microbiological criteria: standards, guidelines and specifications. Standards are legislative and mandatory, and are embodied in law. Failure to comply with standards may lead to prosecution. The International Organization for Standardization (ISO) in Geneva publishes a range of written standards for many types of food. Guidelines are not legal standards, although regulatory bodies may use them. In-house guidelines may vary from country to country, or even from company to company. Specifications are technical requirements that form the basis of a commercial transaction.

All foods are subject to quality judgement by consumers. These may be agreed nationally or internationally, and be developed in an objective manner, for example,
using laboratory tests for contaminants. Criteria may also be informal, subjective and *ad hoc*, and depend on consumer preference and need.

There are no globally accepted standards for testing foods. However, validated methods have been published, for example, by the Association of Official Analytical Chemists (AOAC) and ISO. The US Food and Drug Administration uses the AOAC methods. These methods are not mandatory, and may be modified or varied from country to country based on the local laboratories’ experience, standard operating procedures and local country guidelines. Notwithstanding which methods are used, it is important to be able to justify why a particular sampling plan or analytical method was employed, and this will vary depending on the commodity, amount, specification, etc.

The problem with standard or regulated analytical methods is that they can take years to be validated and accepted by the world community, by which time the science has moved on. Hence there is increasingly a move away from the search for a putative ‘standard method’ to a focus on the efficiency of whatever method is used.

**DATE STAMPS**

The most ubiquitous quality criterion is some form of date stamp, affixed directly to the packet of food. This is often the only evidence of quality on which a field worker can base a judgement, and so there may be concern about commodities that are close to or have exceeded the date on a date stamp.

The introduction of food date stamps was driven by consumer demand for assurances about quality. These dates are primarily intended for food retailers, and are applicable mainly to perishable foods kept under precise and controlled storage conditions. Date stamps offer a less precise guide to the keeping qualities of foods commonly shipped by aid agencies, as the date-stamping system was not designed to cope with food moved and stored across different climatic regions and maintained under less than ideal conditions. However, until devices are developed that enable remote electronic sensing of the environmental conditions to which commodities are subjected, date stamps may offer the only guidelines on the suitability of foods for consumers and beneficiaries. Nevertheless, date marking of commodities may not be appropriate in food aid systems and can lead to unnecessary rejection.

Date stamps use open dating, which is the use of a calendar date as opposed to a code on a food product. It is a date stamped on the package of a product to help the retailer determine how long to display the product for sale. It is a quality date, not a safety date. Open dating is found primarily on perishable foods such as meat, poultry, eggs and dairy products. If a calendar date is used, it must express both the month and day of the month (and the year, in the case of shelf-stable and frozen products).
If a calendar date is shown, immediately adjacent to the date should be a phrase explaining the meaning of that date such as sell by, use before, or best before. A sell by date tells the retailer how long to display the product for sale – the product should be bought before the date expires. A use by date is the last date recommended for the use of the product while at peak quality. In both cases, the date has been determined by the food processor, based on deterioration rates under known conditions for properly packaged and carefully handled goods. There is no uniform or universally accepted system used for open dating of food.

The term ‘shelf-life’ typically refers to the time period for which the quality of the food remains acceptable to consumers, not necessarily the time during which the food may be safely consumed. The length of the shelf-life of non-perishable foods is based on the loss of quality resulting from physical or chemical changes within the food, assuming it is free of insect, microbial or other extrinsic contamination. Certain temperatures and humidities during storage are assumed, so the date may be misleading if conditions are different.

Of more value in canned foods is the residual shelf-life (see Chapter 16). This is the difference between the original shelf-life (on completion of the canning process) and the dissipated shelf-life resulting from storage conditions to date. In practice, neither original shelf-life nor dissipated shelf-life can be determined accurately in the field.

WHY ARE TESTS NEEDED?

There are two main reasons why a food may be tested, both at manufacture and after arrival at the distribution point. Tests may be required for quality (is the food up to specification, and still nutritious?) or for safety (does consumption of the food pose a risk to health?). The two reasons may be linked. Food that is unsafe is, by definition, of poor quality, but poor quality food may still be safe to eat.

From the quality perspective, owners of the goods may wish to check if the food is fit-for-purpose from the manufacturer and if it complies with contractual specifications. This is particularly important for commodities that are nutritionally supplemented, such as dried weaning foods that contain vitamins. Because vitamins are expensive, unscrupulous manufacturers may be tempted to skimp on the vitamin content. The only way to be sure the product meets the specification is to have a sample assayed for every vitamin at the point of manufacture. This can be expensive (in the order of US$ 60–100 per vitamin per sample).

From the safety perspective: Is there a risk to health? How serious is the threat to health (how bad is the food)? How hungry are the beneficiaries? Can the unsafe parts of the consignment be separated out, and are replacement stocks available if all of the commodity has to be destroyed? These questions involve assessment of risk, which is a combination of the likelihood of an event occurring and the seriousness of the event. Risk assessment has to be done by staff on-site, guided by the results and interpretation of any analyses done externally.
WARNING SIGNS

Food may be held in store for long periods and could give cause for concern if the shelf-life limit is near or has been exceeded. Nonetheless, it should be recognized that physical or chemical changes may not of themselves render the food unfit for human or animal consumption, but may make it less palatable and hence unacceptable to beneficiaries. Other warning signs are containers with signs of damage, corrosion or leakage, and cans that are swollen because of the build-up of internal gases resulting from the growth of micro-organisms.

Evidence of insect, bird or rodent activity, caking or fungal growth are also signs for concern.

IS IT WORTH TAKING SAMPLES?

Samples should be taken any time there is a need to obtain scientifically valid conclusions concerning the fitness of a consignment, if justified by the circumstances and by its value and size. Such decisions imply a good understanding of risk assessment and damage mitigation as applied to food aid.

Some cases are difficult to assess. For example, grain infected with fungi may have produced mycotoxins, but testing for mycotoxins may not be needed if the presence of the fungi is itself sufficient to warrant disposal of the grain. However, it may be that a light fungal load can produce significant amounts of mycotoxins, so the opinion of a food microbiologist or mycologist should be obtained.

If a commodity has been embargoed by, for example, a government ministry, then taking samples and sending them for analysis by an independent third party may be the best option for resolving the impasse and allowing disposal or use of the food aid.

Random samples are preferable – the number of samples will depend on the nature and size of the commodity and the problem. As a rough guide, every unit should be sampled if there are fewer than 10 in the batch, and 10 units should be sampled if there are 11–100 in the batch. If there are more than 100 units in the batch, then the square root should be sampled (see Chapter 9). Samples should be divided and half retained by the in-country office so that cross-checks can be done at a later date, if the results of the analysis are contentious or disputed by, for example, a party against whom a claim is pursued.

WHAT TESTS COULD BE DONE, AND WHY?

Deterioration of food is largely dependent on three factors: moisture, relative humidity and temperature, with temperature having the most significant effect on shelf-life. Foods can be tested for many parameters. The key is deciding whether any test is required in the first place, and efforts put into sampling and testing must be commensurate with the health risk, extent of damage, cost benefit of analysis and
stakeholder input. Political considerations may also be important if, for example, a consignment has been ‘condemned’ by a government ministry on import and there is a need to have the decision verified.

If it is decided that tests are needed, then a decision has to be taken on the most appropriate tests to request. There is no straightforward answer, as commodities and circumstances differ widely. However, there is a range of tests that can be used (Table 10.1).

1. Test for decline in quality resulting from lengthy storage periods that change texture, colour, flavour or nutritive value, for example, protein content, vitamin and micronutrient content, palatability, organoleptic testing. Flour can lose its baking power after 6 months, although not its suitability for human consumption.

2. Test for physical changes such as melting of fats in canned meats at high temperatures; or crystallization of sugars at low temperatures; or water absorption by sugar, salt or milk powder leading to crystallization and caking.

3. Test for chemical changes such as oxidation of fats, vitamin loss, non-enzymic browning, production of off-flavours, flour gluten content and acidity and corrosion of containers.

4. Test for the presence of insects or micro-organisms; or the effects of poor processing that does not kill all contaminants when the food is cooked, for example, meat or fish in cans. Micro-organisms may cause discoloration, caking or physical deterioration, fermentation, putridity or rancidity, or may produce carcinogens such as mycotoxins and other toxic chemicals, or transmit diseases such as salmonellosis.

5. Test for poor quality packaging or damage accrued in transit, from internal or external corrosion, to claim against manufacturers, shippers, handlers or storage agencies.

6. Test for specific contaminants where there is evidence that a problem has arisen.

**WHICH TEST FOR WHICH COMMODITY?**

**Cereal grains and flours**

**Insect damage** – identify species and count numbers per kilogram. Compare against relevant standards, and the standard that was specified when the commodity was ordered, as described on tender, shipping or phytosanitary documents.

**Physical damage** – sieve and count damaged fractions. Compare against international standards, and the standard that was specified in the order.

**Moisture content** – measure using internationally agreed (ISO) oven methods, or calibrated electrical resistance and capacitance meters. Compare result with the specified standard for the commodity.
### Table 10.1 Food aid commodities, shelf-lives, spoilage agents and recommended tests

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Packaging</th>
<th>Typical shelf-life (years) in temperate zones</th>
<th>Typical shelf-life (years) in tropical zones</th>
<th>Physical or chemical spoilage</th>
<th>Biological spoilage</th>
<th>Action by delivery point on receipt</th>
<th>Possible tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>Polypropylene or jute sacks, or in bulk</td>
<td>2–3</td>
<td>&lt;3 if moisture content ≤14%</td>
<td>Breakage during handling, wetting</td>
<td>Storage fungi, e.g. Aspergillus, Penicillium, Mucor and Rhizopus; insects, e.g. Sitophilus, Rhizopus, Sitotroga; rodents; birds</td>
<td>Inspect for signs of insects, fungi, rodents or wetting</td>
<td>Identities and numbers of colony-forming units; moisture content; insect counts and identities; broken grains</td>
</tr>
<tr>
<td>Maize</td>
<td>Polypropylene or jute sacks, or in bulk</td>
<td>2–3</td>
<td>&lt;2 if moisture content ≤14%</td>
<td>Breakage during handling, wetting</td>
<td>Storage fungi, e.g. Aspergillus, Penicillium, Mucor, Fusarium and Rhizopus; insects, e.g. Sitophilus, Rhizopertha, Prostephanus, Sitotroga; rodents; birds</td>
<td>Inspect for signs of insects, fungi, rodents or wetting</td>
<td>Identities and numbers of colony-forming units; moisture content; insect counts and identities; broken grains</td>
</tr>
<tr>
<td>Rice (polished)</td>
<td>Polypropylene or jute sacks, or in bulk</td>
<td>2–3</td>
<td>&lt;1 unless very well polished and moisture content &lt;14%</td>
<td>Breakage during handling, wetting; oxidation of oils</td>
<td>Storage fungi, e.g. Aspergillus, Penicillium, Mucor and Rhizopus; insects, e.g. Sitophilus, Ephesia, Plodia, Tribolium, Corcyra and Cryptoles; rodents; birds</td>
<td>Inspect for signs of insects, fungi, rodents or wetting</td>
<td>Identities and numbers of colony-forming units; moisture content; insect counts and identities; broken grains; Totex value and free fatty acid content; possibly vitamin content</td>
</tr>
<tr>
<td>Sorghum</td>
<td>Polypropylene or jute sacks, or in bulk</td>
<td>10–12</td>
<td>Breakage during handling, wetting</td>
<td>Storage fungi, e.g. Aspergillus, Penicillium, Mucor and Rhizopus spp.; insects, e.g. Cryptoles, Sitotroga, Rhizopertha, Sitophilus; rodents; birds</td>
<td>Inspect for signs of insects, fungi, rodents or wetting</td>
<td>Identities and numbers of colony-forming units; moisture content; insect counts and identities; broken grains</td>
<td></td>
</tr>
<tr>
<td>Processed cereals (flours)</td>
<td>Lined sacks</td>
<td>1</td>
<td>0.5</td>
<td>Damage to sacks during handling, wetting</td>
<td>Insects, e.g. Tribolium, Cryptolestes, Ephestia, Plodia</td>
<td>Inspect for signs of insects, fungi, rodents or wetting</td>
<td>Identities and numbers of colony-forming units; moisture content; insect counts and identities; broken grains; package integrity</td>
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<tr>
<td>Pulses                    Polypropylene or jute sacks</td>
<td>2</td>
<td>1</td>
<td>Breakage during handling, wetting</td>
<td>Storage fungi, e.g. Aspergillus, Penicillium, Mucor and Rhizopus spp.; insects, e.g. bruchid beetles, Plodia, Ephestia, Tribolium; rodents; birds</td>
<td>Inspect for signs of insects, fungi, rodents or wetting</td>
<td>Identities and numbers of colony-forming units; moisture content; insect counts and identities; broken grains; cooking time</td>
<td></td>
</tr>
<tr>
<td>Blended foods, e.g. corn soya blend</td>
<td>Lined sacks</td>
<td>1</td>
<td>&lt;1</td>
<td>Damage to sacks during handling, wetting; non-enzymic browning; oxidation of oils</td>
<td>Insects, e.g. Tribolium, Cryptolestes, Ephestia, Plodia; rodents</td>
<td>Inspect for signs of insects, fungi, rodents or wetting</td>
<td>Identities and numbers of colony-forming units; moisture content; insect counts and identities; Tox value and free fatty acid content; possibly vitamin content; package integrity</td>
</tr>
<tr>
<td>Biscuits                  Cartons</td>
<td>0.5–0.75</td>
<td>0.5</td>
<td>Damage to containers during handling, wetting</td>
<td>Insects, e.g. Tribolium, Cryptolestes and Stegobium</td>
<td>Inspect for signs of insects, fungi, rodents or wetting</td>
<td>Identities and numbers of colony-forming units; moisture content; insect counts and identities; package integrity</td>
<td></td>
</tr>
<tr>
<td>Sealed tins</td>
<td>5</td>
<td>3</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Dried milk powder         Lined sacks</td>
<td>Instant, 1</td>
<td>1</td>
<td>Crystallization from water uptake in high humidity atmospheres, leading to caking</td>
<td>Toxins from Staphylococcus spp. (rare), fungi</td>
<td>Inspect for signs of insects, fungi, rodents or wetting</td>
<td>Identities and numbers of colony-forming units; moisture content; insect counts and identities; package integrity</td>
<td></td>
</tr>
<tr>
<td>Non-instant, 2–4</td>
<td>2</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Commodity</td>
<td>Packaging</td>
<td>Typical shelf-life (years) in temperate zones</td>
<td>Typical shelf-life (years) in tropical zones</td>
<td>Physical or chemical spoilage</td>
<td>Biological spoilage</td>
<td>Action by delivery point on receipt</td>
<td>Possible tests</td>
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<tr>
<td>Salt</td>
<td>Lined sacks</td>
<td>Indefinite</td>
<td>Indefinite</td>
<td>Crystallization from water uptake in high humidity atmospheres, leading to caking</td>
<td></td>
<td>Inspect for leakage and wetting</td>
<td>Iodine content</td>
</tr>
<tr>
<td>Sugar</td>
<td>Lined sacks</td>
<td>Indefinite</td>
<td>Indefinite</td>
<td>Crystallization from water uptake in high humidity atmospheres, leading to caking</td>
<td></td>
<td>Inspect for leakage and wetting</td>
<td></td>
</tr>
<tr>
<td>Vegetable oils</td>
<td>Plastic bottles, cans, steel drums</td>
<td>&gt;1</td>
<td>1</td>
<td>Poor lid seals or seams, leaks from split bottles; oxidation of oils</td>
<td></td>
<td>Inspect for blown, damaged or leaking containers</td>
<td>Totox value and free fatty acid content; possibly vitamin content; package integrity</td>
</tr>
<tr>
<td>Dried salt fish (local)</td>
<td>Cloth bales</td>
<td>0.2</td>
<td>0.2</td>
<td>Wetting</td>
<td>Bacteria, fungi, insects such as <em>Dermestes</em>; rodents</td>
<td>Inspect for signs of insects, bacteria, fungi, rodents or wetting</td>
<td>Identities and numbers of colony-forming units; moisture content; insect counts and identities</td>
</tr>
<tr>
<td>Stockfish (tins)</td>
<td>Cloth bales</td>
<td>0.75</td>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dried fruit</td>
<td>Plastic bags</td>
<td>0.75–5 (if hermetically sealed)</td>
<td>0.25</td>
<td>Crystallization from water uptake in high humidity atmospheres, but no caking</td>
<td>Yeasts, fungi, e.g. <em>Aspergillus</em>, <em>Penicillium</em>, <em>Mucor</em>, <em>Rhizopus</em>; mites; rodents; birds</td>
<td>Inspect for signs of insects, fungi, yeasts, rodents or wetting</td>
<td>Identities and numbers of colony-forming units; moisture content; insect counts and identities</td>
</tr>
<tr>
<td>Product</td>
<td>Package</td>
<td>Residual or guaranteed shelf-lives</td>
<td>Identities and numbers of colony-forming units</td>
<td>Package integrity</td>
<td></td>
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</tr>
<tr>
<td>Meat</td>
<td>Cans</td>
<td>3*</td>
<td>Poor lid seals or seams</td>
<td>Examine contents; if over-cooked distribute quickly</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corned beef and mutton</td>
<td>Cans</td>
<td>4*</td>
<td>Poor lid seals or seams</td>
<td>Examine contents; if over-cooked distribute quickly</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fish in tomato sauce</td>
<td>Cans</td>
<td>2*</td>
<td>Poor lid seals or seams</td>
<td>Examine contents; if over-cooked distribute quickly</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fish in oil</td>
<td>Cans</td>
<td>3*</td>
<td>Poor lid seals or seams</td>
<td>Examine contents; if over-cooked distribute quickly</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cheese</td>
<td>Cans</td>
<td>2.5**</td>
<td>Poor lid seals or seams</td>
<td>Examine contents; distribute before other canned goods</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Residual or guaranteed shelf-lives; effective shelf-lives could be two to four times longer.
**Chemical changes** – fats in cereals stored for long periods are subject to oxidation which may lead to rancidity and off-odours, so tests for free fatty acid (FFA) content may be appropriate. The sample would be compared against a control sample. In rice, the FFA content declines at a known rate, so this test can be useful in providing a rough guide to the age of a consignment.

**Wetting of dried products (cereals or dried powders)** – leads to microbiological contamination, which may also follow in the wake of insect infestation as the metabolism of insects raises the moisture content of the commodity. Laboratory analysis would involve plating grains on microbiological growth media to identify contaminant species and assessing the numbers per gram of sample.

Flour may lose its baking qualities over time. Simple baking and organoleptic tests will usually suffice.

**Canned goods**

Damaged cans should be destroyed because of the risk of contamination with *Clostridium botulinum*, which produces a heat-stable botulinum toxin that is potentially fatal. Testing the contents is probably not worthwhile. However, samples should be sent for examination in all instances where claims or retort actions are contemplated against the donor, shipper or manufacturer as a result of poor or defective quality of cans.

**Oils and fats**

Changes in oil structure over time lead to rancidity and off-odours, which may lead to rejection by beneficiaries. Chemical analysis of FFA, peroxide value and *p*-anisidine value are usual. At production, vegetable oil is likely to have an FFA content of less than 0.05%; FFA levels higher than this indicate that the oil has deteriorated. The peroxide value (PV) indicates the level of primary oxidation through measurement of the primary oxidation products. As the oil deteriorates further, these primary products (hydroperoxides) break down to give off-flavour and odour-producing compounds which are detected by the *p*-anisidine (AV) test. Effectively, the PV indicates the current oxidation state of the oil and the AV indicates its oxidation history. Neither figure should be relied on alone. Rather, they should be combined (AV + 2PV) to give the Totox value, which is an overall indicator of rancidity. A Totox value of about 10 is generally accepted as the upper limit for oil considered fit for human consumption.

Oils are sometimes supplemented with vitamin A, which can also be measured. However, if the Totox value is high there is little point, as the oil can be condemned on the Totox value alone.

**Pulses**

Changes in protein structure over time lead to the hard-to-cook phenomenon, which means that long cooking times may be needed, leading to high demands for fuel.
Even when these beans are well cooked they may be unpalatable or lead to stomach upsets when eaten. The hard-to-cook phenomenon can be assessed using organoleptic methods or by measuring hardness with a penetrometer.

Insect and microbiological examination can also be done, as mentioned above.

**WHO SHOULD DO THE TESTING?**

Examination of commodities when they first arrive should be done by staff on-site.

Physical tests of dried cereals and cereal products, such as insect counts, moisture contents and assessments of broken grains, etc., can often be done in-country using an accredited laboratory, or by local staff trained and equipped in the methods. Donors should ascertain whether such laboratories exist in the relevant country before any problems arise.

Samples for chemical tests that require more stringent quality control, pure reagents, or expensive or delicate equipment may need to be sent to European, American, South African, Australian or Far East laboratories. Those accredited by the Grain and Feed Trades Association (GAFTA), the United Kingdom Accreditation Service (UKAS) or ISO should be used. (UKAS is the sole national accreditation body recognized by the British government to assess, against internationally agreed standards, organizations that provide certification, testing, inspection and calibration services.)

**INTERPRETING THE RESULTS**

Analytical laboratories tend to confine their findings to a statement of results which will reveal, for example, concentrations of contaminants or identities of insects. This information is of limited use unless it is accompanied by some interpretation – what do the results mean; is the produce safe; and what can the manager do about the problem, either to deal with the contaminated produce or prevent the problem recurring?

Interpretation is particularly important given the complexity of international safety recommendations and limits, and the varied nature of the commodities and situations in which food aid is deployed. For example, 10 insects per kilogram of grain will be noticed by storekeepers and consumers, and may lead to rejection by beneficiaries. Insects present in these numbers may taint the food, depending on the species, but may not necessarily render it unfit for human consumption, particularly if the insects can be removed during processing. However, if the grain is to be kept for long periods under tropical conditions, then the occurrence of half an insect per kilogram may be sufficient, as an action threshold, to institute a fumigation programme. International standards for mycotoxins range from 0–20 parts per billion (ppb) for aflatoxin, but up to several thousand ppb for fumonisins. The recommended ‘safe’ limit for fungi in processed food is 103–104 colony-forming units (cfu) per gram, but is much higher in fermented foods such as yoghurt and cheese. Similarly, bacterial limits range from 102–104 cfu/g for processed meat, but up to 107 cfu/g for raw meat.
Occasionally, no safety testing of commodities is required. Interpretation can be done by staff on-site and prompt action taken without further delay. For example, blown cans should be destroyed and never released into the human or animal food chain. Analysis of the reasons for blown cans may be sought at a later date if the donor wants to investigate taking action against the manufacturers or fillers of the cans.

In most cases, however, safety testing and interpretation would have to be done off-site.

WHAT TO DO WITH DOWNGRADED FOOD?

This depends on the commodity and needs to be determined on a case-by-case basis. Options include export to another country; destruction; blending at 5–10% with good quality food; or diversion, neat or blended, for animal feed. Every case is different, and local circumstances and priorities will strongly influence the end use of the foodstuff.

FURTHER READING


Chapter 11

Food safety and microbiology

Contamination of food before consumption is a particular problem where the need to eat may override concerns about the safety of the food, and the anxieties of consumers regarding food safety vary widely from person to person and from country to country. Thus food safety is a relative concept. It may be defined as ‘the practical certainty that injury or damage will not result from consuming a food or ingredient used in a reasonable and customary manner and quantity’.

Food poisoning describes the food-borne illnesses that upset the gastrointestinal tract, with symptoms of abdominal pain and diarrhoea, sometimes accompanied by vomiting. There are many causes of food poisoning, including overeating, allergic reactions, nutritional deficiency, poisoning by chemicals or naturally occurring compounds, infestation by parasites, and contamination by micro-organisms and their toxins. It is the latter which are the subject of this chapter, because safety concerns in food aid are mainly related to the risks posed to human health by the presence of micro-organisms and/or the toxins they may produce.

Micro-organisms include moulds, yeasts, bacteria and actinomycetes. Individually they are microscopic in size. However, they may be visible to the naked eye when large numbers form colonies or surface films. Micro-organisms in their various forms are ubiquitous.

Micro-organisms in foods can be either beneficial, as in fermented foods such as yoghurt, or harmful, causing spoilage and disease. Deterioration of packaging and sealing materials due to mould growth often results in spillage; damp and mouldy cereal grains can become caked and difficult to handle; even the structure of stores can be weakened by certain micro-organisms.

The significance of micro-organisms in stored food commodities depends on a number of conditions, including:

- type of micro-organism
- number present
- type of food commodity and the treatments to which it has been exposed
- the processing or storage treatment the foodstuffs will receive
- whether the foodstuff will be cooked
- who or what will consume the food.
**BIOLOGY OF MICRO-ORGANISMS**

Recognition of all the microbial species that cause spoilage is not possible without a considerable amount of experience and laboratory equipment. However, an adequate field recognition of the likely causes of spoilage can often be achieved by simple observation.

Bacteria are the smallest of the micro-organisms normally associated with food spoilage. They may be seen as slimy colonies on some spoiled commodities.

Actinomycetes are similar to bacteria. Actinomycetes will often impart a white, speckled appearance to grain. *Thermoactinomyces* spp. grow on grain which heats in store. Some species have been associated with the production of carcinogenic compounds in dried fish products.

Moulds and yeasts are part of a larger group of micro-organisms called fungi. Moulds frequently produce a cottony or velvety appearance on spoilt commodities, and are also often associated with discoloration of cereal products.

**FOOD SPOILAGE CAUSED BY MICRO-ORGANISMS**

Microbial deterioration of a foodstuff is usually apparent from alterations in the appearance, texture, odour or flavour, or by slime formation. Most of the foods used in aid programmes are susceptible to spoilage by micro-organisms; the types of spoilage that may be encountered are illustrated in Table 11.1. Many food

<table>
<thead>
<tr>
<th>Table 11.1</th>
<th>Types of food spoilage caused by micro-organisms</th>
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</thead>
<tbody>
<tr>
<td><strong>Alteration of colour or texture</strong></td>
<td></td>
</tr>
<tr>
<td>Discoloration</td>
<td>Fungal/bacterial pigments, chemical changes, browning reactions due to microbial heating</td>
</tr>
<tr>
<td>Caking</td>
<td>Fungal growth</td>
</tr>
<tr>
<td>Physical deterioration</td>
<td>Growth of fungi, bacteria and actinomycetes</td>
</tr>
<tr>
<td><strong>Unpalatability</strong></td>
<td></td>
</tr>
<tr>
<td>Fermentation</td>
<td>Acid and gas produced from carbohydrates</td>
</tr>
<tr>
<td>Putridity from protein breakdown</td>
<td>Objectionable flavours and odours produced</td>
</tr>
<tr>
<td>Rancidity</td>
<td>Objectionable odours and flavours produced by fat hydrolysis and oxidation</td>
</tr>
<tr>
<td><strong>Production of toxic chemicals</strong></td>
<td></td>
</tr>
<tr>
<td>Carcinogens</td>
<td>e.g. Aflatoxins, formed by fungi in the food</td>
</tr>
<tr>
<td>Toxic chemicals</td>
<td>Produced by micro-organisms that may cause chronic or acute toxicity if eaten</td>
</tr>
<tr>
<td><strong>Transmission of disease</strong></td>
<td></td>
</tr>
<tr>
<td>Salmonellosis</td>
<td>Due to the presence of pathogenic bacteria</td>
</tr>
</tbody>
</table>
commodities have to be reconstituted with water before use, so the bacteriological quality of the water used must also be taken into consideration, especially for foods that are not cooked prior to consumption.

Food which is clearly unpalatable is unlikely to be eaten. However, food spoilage can occur under conditions in which the food appears and smells normal, and yet food poisoning still results.

**EXAMPLES OF FOOD SPOILAGE**

**Canned meat and cheese**

Application of heat, after the filling and sealing of the can, is relied on for complete destruction of all micro-organisms. Occasionally, organisms enter the can after heat processing, or bacteria spores survive the heating process, and spoilage may occur. Where organisms gain entrance after processing, gas production will normally cause swelling or doming of a can. Almost any bacterium or fungus may be the cause. Doming of cans due to microbial growth should not be confused with physical distortion of the can due to mechanical damage.

If, due to a manufacturing defect, spore-forming bacteria such as *Clostridium* spp. and *Bacillus* spp. survive the heating process, they may grow and cause putrefaction, fermentation or rancidity. Many of these bacteria are adapted to high temperatures and develop only where the storage temperature is high. Some do not produce gas; accordingly the can does not become swollen.

In processed cheese, in particular, nisin is sometimes added to inhibit the germination of bacterial spores. Sorbic acid may also be added to processed cheese as an antifungal preservative.

**Dried salt fish and stockfish**

The presence of salt, together with low moisture content, is relied on to prevent spoilage by micro-organisms. If dried salt fish is allowed to absorb moisture to give a water activity of 0.75 or higher during storage, bacteria and moulds are likely to cause spoilage. In stockfish, which is not salted, microbial growth is prevented by maintaining a moisture content such that the water activity is less than 0.7.

Some bacteria are adapted for growth at high concentrations of salt. The putrefied fish turns pink and eventually begins to disintegrate. The source of such bacteria is commonly the salt used to cure the fish.

*Polypaecilum pisce* is a fungus able to grow in foods that have very low moisture contents. It causes a white discoloration of salted dried fish. *Wallemia sebi*, another such fungus, causes a brown discoloration known as ‘dun’. Other fungi on stockfish with high moisture content cause various types of discoloration.
Dried milk

Under normal circumstances, dried milk products have a water activity too low to permit the growth of micro-organisms.

The production of toxins by the bacterium *Staphylococcus* in raw milk and the survival of these toxins in the dried product has been known to occur in rare instances. Food poisoning results from ingestion of the reconstituted product. Fungal spoilage may occur if dried milk is allowed to become damp or wet at any time, or if it is stored in conditions of high humidity. In such circumstances fungal growth may be seen on the surface of the product; a musty odour and discoloration may also be evident. Such milk powder should not be used for human consumption.

Dried fruit

Spoilage is controlled by limiting the moisture content of the fruit to give a water activity of less than 0.7. Treatment of dried fruit with sulphur dioxide may restrain the growth of some fungal species.

Yeasts may sometimes cause spoilage. Dried fruit in which yeasts are growing has been found to be very susceptible to infestation by mites. Moulds such as *Aspergillus* spp. and *Penicillium* spp. may occur on dried fruit that has been damp. The grey moulds *Mucor* spp. and *Rhizopus* spp. are associated with fruit that has become very moist. Extensive mould growth on dried fruit may lead to caking.

Cereals and pulses

Rice, wheat and beans

Spoilage is prevented by maintaining a water activity of less than 0.7. In the humid tropics, mould growth can be a serious problem resulting in major post-harvest losses.

Storage fungi (most commonly *Aspergillus* spp., *Penicillium* spp., *Rhizopus* spp. and *Mucor* spp.) infect cereal grains after harvest. They can grow in grain stored at water activity levels greater than 0.7, causing considerable damage. Fungal growth can cause heating and caking of the grain, and subsequent discoloration due to either production of fungal pigments or browning reactions occurring at the elevated temperatures. Caking and heat damage of grain are typical signs of fungal growth having already occurred.

Fungal growth usually starts at the embryo, and growth on the outer surface of the grain can be seen only at an advanced stage of fungal attack. Discoloration of the grain may be visible either as a band near the embryo, or covering the entire surface of the grain (Figure 11.1).

Mycotoxins may be produced in cereals or pulses as a result of fungal growth. For example, aflatoxin, islanditoxin and citrinin have been detected in rice following fungal growth by some species of *Aspergillus* and *Penicillium*. 

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Maize

The most common storage fungi associated with maize are *Aspergillus* spp., *Penicillium* spp., *Rhizopus* spp., and *Mucor* spp. Storage fungi do not invade maize kernels to any great extent before harvest, although spores may be present on the grain. One exception is *Aspergillus flavus* infection of maize cobs in the field. This is of particular importance, as this mould is capable of producing aflatoxin prior to harvest.

Development of spore masses in the embryo region, usually termed ‘blue eye’, is often attributable to members of the *Aspergillus glaucus* group and *Penicillium* spp. Heat-damaged, caked and discoloured kernels are usually the result of mould damage.

*Aspergillus flavus* and *Fusarium* spp. are particularly important with respect to mycotoxin formation in maize. While post-harvest growth of the latter may occur in maize with high moisture content, a low storage temperature is generally required for toxin production. Maize heavily infected with *Fusarium* spp. can generally be detected by the characteristic streaking that occurs on the maize kernels; however, this does not indicate whether the toxins are present.

**TOXICITY AND INFECTIONS CAUSED BY BACTERIA**

Two different types of bacterial poisoning can result from contaminated food. Symptoms may be caused by toxins formed in the food by bacterial growth, for example, *Staphylococcus* and *Clostridium* spp., or by multiplication within the body of ingested pathogenic micro-organisms, for example, *Salmonella* spp.

Staphylococcal food poisoning usually appears 1–6 hours after the food is eaten, and includes headache, abdominal pain, violent vomiting, some diarrhoea and prostration. There is little or no fever, and recovery occurs within 24–48 hours. Fatalities are uncommon in healthy adults.

The causative organism is commonly found on the skin, nose and boils of people, and on domestic animals. The organism is readily destroyed during cooking; however, the toxins responsible for the food poisoning symptoms produced by the organism are not rendered harmless by cooking.

Milk products that are allowed to stand for some time at temperatures suitable for bacterial multiplication are commonly affected. Pre-cooked meat products and even canned meat can be affected.

*Clostridium* food poisoning has many forms, but botulism is a serious disease caused by toxins of the bacterium *Clostridium botulinum*. The disease is relatively rare, but when it occurs it is often fatal. Symptoms usually occur within 24–72 hours of eating infected food, and include vomiting, constipation, thirst and, most characteristically, double vision, paralysis of the throat muscles and profuse salivation. Body temperature is often subnormal, and the patient relapses into a
coma and dies within a week. The organism occurs commonly in the soil and occasionally in the faeces of farm animals, but not human faeces.

Canned meat is the food aid commodity most likely to be associated with botulism. Cans are often swollen, the contents being pulpy in texture and smelling like rancid butter or cheese. With pre-cooked meat products such as ham, the meat is often pale in colour and has a slightly rancid odour. It must be remembered that these defects may not always be present, and it is possible to contract the poisoning from food that is normal in taste and appearance.

Salmonella poisoning usually occurs within 8–24 hours of eating contaminated food. Symptoms include high fever and severe headache followed by nausea, vomiting, diarrhoea and abdominal pain. The symptoms may gradually abate, the patient recovering within a week, but in severe cases the initial symptoms are followed by marked restlessness, extreme thirst, cramp, coma and death. Most outbreaks of food poisoning due to salmonella follow the consumption of food directly or indirectly contaminated by man or animals. Ducks, fowls, pigs, cattle, horses, sheep, cats and dogs are all susceptible to salmonella, which is commonly spread to human foodstuffs by flies, cockroaches, rats and mice.

Food poisoning by salmonella frequently occurs in meat products prepared with insufficient cooking. Milk powder has also been implicated in salmonella outbreaks.

**TOXICITY DUE TO MYCOTOXINS**

The growth of certain strains of some moulds on foodstuffs can lead to the formation of toxic metabolites known as mycotoxins. Mycotoxins occur in all climates around the world and are defined as fungal metabolites which, when ingested, inhaled or absorbed through the skin, cause lowered performance, sickness or death in man or animals, including birds. The amount formed depends on several factors, including temperature, moisture content, and type of foodstuff. Food commodities that have been found to be affected include various cereal grains and pulses (Figure 11.2).

The resultant diseases in man and other animals are not contagious or infectious, and cannot be treated with drugs and antibiotics. Their effects depend on the animal species and the toxin concerned. Some animals appear to be more susceptible than others, and different mycotoxins affect different organs of the body, including liver, kidneys, skin and the nervous system. The possible concentration of mycotoxins or their metabolites in animal products, especially milk, could be a further source of danger to consumers.

**Aflatoxin**

This is produced by some strains of the mould *Aspergillus flavus* and is regarded as the most important mycotoxin in developing countries. It is a liver toxin which can induce cancer in susceptible animals, and is the most potent liver carcinogen known.
The growth of the mould can be very rapid under tropical or subtropical conditions, and aflatoxin has been found in a wide variety of foodstuffs from such areas, including cereals and cereal products, groundnuts and other pulses, dried fruit and dried fish.

Studies with animals have shown that the toxicity of aflatoxins varies greatly between species, and also depends on age, sex, nutritional status and duration of exposure. Younger animals are generally more susceptible than older ones of the same species. Possible causes of acute aflatoxin poisoning in people have been reported from several countries, and much circumstantial evidence suggests that it may be a factor in the high incidence of human liver cancer in some parts of the tropics and subtropics.

**Trichothecenes**

These mycotoxins are produced by the *Fusarium* fungi and contaminate a variety of cereals, including maize and wheat.

**Zearalenone**

Produced by the *Fusarium* fungi, this oestrogenic mycotoxin is widely distributed mainly in maize, in low concentrations, in Europe, Japan and North America. However, higher concentrations can occur in developing countries, especially where maize is grown in highland or more temperate regions.

**Fumonisins**

The fumonisins are a group of mycotoxins produced by *Fusarium moniliforme*, a fungus that occurs worldwide and is frequently found in maize grown under warm, dry conditions.

**Ochratoxin A**

This mycotoxin, associated with *Aspergillus ochraceus* and *Penicillium verrucosum*, occurs mainly in wheat and barley grown in temperate areas of the northern hemisphere, and in beans, cowpeas, maize, peas and rice in developing countries.

**PREVENTING DAMAGE BY MICRO-ORGANISMS**

Inhibition of microbial growth can be achieved by various means. Maintaining a low moisture content is the most common and successful strategy for preventing the growth of fungi and other micro-organisms on stored foodstuffs. If properly packaged, most dried foods can be stored at ambient conditions with no special freezing or refrigeration requirements. Suitable precautions should be taken to prevent the entry of moisture and moisture migration during processing or while in transit. The lower the temperature, the slower the rate of microbial growth.
Salting of foodstuffs limits the types and numbers of micro-organisms present. This is partly due to the reduction in the water activity of the food, brought about by adding salt, and partly due to the inhibitory nature of salt itself. As the salt content is raised, all but a few salt-tolerant bacteria and fungi are inhibited; however, some bacteria tolerate very high levels of salt and are unable to develop without 10% or more salt in the food.

Sulphur dioxide and sulphites are preservatives added to acidic foods to prevent microbial growth of all kinds. They are effective against bacteria and fungi at concentrations varying from 0.025 to 0.25% depending on the food commodity. In addition, sulphites are added to control enzymatic and non-enzymatic browning, and as anti-oxidants and bleaching agents.

Sorbic acid is very effective against fungi in acidic foods, but has little effect on yeasts and lactic acid-producing bacteria. It has been used in processed cheese at concentrations varying from 0.05–0.1%.

Sodium nitrate and sodium nitrite are used in the preservation of meat products. They also stabilize red meat colour and contribute to flavour development. Nitrite is particularly effective in controlling Clostridium botulinum. However, it has also been used in cheese to control gas caused by C. butyricum and C. tyrobutyricum.

Nisin is an antibiotic produced by Streptococcus lactis. At concentrations around 0.00025% it prevents the germination of most bacterial spores that survive the canning process. Nisin is frequently added to processed cheese and canned goods to prevent post-processing spoilage.

**FURTHER READING**


Chapter 12

Insect pests of food aid

About 30 species of insect (Figure 12.1) commonly infest food aid grain and grain products, although there are 200–300 species that may occur from time to time. Most insect pests are either beetles or moths (Figure 12.1), although there are some other types that are mentioned below. In addition to insects, the only other invertebrates that are commonly found in stored food are mites. These are difficult to see as they are often less than 0.5 mm long; unlike insects they have eight legs and lack both wings and antennae.

When these pests feed on grain, they produce heat and moisture and contaminate the food with their waste products and secretions. The various types of damage caused by insects and mites can lead to a weight loss of food, downgrading due to loss of quality, or even rejection of the commodity by the customer, all of which result in financial losses (Figure 12.2). The increase in moisture associated with pest infestation encourages the growth of moulds. Most moulds give the commodity an off-taste and colour, but some, such as Aspergillus flavus, may produce mycotoxins that can cause cancer in people and animals. Waste products from the pests, such

Figure 12.1  Stored grain and grain products are commonly infested by beetles (left) and moths (middle). Mites (right) may sometimes be encountered, they are much smaller than insects and differ from them in having eight legs and lacking both wings and antennae.
as faeces, cast skins and chemical secretions, are sometimes harmful and often give the food an unacceptable flavour and colour. An allergic reaction can occur in some people when eating or handling such contaminated commodities.

As well as attacking the commodity, several insect pests create other types of damage. Some species that bore into grain may also burrow into wooden or plastic structures, weakening them. The larvae of many moths produce large quantities of silken threads when moving over surfaces. This builds up into webbing that can bind flour and grain together into a solid mass, blocking machinery or causing additional machine wear and breakdowns.

**LIFE STAGES OF INSECTS IN STORED FOOD**

During the course of their lives, insects pass through a number of stages. The adult stage is responsible for reproduction. After mating, females lay eggs in selected places. Immature insects hatch from the eggs and then feed and grow to become adults. For many insects, the immature stage differs in form greatly from the adult, and is called a larva (Figure 12.3). When the larva hatches from an egg it is very small, typically 1–2 mm long. It begins to feed and grow immediately, but the larval skin is unable to stretch so the larva must shed its outer skin, a process called moulting, to allow growth. Moulting occurs several times, and when a larva is fully grown the final moult produces an immobile stage known as a pupa (Figure 12.3). Although the pupa is unable to move about, it is physiologically very active with the tissues becoming reorganized in such a manner that the larva changes (or metamorphoses) into the adult. At the end of the pupation period (typically 5–6 days), the fully formed adult emerges from the pupal skin (Figure 12.3).
Another mode of development, ‘incomplete metamorphosis’, is shown by certain other insects and mites. In this case the immature stages resemble the adult (Figure 12.4) and are known as nymphs. Although they are similar to the adults, nymphs lack certain adult features such as sexual organs and wings. Nymphs grow through a series of moults, and gradually adult features begin to develop. The most obvious of these features is the development of wing ‘buds’ that eventually develop into complete wings. The adult features become mature and functioning only after the final moult.

**TYPES OF INSECTS FOUND ON STORED COMMODITIES**

The insects of most concern are those that attack and feed on stored food aid commodities. Other groups of insects that do not feed directly on the stored food, such as mould-feeders, scavengers, parasites and predators, may also be present. The identification of insects in a commodity is often important when planning control measures. Detailed identification keys and information on the biology of storage insects are available.

**Pest species**

Insects that attack cereals and grain pulses are usually divided into two groups: primary pests and secondary pests. It is useful to distinguish between these, as
primary pests are usually more destructive than secondary pests, especially in short-term storage.

Primary pests attack and breed in previously undamaged cereal grains and pulses. Such pests also feed on other solid but non-granular commodities, but they are rarely successful on milled or ground foodstuffs. Examples of primary pests include the beetles *Sitophilus* spp. and *Rhizopertha dominica*, and the moth *Sitotroga cerealella*. Many primary pests attack the commodity in the field prior to harvest. Some species spend their pre-adult life concealed within a grain, making them difficult to detect by visual inspection.

Secondary pests are not capable of successfully attacking undamaged grains. They are, however, able to attack materials that have been previously damaged either by other pests (especially primary pests) or by poor threshing, drying and handling. They are also able to attack processed commodities such as flour and milled rice, where they may form the majority of insects present. Secondary pest species appear to attack a much wider range of commodities than primary pests. Feeding stages of these pests usually live freely – they are not concealed within individual grains. Examples of widespread secondary pests are beetles such as *Tribolium castaneum*, and moths such as *Ephestia cautella*.

Some pests do not fall easily into either category. For example, the beetle *Trogoderma granarium* is just capable of attacking undamaged commodities, but develops much more rapidly if some previous damage is present. In such cases, it is
best to classify these species as secondary pests, partly because they do not
develop successfully on undamaged grains, but also because they usually exhibit
other secondary pest characteristics, e.g. a wide range of food preference.

**PRIMARY PESTS OF CEREALS**

*Sitophilus* spp.

Beetles of the genus *Sitophilus* are important primary pests of whole cereal grains
and are called weevils. Three species are pests of stored grain: *Sitophilus zeamais*
(maize weevil), *Sitophilus oryzae* (rice weevil) and *Sitophilus granarius* (granary
weevil). The common names are misleading because they suggest the pest is
restricted to particular grains, which is not the case. The adults of all three species
are small, active insects with a narrow snout that carries the mouthparts. The body
colour ranges from light to dark brown, and both *S. zeamais* and *S. oryzae* often have
four large, reddish-orange spots on their wing cases (Figure 12.5).

*Sitophilus* larvae are whitish, legless grubs that spend all their pre-adult life tunnelling
in a cereal grain. Eventually the fully grown larva pupates within the grain, and the
adult that emerges bites its way out of the grain leaving a characteristic large,
somewhat irregular emergence hole.

*Sitophilus granarius* is essentially a temperate pest and is not found in tropical
countries, except occasionally in cooler, upland areas. *Sitophilus zeamais* and *S.
oryzae* are commonly found throughout the world in tropical and subtropical regions,
especially where ambient humidities are fairly high. Under favourable conditions,

![Figure 12.5](image)

*Figure 12.5* *Sitophilus zeamais* (adult life-size, 2.5–4.5 mm long) showing its life cycle in
a wheat grain; note female laying egg in hole in the grain
such as 27 °C and 70% RH, development from egg to adult in all three species is completed in about 35 days.

**Rhyzopertha dominica and Prostephanus truncatus**

*Rhyzopertha dominica* and *Prostephanus truncatus* belong to the family Bostrichidae. They thrive in stored products such as cereals and dried cassava roots, and are important primary pests. Adult *R. dominica* are small (about 2.0–3.0 mm long) and *P. truncatus* are somewhat larger (about 3.0–4.5 mm long), both are cylindrical brown beetles (Figure 12.6).

*Rhyzopertha dominica* is widespread throughout the tropics and subtropics, and is most important as a pest of wheat and paddy rice although it does occur on other cereals and roots such as dried cassava. *Prostephanus truncatus* is a sporadic but locally serious pest of maize stored on the cob in Central America. In the late 1970s it became established in Africa. It is now a quarantine pest in many countries. Like *Sitophilus* spp., the pre-adult stages of *R. dominica* and *P. truncatus* develop within cereal grains (Figure 12.7). Adult *R. dominica* and *P. truncatus* feed throughout their lives, producing large quantities of dust and frass containing a high proportion of undigested fragments which can support the development of larvae if sufficiently compacted. Both species are adapted to rather higher temperatures and lower moisture contents than *Sitophilus* spp. and they are, therefore, the dominant pest in hot, drier areas.

![Figure 12.6 Rhyzopertha dominica (left life-size, 2–3 mm long) and Prostephanus truncatus (right life-size, 3–4.5 mm long)](image_url)
Sitotroga cerealella

Sitotroga cerealella is an important primary pest of cereals. In S. cerealella the forewings of newly emerged adults are covered with yellowish-golden scales, but in older adults the body is entirely grey. The hindwings carry a fringe of very long hairs (Figure 12.8).

Female S. cerealella lay eggs in masses on the commodity; on hatching, the larvae bore into the grain. Subsequent development takes place within the grain, but the larvae may leave one grain and enter another, especially if the grains are small. Pupation usually takes place within the grain, and the adult pushes its way out of the grain leaving a characteristic hole behind, with a partial covering at the edge of the hole in the form of a ‘trap-door’ (Figure 12.8). The adult is rather short-lived (typically 7–14 days) and is an active flyer.

Sitotroga cerealella attacks any cereal with grains large enough to support larval development. This moth is widespread over tropical and subtropical parts of the world, sometimes entering warmer temperate areas. The adults are good fliers and cross-infestation occurs easily. They are delicate and cannot penetrate far into densely packed grain; infestations in bulk grain are generally confined to the outermost exposed layers. However, quite serious infestations can develop in cereals stored in bag stacks, especially if the pre-harvest infestation has been heavy.

Figure 12.7 Larva and pupa of Rhyzopertha dominica in grain

Figure 12.8 Sitotroga cerealella adult (wingspan, 10–18 mm), pupa, larva and grain with emergence window
Infestations of the pest are most frequently encountered in farm storage. Because the larvae compete with those of *Sitophilus* spp., *S. cerealella* is relatively more important in dry conditions that are less favourable to *Sitophilus* spp.

**PRIMARY PESTS OF PULSES**

Pulses (peas, beans, grams, etc.) are the edible seeds of legumes. They are fairly resistant to attack by most storage pests, but one family of beetles, the Bruchidae, is adapted to attack them. All major pests of pulses are Bruchidae.

**Acanthoscelides obtectus**

*Acanthoscelides obtectus* is a common pest of *Phaseolus* beans. It sometimes attacks other legumes, but it is seldom a serious pest on these. The adult is a robust, active beetle, the body colours of which are greys, browns and reddish-browns forming vague and indistinct patterns. The wing cases do not completely cover the abdomen (Figure 12.9).

Adult beetles are able to infest beans before or after harvest. Eggs are laid loosely in or around pods or beans, often under cracks in the testa. After hatching, the larvae bore into the beans and spend their larval life feeding on the cotyledon, excavating a feeding chamber as they grow. The larvae pupate within the bean, but prepare the site of eventual escape by chewing their way to the outside, leaving only the testa of the seed separating the pupation chamber from the exterior.

![Image](https://example.com/figure12.9.jpg)

*Figure 12.9  Acanthoscelides obtectus* (life-size, 3.0–4.5 mm long)
The adult, which has relatively feeble mouthparts, is able to penetrate the testa and escape. The area of undermined testa is easily seen before adult emergence, and is known as a window. The window itself is usually completely removed on emergence, leaving a neat round hole in the bean.

Adult beetles are short-lived (typically 7–14 days) and do not feed in store. In the field, however, they may feed on the pollen of many plant species. The beetles are capable of tolerating quite low temperatures, which has resulted in their spread to cool, highland regions of the world and into some temperate areas. _Acanthoscelides obtectus_ is less common in those parts of South and South-East Asia where grams, peas and lentils ( _Vigna, Lens_, etc.) are more commonly grown than _Phaseolus_ beans.

**Callosobruchus spp.**

Species of _Callosobruchus_ are important primary pests of a number of legumes including cowpeas, pigeonpeas, chickpeas, adzuki beans, peas, grams and (occasionally) soyabeans. They do not usually attack kidney beans or butter beans (_Phaseolus_ spp.).

The adults are of the same general form as _A. obtectus_ (Figure 12.9), but are usually somewhat smaller. The wing cases of some species are distinctly patterned, especially in the females (Figure 12.10).

The life cycle of _Callosobruchus_ spp. is similar to that of _A. obtectus_, except that the eggs are stuck firmly to the seed coat or to the wall of a pod. On hatching, the larva
bores through the floor of the egg, directly into the seed or the pod. There are several species, including *C. chinensis*, a common Asian pest which is also found throughout the tropics and subtropics; *C. maculatus*, which originated in Africa but is now widespread; and *C. analis*, a common species in Asia.

**Zabrotes subfasciatus**

*Zabrotes subfasciatus* is a common pest of kidney beans and butter beans, and seldom attacks other legumes. It is similar in size to *Callosobruchus* spp., the wing cases are rather square and broad and are strongly marked with white patches on a dark (almost black) background (Figure 12.11).

The life cycle of *Z. subfasciatus* is similar to that of *Callosobruchus* spp. *Zabrotes* originated in tropical America, but is now common in many tropical and subtropical regions, especially Central and East Africa, Madagascar, the Mediterranean and India.

**SECONDARY PESTS**

A large number of unrelated pests can be conveniently classified as secondary pests. They are predominantly associated with commodities that have suffered previous physical damage caused by a primary infestation or a milling process. Many are pests of cereal products, but others are associated with oilseeds, spices and other commodities.

**Trogoderma granarium**

*Trogoderma granarium* is a very serious pest of cereal grains and oilseeds, and many countries have specific quarantine regulations against possible importation. Massive

![Zabrotes subfasciatus](image)

Figure 12.11  *Zabrotes subfasciatus* (life-size, 2.0–2.5 mm long)
populations may develop, and grain stocks can be almost completely destroyed. Attacks occur in large-scale stores. The presence of *T. granarium* on grain exported to some countries will result in an order to carry out expensive pest control measures or a rejection of the shipment.

*Trogoderma granarium* adults are small (2.0–3.0 mm long), oval beetles (Figure 12.12). The females are larger than the males. The wing cases are lightly clothed with fine hairs and are mid-brown in colour or irregularly mottled. Although the adults have wings, they are not known to fly and appear to rely on transport in old bags, etc., to move from one store to another. The larvae are extremely hairy (Figure 12.12) and their cast skins may cover the surface of infested grain. Hairs from the skins are allergenic, presenting a health hazard to storage workers and consumers.

*Trogoderma granarium* is very tolerant of high temperatures (up to 40 °C) and low humidities (down to 2% RH). It is, therefore, a pest in hot, dry regions where other storage pests cannot survive. In addition, the larvae are able to enter diapause (a resting stage) when physical conditions are unfavourable. When in diapause the larvae move very little, or not at all, and their metabolic rate is lowered. In this state they can survive several years of adverse conditions. In diapause, larvae usually hide in cracks or crevices in the store, and are thus protected against contact insecticides. Their low metabolic activity also helps reduce the rate of pesticide uptake and translocation. They are, therefore, very difficult to kill with residual insecticides or fumigants, although out of diapause they would otherwise be susceptible to the usual storage insecticides and fumigants.

*Trogoderma granarium* is widespread in the Indian subcontinent and adjacent areas, and in many hot, dry regions around the world. It is not usually found in humid regions.

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Figure 12.12  *Trogoderma granarium*, adult (life-size, 2.0–3.0 mm long) and larva
**Tribolium castaneum**

*Tribolium castaneum* feeds on a range of commodities, especially cereals, but also groundnuts, nuts, spices, coffee, cocoa, dried fruit and occasionally pulses. It will also feed on animal tissues, including the bodies of dead insects, and will attack and eat small or immobile stages of living insects, especially eggs and pupae. Under conditions of overcrowding there is considerable cannibalism.

Adult *T. castaneum* are brown, medium-sized (2.5–4.5 mm long), parallel-sided beetles that are partially flattened (Figure 12.13). The larvae are cream or pale brown, have little hair and are very active.

Under optimum conditions (33–35 °C at about 70% RH) adults live for many months. Throughout their lives, females lay eggs loosely among their food and the larvae feed and complete their life cycle without necessarily leaving the food commodity. Development can be very quick (about 30 days) and population growth is very rapid. Heavy infestations by *T. castaneum* and other tenebrionids can produce disagreeable odours and flavours in commodities due to the production of quinones from the abdominal and thoracic defence glands of the adults. Flour exposed to *T. confusum*, at 100 adults/kg for 3 weeks, showed a distinct change in viscosity and extensibility when made into dough. Tumours have been observed in mice that had been fed flour on which an initial population of *T. castaneum* at 20 adults/kg had been allowed to develop for 1 year. However, quinones did not appear to accumulate on milled rice.

![Figure 12.13 *Tribolium castaneum*, adult (life-size, 2.5–4.5 mm long), larva and pupa](image-url)
It was concluded that flour absorbed quinones, probably due to the finely divided nature, while solid semi-crystalline grains did not.

Many species of Tenebrionidae, at least 10 of which are very similar in appearance to *T. castaneum*, are found in farm and central stores. As *T. castaneum* is a very well known insect, these other species are often misidentified as *T. castaneum*.

**Cryptolestes**

Several species of *Cryptolestes* are common in mills and stores where they are secondary pests of cereals, nuts, oilcakes, dried fruit and other commodities. The adults are small (2.0–2.5 mm long), elongate, very flat, light-coloured beetles. They have long, thin antennae (Figure 12.14).

Small larvae of *Cryptolestes* spp. may enter cereal grains at points of minor damage, especially in wheat where the embryo is often exposed. The embryo of cereals is often attacked preferentially. *Cryptolestes* spp. prefer food with a high moisture content, and the presence of large numbers may indicate moisture problems.

**Oryzaephilus**

*Oryzaephilus* spp. are moderately small (2.5–3.5 mm long), rather flat, parallel-sided beetles which are distinguished by six large, tooth-like projections on each side of the prothorax (Figure 12.15).

![Image of Cryptolestes sp., adult (life-size, 2–2.5 mm long)](image-url)
There are two common species, *O. surinamensis* and *O. mercator*, which are similar in appearance but differ biologically. *Oryzaephilus surinamensis* develops more quickly than *O. mercator* at high temperatures and humidities (35 °C, 90% RH) and is more tolerant than *O. mercator* of extremely high and low temperatures and humidities.

Both species attack cereals, cereal products, oilseeds, copra, spices, nuts and dried fruit. However, *O. surinamensis* is most successful on starchy, cereal diets, while *O. mercator* prefers diets with high oil content.

**Lasioderma serricorne**

*Lasioderma serricorne* is a rounded, light-brown beetle with smooth wing cases. The head is carried beneath the body and so cannot be seen from above. The antennae are long with saw-like segments at the ends (Figure 12.16). This beetle is a well known pest of dried tobacco and manufactured tobacco products. However, it will attack a wide range of commodities, including cocoa, cereals, spices, dried fruit and processed foodstuffs.

A closely related species, *Stegobium paniceum* (Figure 12.17), attacks a similar range of commodities but is seldom found on tobacco. It can be distinguished from *L. serricorne* by the shape of its antennae.

**Cadra cautella**

*Cadra cautella* is a common and important secondary pest of cereals, cereal products, cocoa, dried fruits, nuts and many other commodities. In newly emerged adults the forewings are greyish-brown in colour with an indistinct pattern. Older specimens which have lost most of their scales are dull grey in colour (Figure 12.18). Adult *C. cautella* are fairly short-lived (usually 7–14 days) and do not feed. The
females lay their eggs loosely on the surface of the commodity. The larvae move extensively through the produce as they feed and, as they move about, spin copious quantities of silk called webbing. The webbing from heavy infestations can mat the commodity together and render it unfit for consumption.

OTHER MOTH SECONDARY PESTS

Two other moth species are common secondary pests: Corcyra cephalonica and Plodia interpunctella. The life history of both is very like that of C. cautella and both also attack a very wide range of stored commodities. Corcyra cephalonica is a robust, medium-sized (5–10 mm long) moth. The wings are greyish-brown in newly emerged specimens. The eggs are rather sticky and the webbing produced by the larvae is very tough. Newly emerged specimens of P. interpunctella are easily identified by their forewings, the inner parts of which are pale yellow, while the basal parts are dark reddish-brown (Figure 12.19).
Psocids, or booklice as they are sometimes called, are small insects only about 1 mm long, and for that reason are often confused with mites. However, the presence of six legs and very long antennae (mites have no antennae) should make them easy to distinguish (Figure 12.20).

Figure 12.18  *Cadra cautella*, adult (wingspan, 11–28 mm), larva and pupa

Figure 12.19  *Plodia interpunctella*, adult (wingspan, 11–28 mm)

**Psocids (*Liposcelis* spp.)**

Psocids, or booklice as they are sometimes called, are small insects only about 1 mm long, and for that reason are often confused with mites. However, the presence of six legs and very long antennae (mites have no antennae) should make them easy to distinguish (Figure 12.20).
Psocids can often be seen moving rapidly across bag surfaces and on walls and floors. They are not normally associated with any significant damage or losses to the commodity, although their presence in stores is undesirable not least because contact with them can cause some skin irritation to storage workers. Unless numbers are very high they are of no serious concern, and in many situations their numbers can be kept low by simple hygiene measures. Store surfaces and the surfaces of bags must be kept free of dusts and detritus. Often the seams of polypropylene bags hold significant collections of dust, making an ideal breeding ground for psocids. In some parts of the world an industrial vacuum cleaner is provided for cleaning stacks. This has the advantage that dust is not just redistributed within the store by brushing, but can be collected and removed. A vacuum cleaner should be used where electricity is available in store.

In recent years it has become clear why psocids may reach very high numbers in stores, especially those subject to regular pest control operations. The eggs of psocids are particularly tolerant of the fumigant phosphine, so that unless fumigation is done to a very high standard they will survive. Frequently they survive when all other insects have been killed, including Tribolium castaneum and Cryptolestes spp., which are known to be psocid predators. The psocids that emerge after a fumigation are thus free to increase without the constraint of competition with, or predation from, other storage pests. So how to control psocids? It is usually not necessary to undertake any special pest control against them, but if they are proving to be a serious problem there are two options. The first is to attempt a single, very good quality fumigation. This could be a 5-day treatment of phosphine (at 27 °C) in which at least 1275 ppm (1.7 mg/l) is still retained on the last day, or an 8-day treatment in which not less than 38 ppm (0.05 mg/l) is retained on the last day. If sufficient gas cannot be retained, the second option is to undertake two normal fumigations in succession. The second fumigation follows after about 10 days, when any surviving eggs will have developed into nymphs.
Mites such as *Tyrophagus putrescentiae*

Mites are small or very small with legs of moderate length. Those found in stored products are whitish, cream or milky translucent in colour (Figure 12.21). *Tyrophagus putrescentiae* is a cosmopolitan and common mite pest in food stores, recorded from a wide range of commodities. It is known to feed on storage fungi, and to develop rapidly when preferred fungi are present. It can develop successfully in the absence of fungi, for example, on wheat germ in laboratory tests, and thus can cause direct damage to the produce. It develops more rapidly in higher humidities, but development is possible at all humidities over 60%. Its upper temperature limit is about 35–37 °C, with an optimum at about 32 °C. Mites that feed directly on the commodity, whether or not they also consume fungi, cause quantitative losses, although these may become significant only when the numbers of mites are very high. Such infestation may taint the stored commodity with off-odours or off-flavours. Mites can also cause allergic responses in animals eating the infested food and in the storage workers handling it.

**OTHER SPECIES**

Mould-feeding beetles are frequently found in food warehouses. While they do little direct damage, they act as vectors to spread fungal spores and help to spread mould quickly through a commodity. The presence of large numbers of these insects may indicate poor physical condition of all or part of the consignment. Examples of such beetles are *Carpophilus* spp. and *Typhaea stercorea*.

Various wood-boring beetles and termites attack storage structures. They can also damage the commodity or its packaging by boring. Several insects that occur in stores do not attack the grain directly, but feed on dust and residues or on the dead bodies of insects and other animals. These are referred to as scavengers, and their numbers are high when conditions in store are unhygienic. Typical scavengers are cockroaches, earwigs and silverfish (Figure 12.22), as well as flies and ants. Cockroaches are often highly visible and associated with rubbish in unhygienic stores.
Both flies and cockroaches are vectors for a number of food poisoning organisms and are a public health risk. Ants may cause losses by removing food to their nests. They may be a particular problem in stores containing goods with a high sugar content.

Several species consume the pests found in stores and so are described as ‘beneficial’. These include predatory beetles such as *Tenebroides mauritanicus* (Figure 12.23) although, besides eating storage pests, this species also attacks the stored commodity; and *Xylocoris* bugs which are common and effective predators of insect eggs and small, soft-bodied insects. Some species of mites prey on the eggs of moth pests.

There are also parasitic species attacking the pests. In the storage environment most parasites are parasitic wasps (Figure 12.24) or prostigmatid mites. Parasitic wasps

![Figure 12.22 Typical scavengers (a) cockroach, (b) earwig and (c) silverfish](image)

![Figure 12.23 *Tenebroides mauritanicus* (life-size, 5.0–11.0 mm long), both predator and pest of stored grain](image)
lay their eggs in or on the eggs or larvae of many moth and beetle pests. The parasites develop inside the host, eventually causing its death. Some parasitic mites feed on the body fluids of insects. However, some can also attack people, causing irritation to store workers.

Finally, various strays and intruders from the local fauna may sometimes enter stores. It is important not to mistake them for pest species.

**FURTHER READING**

The first step in managing insect pests of food aid stocks is to inspect them regularly to check their condition. Such inspection is described in Chapter 9. If pests are found and considered to pose a risk – bearing in mind that not all insects in stores are pests (Chapter 12) – pest control operations may be needed.

The account given here of pest management in stores, particularly fumigation with phosphine and the use of contact insecticides, is meant as a reference guide so that field staff can understand what is required to maintain stocks in good condition and can monitor the work of pest control contractors. It is not provided in the expectation that food aid programme staff themselves will undertake all aspects.

**APPROACHES TO PEST MANAGEMENT**

The principal means of pest control in stored foods is by fumigation. This is the process of holding the stored commodity with a poisonous gas (phosphine, PH₃) in order to kill any infesting organisms. Contact insecticides may also be used to support fumigation. A further important element in pest management is to ensure that stores are well cleaned and well maintained; such stores require less expenditure on costly pest control procedures.

Until recently two fumigant gases were in common usage: methyl bromide and phosphine. Methyl bromide is a very effective fumigant, although somewhat more dangerous to use than phosphine. However, the World Food Programme (WFP) as a UN Agency has a policy not to use methyl bromide because, when released into the atmosphere, it depletes stratospheric ozone. For this reason WFP relies on phosphine alone.

In order to hold phosphine with the commodity for long enough to kill pests, the commodity must be in a gas-tight enclosure. Most commodities are in bags, so to provide a gas-tight enclosure, bag stacks are placed under gas-proof sheets held down at the edges by flexible, sand-filled tubes called sand snakes (Figure 13.1). This is the type of fumigation most commonly used for food aid. Fumigation in other situations, such as in silos, rail cars, transport containers, barges and ships, is discussed later in this chapter.
Phosphine penetrates easily into a commodity so that a good fumigation will kill 100% of the pests under the gas-proof sheet. However, once the phosphine has dispersed, the grain has no protection against re-infestation unless the gas-proof sheet is left in place to act as a physical barrier. Fumigation sheets are expensive so usually there are not enough available to cover all bag stacks for the duration of storage. Consequently, the sheets are normally removed so that they can be used in another fumigation. This gives insects the opportunity to migrate into the fumigated stock and re-infest it. Stocks held in stores for long periods will probably need several fumigation treatments. Under tropical conditions where insect activity is high, it may be necessary to fumigate as often as once every 3 or 4 months although, with good hygiene practices and good fumigation, treatment once every 6 months is achievable.

To slow down the rate at which grain stocks become re-infested, contact insecticides may be sprayed onto the floor and internal walls of stores as a secondary measure. Insects and mites take up contact insecticides by coming into direct contact with them, although some insecticides are sufficiently volatile to have effects as vapours, but they are quite different from fumigants. Contact insecticides are used:

- when the store is empty, as a hygiene measure to ensure incoming stock does not become infested by insects emerging from the cracks and crevices of store structures
- at the time of fumigation, to ensure that when fumigation sheets are removed there are no live insects present on the store structure that can re-infest the stock.

Figure 13.1 A bag stack placed under gas-tight sheets ready for fumigation to begin
In the past, to reduce the frequency of fumigation, it was recommended that during the period between fumigations there should be regular insecticide treatment of store surfaces, including bag stacks. The idea was that this would reduce the population growth of insects and so reduce the need for fumigation. However, recent evidence suggests that for tropical storage, regular spraying is not cost-effective. Instead, it is recommended that spraying is confined to store surfaces, particularly floors and internal walls, to prevent insects moving from them to the clean commodity when stocks enter a store or when fumigation sheets are removed.

Insecticide usage in food aid stores does not involve direct application of insecticide onto stored food. In some situations contact insecticides may be admixed directly with grain stocks, and this can be a substitute for fumigation. However, this is not practised by most food aid agencies in order to ensure that the beneficiaries receive products relatively free of insecticide residues. Information on the toxicity of contact insecticides, in relation to cases where they are added to grain or grain products, is presented in Annex 2.

Pest management in stores is achieved by the application of good store hygiene, timely fumigation and the spraying of store surfaces with contact insecticide, as appropriate. These processes are summarized in Figure 13.2.

HOW TO DECIDE WHEN PEST CONTROL IS NEEDED

Fumigation and spraying with contact insecticides are expensive, and decisions about whether or not to use them should not be taken lightly. In any particular situation, the need for pest control is affected by:

- the acceptability of the pest numbers present
- the suitability of the environment for the multiplication of these pests
- how long the commodity is to be held before being consumed
- for stocks that will be sent across borders, the phytosanitary requirements of the importing country.

Following an inspection for pests, it is necessary to decide whether the existing pest problem is sufficient to require immediate pest control, whether a treatment is needed to prevent an anticipated pest problem, or whether no treatment is needed. Most insect pests under humid tropical conditions can be expected to multiply about 50-fold every 6 weeks. This rule of thumb can be used to anticipate future problems. It is worth remembering that pest control should be applied as soon it is believed that there is definitely going to be a pest problem. In this case, the costs will be the expense of pest control. If, on the other hand, pest control is applied late, when significant contamination and weight loss have already occurred, then costs are the loss in value of the stock plus the cost of pest control.

Judgements about the acceptability of distributing stock with live insects vary greatly according to circumstances. In most situations, the presence of one or two live
Pest management cycle for the protection of bag stacks using good hygiene, fumigation under gas-tight sheets and insecticide treatment of store surfaces.

- **Empty store**
  - Prepare for entry of stock:
    - Sweep and clean surfaces
    - Spray insecticide on store surfaces

- **Stock moved in**
  - **Insects invade**
    - Sweep and clean store surface
    - Monitor for pest presence
    - If commodity at risk, request a fumigation in good time
    - Prepare for fumigation
    - Fumigate under gas-tight sheet
    - Spray insecticide on store surfaces

- **Stock under fumigation**
  - Prepare for entry of stock
insects per kilogram of grain is acceptable if the grain is to be consumed soon after
distribution. Higher levels may be acceptable in human food that will be milled before
consumption or in animal feed.

FUMIGATION WITH THE GAS PHOSPHINE

To achieve a good fumigation with phosphine, the gas must be retained with the
commodity at the correct dosage and for the correct length of time. If either the
dosage of gas or the length of exposure are below specified standards, some pests
will survive the treatment and such fumigations are failures. These failures are costly.
This is because either:

• the fumigation will need to be repeated immediately, as a large number of
survivors are visible when the sheets are removed, or

• another fumigation is required sooner than normal – say after only 2 months instead
of after 3 or 4 months – as a small number of survivors (although inconspicuous)
breed rapidly so the stock becomes re-infested sooner than normal.

It is common that insect survivors are not seen after a failed treatment, as the stages
in the insect life cycle that are most resistant to phosphine are eggs and pupae. These stages are immobile and difficult to see in stored food, so on removal of the
fumigation sheets it may appear that the treatment has been successful. Fumigation
failures very often become apparent only when commodities are moved in the
distribution chain soon after fumigation. This is because movement of bags gives
close contact for inspection; it also disturbs the insects so that they move about and
are noticed more easily.

What you should know about phosphine

It is important to remember that the fumigant phosphine is very toxic to people as
well as to pests. Health and safety considerations are very important for pest control
staff, store workers and anyone else who might be exposed to this toxic gas.

Properties of phosphine gas

Phosphine gas for the fumigation of bag stacks is generated from solid formulations of
aluminium or magnesium phosphide, usually in the form of tablets or sachets (Figure
13.3), although other forms may sometimes be used. These preparations begin to
release phosphine when they come into contact with the moisture present in air. Magnesium phosphide formulations are more reactive with moisture and so will
generate gas more rapidly. They are thus particularly useful in cool climates where
aluminium phosphide may react too slowly. However, the slower release from
aluminium phosphide formulations is preferred in tropical and subtropical climates as
it gives safer and better fumigations. Release is also slower and more uniform from
sachets than from tablets, so sachets are generally preferred unless conditions are
exceptionally dry (relative humidity less than 40%) where lack of moisture can result in
incomplete decomposition of the phosphide within the normal period of a fumigation.
Pure phosphine is colourless and odourless. However, impurities result in a garlic-like smell. It is slightly soluble in water and explosive at a concentration above 1.7% in air. When the phosphide is in contact with liquid water, rapid generation of phosphine can occur so that explosive concentrations are formed. To avoid fire it is important that phosphide preparations do not come into contact with liquid water, such as rain water leaking in from the roof during a fumigation. Phosphine will also combust spontaneously at temperatures above 100 ºC and at reduced pressures, thus fans in recirculation systems must be of a special design to prevent combustion. Phosphine has a density similar to air, so it penetrates a stack or bulk of grain easily. Very little of the gas binds chemically to the grain. After airing, only minute traces of phosphate residues remain, which in any case are typical components of the food being treated.

There are, therefore, no limits to the number of times that a given sample of grain could be fumigated with phosphine. The residual powder from the decayed phosphide preparation may, however, contain traces of undecomposed phosphide that must be disposed of carefully; details are given later in this chapter.

Unfortunately, phosphine reacts with copper, copper alloys or copper salts. Any exposed copper wiring or contacts in electrical fittings must, therefore, be protected. Electrical instruments or equipment may have to be removed before a fumigation. Also, pallets freshly painted with wood preservative containing copper salts have been known to absorb so much phosphine that a fumigation treatment was ineffective.

**Exposure periods and dosage**

Phosphine is most effective as a fumigant when used at low concentrations over long periods. The exposure period is affected by temperature. The minimum temperature for the use of phosphine is about 15 ºC and, at temperatures below 20 ºC, long exposure periods of up to 16 days are recommended. Even in tropical countries where there are high ambient temperatures, exposure periods of less than 5 days
should not be used. There is no maximum exposure period, and if fumigations can be extended to at least 7 days then the chances of failure are reduced.

For commodities held under gas-proof sheets, the recommended dosage of gas is normally 2–3 g/tonne. When fumigating with typical 3 g aluminium phosphide tablets, each tablet releases 1 g of gas. So normally there would be two or three tablets for each tonne of commodity. It is also possible to calculate dosage by the volume to be treated rather than the weight of commodity. This is important when there is a large amount of free space included in the fumigation. Normally, there should be 1.5–3 g of phosphine for each cubic metre.

Phosphine can become strongly adsorbed by certain commodities, particularly paddy rice, brown rice, grain legumes in-shell, and some varieties of wheat, so when fumigating these commodities it is recommended that the dosage should be increased to 4 g/tonne.

**Measuring phosphine concentrations**

Although it is often suggested that the smell of phosphine (due to impurities within the gas) can be used as a warning to people of its presence, the smell is only noticeable at concentrations above acceptable exposure limits. Lack of smell should, therefore, not be used as an indication of a safe working environment. Concentrations should be determined using a suitable monitoring device. Although there are several methods of determining concentrations of phosphine in air, the two most common methods are gas detector or Dräger tubes (Figure 13.4), and electronic meters (Figure 13.5).

**Figure 13.4** Hand pump with Dräger tube for estimation of phosphine concentration. A gas sampling line is fixed to the tube so that gas can be drawn from beneath the fumigation sheet.
Gas detection tubes provide a rapid and simple method of determining the level of phosphine present. Different tubes are produced to cover a wide range of concentrations.

Electronic meters are fitted with electrochemical sensors that measure phosphine concentrations directly, in the range 0–2000 ppm, on a digital display. Samples may be drawn directly into the meter using an aspirator bulb, or by syringe injection. Meters should be calibrated by the manufacturer to give optimal reading in the range 100–200 ppm and if being used to monitor the success of fumigations, they should be recalibrated at the frequency specified by the manufacturer (typically every 6 months).

**Criteria for a successful phosphine fumigation**

For a successful phosphine fumigation, the gas concentration must not fall below a minimum value during the required exposure period. In a 5-day treatment it must not fall below 150 ppm before the end of the fifth day (Figure 13.6), or in a 7-day treatment not below 100 ppm before the end of the seventh day. Somewhat higher standards are required for full control of psocids (see Chapter 12).

**Important safety considerations**

Fumigants are highly toxic, and over-exposure in humans leads rapidly to death. For this reason, only properly trained and preferably certificated personnel should do fumigations. In any of the operations involved in fumigation there should never be fewer than two staff involved.
Phosphine toxicity and poisoning

Depending on the degree of exposure, the symptoms of phosphine poisoning in humans may be delayed or occur immediately. Slight poisoning can result in fatigue, ringing in the ears, nausea, etc., and such symptoms may disappear on contact with fresh air. More severe poisoning may cause vomiting, diarrhoea and difficulty with breathing, so artificial respiration may be needed. Severe poisoning may result in a bluish-purple skin colour leading to unconsciousness and death. After the removal of affected persons to fresh air, expert medical advice must be sought immediately.

Those in charge of fumigations must be in a position to provide medical practitioners with details of the poisoning that has occurred and, where available, the details of medical advice on the labels of some fumigant containers.

Human exposure to fumigant gases is regulated by reference to two safety limits:

- threshold limit value – 0.3 ppm, the maximum concentration to which nearly all workers may be repeatedly exposed in a normal working day or week without adverse effects
- short-term exposure limit – 1.0 ppm, the maximum concentration to which workers can be repeatedly exposed for a period of 15 min without suffering from:
  - chronic irritation
  - chronic or irreversible tissue change
  - narcosis of sufficient degree to contribute to accident-proneness, impair self-rescue and materially reduce working efficiency.
**Essential precautions**

All operators must be trained in the use of respirators, equipment for the detection of fumigant gases and first aid. All fumigations should follow procedures that ensure the:

- safety of operators and other persons in close proximity to the fumigation
- avoidance of damage to the commodities treated and of hazard to consumers
- effectiveness of the treatment.

When considering the safety of a fumigation, everyone who may come into contact with the fumigant must be taken into account. This may include fumigation personnel, store personnel, visitors (management, other workers), consumers and the neighbourhood. Care should also be taken so that animals (domestic, livestock, wildlife) are not exposed.

As with all pesticide operations, all potential hazards must be considered before suitable safety precautions can be taken. These include:

- contact with the fumigant – touching the solid fumigant or breathing in the gas
- physical hazards – falling from the top of the stack (when covering a bag stack with sheets), collapse of the stack, physical exertion/exhaustion (damaged backs, over-tiredness, etc.)
- other hazards – fungal spores on the grain, dust, allergies, poor hygiene, poor health of the staff.

Having identified the people at risk and the dangers to them, a number of precautions can then be taken:

- train all personnel involved, not only those who perform the fumigation but also any staff whose work may be affected (managers, labourers, security guards, etc.) – personnel need to know facts such as when they can enter the building, and any precautions that must be taken during the fumigation
- follow instructions/good practice
- plan and prepare
- provide safety equipment
- notify all parties – this should include the staff at the site and any other people in the vicinity who could be affected – local laws may dictate that other parties, such as local emergency services, also be notified
- provide good quality, well maintained equipment/materials – this will minimize the risks from fumigant leakage and help ensure fumigations are successful
- minimize the need for pest control operations – as with the use of contact insecticides, rather than fumigating on a regular basis, fumigate only when you need to.
Prior to application of a fumigant, survey the neighbouring area to determine if any possible hazard is likely to occur subsequent to application of the gas. Neighbouring work areas are important, and continuation of work in these areas must depend on checks to determine if contamination with the fumigant is possible. In many situations it is necessary to prohibit work in the treatment area or store. At the time of phosphide application, all persons not directly involved must be a safe distance away, and all personnel involved in the application must have a respirator to hand.

During aeration, respirators will be required at all times when operators are exposed to any concentration of the fumigant, irrespective of its type. Other workers must be kept away from the area, and permission to return to the treated area given only after full safety checks have been made.

Each operator involved in a fumigation should be provided with a personal respirator fitted with the correct type and size of filter canister for phosphine (Figure 13.7). A self-contained or distance breathing apparatus (Figure 13.8) is only required where exposure to high concentrations is likely. The personal respirator is adequate for situations in which normal levels of leakage are anticipated. Respirators must be in perfect working order, and operators must have confidence at every fumigation that the respirator and canister are capable of safeguarding them from any exposure that may occur.

Respirators must be well maintained and give a gas-tight seal around the face. The seal must be checked each time the respirator is put on by covering the air intake completely with the hand. If a good seal is formed then normal breathing will be impossible. It is usual to discard canisters after a set period, or after a set number of fumigations, unless there has been excessive exposure to a fumigant, when it is recommended that canisters be discarded immediately.
How to fumigate bag stacks with phosphine

Fumigation of a bag stack may be divided into eight key stages:

1. initial preparations
2. sheeting the stack
3. spraying store surfaces with insecticide
4. applying the fumigant and sealing the stack
5. monitoring the fumigation
6. aeration
7. disposal of the residue
8. inspection of fumigation performance.

1. Initial preparations

(a) Measure up the store for fumigation/spraying and determine required dosages with reference to current standing instructions. If the fumigation includes any empty space, the dosage rate must be calculated on a volume rather than a tonnage basis.

(b) The current recommended dosage rate for phosphine is 2 g gas/tonne or 1.5 g gas/m³. Small increases in dosage rate may be acceptable if the target gas concentration on day 5 is difficult to achieve (see below), although this should not normally be necessary.

(c) Confirm there are no human habitations within 100 m of the planned fumigation; if there are, check that arrangements can be made for people to be relocated during the treatment.
(d) Check that stacks can be sheeted (Figure 13.9) and there are no store imperfections such as cracks in the floor, unfilled floor joints, roof leaks, etc., which might jeopardize the success of the fumigation. Expectation of adverse weather, such as high winds, must be taken into account as these may prevent adequate phosphine concentrations being achieved.

(e) Check that the surfaces of floor, walls and bag stacks are clean and free of food residues.

(f) Check on the availability of essential safety equipment such as respirators and canisters, gloves, dust masks and protective overalls, detector tubes/monitoring equipment, warning signs, etc.

(g) Consider the needs for prophylactic pest control such as spraying of the store structure and stack surfaces with a residual insecticide.

Figure 13.9 An example (left) of an insecurely built bag stack with bags not properly ‘keyed’ and closer than 1 m to a pillar, compared with a well constructed bag stack (right) with a good 1.5 m alley separating it from an adjacent stack

2. Sheeting the stack

(a) Before sheets are placed on a stack, secure two nylon gas-sampling lines, a long one that comes from the top of the stack close to the middle, and a short one from the side of the stack just above ground level.

(b) Place any store residues or sweepings in a sack by the bag stack so that they will be included in the fumigation.
(c) Unfold the sheet towards the stack.

(d) Always carry the sheet; never drag it over the ground.

(e) Place the sheet over the stack, and position with 1 m of sheet on the ground.

(f) Unroll the sheet to cover that part of the stack.

(g) In larger stacks needing more than one sheet, repeat this operation for the remaining sheets.

(h) If more than one sheet is used, join the sheets as shown below.
(i) Smooth out any wrinkles and folds in the sheets before placing the sand snakes on them.

(j) Take care to fold or roll the sheets correctly at the corners of the stack to avoid excess bunching of the sheet at the base and, therefore, difficulties in sealing the sheet to the ground with the sand snakes.

(k) Place the sand snakes on the sheets along the sides of the stack. Ensure each sand snake overlaps the next by at least 0.3 m so that a good seal is achieved along the whole length of the sheet. Wooden poles or metal chains are not acceptable in place of sand snakes. In cases where a base sheet has been placed beneath the bag stack, roll together the edges of the fumigation sheet and base sheet to form a good seal before locating the sand snakes.
(l) Re-check the condition of the sheets for damage, and repair any holes using pieces of spare sheeting and glue.

3. **Spraying the store surfaces with insecticide**

(a) The floor and internal walls of the store should now be sprayed with an approved residual insecticide at the manufacturer’s recommended dosage. Although the surface of the bag stack cannot be treated in this situation, such a treatment is, in any case, not recommended.

(b) Insecticide application to walls should be until run-off, that is, sufficient spray is applied to the surface to the point where it just starts to run down the wall. The floor is sprayed until there is a slight excess of liquid. To achieve this typically requires the application of between 3 and 5 l insecticide diluted in water for every 100 m² to be treated; more porous surfaces require the larger volumes.

(c) Spraying should always start at the highest point on the walls. The area for treatment should be divided visually into bands 2–3 m wide and, starting at the top, the spray should come down in a zig-zag pattern to the floor.

4. **Applying the fumigant and sealing the stack**

(a) Decide on each person’s responsibility.

(b) If using phosphide tablets, lay out trays around the stack; remove the sand snakes that hold down the sheets next to the trays.

(c) Place warning signs on the warehouse doors and on the sides of the stacks being fumigated (Figure 13.10).
(d) Remove from the area all people who are not going to be involved with the gassing.

(e) The stack is now ready for gassing. Open aluminium phosphide containers with caution and, if using tablets, handle only with gloves. If there is danger of inhaling aluminium phosphide dust, a dust mask must be worn.

(f) If using aluminium phosphide tablets, these must be in a single layer on trays and placed beneath the sheet, preferably beneath the pallets (Figure 13.11), in a manner that will not result in any contamination of stored food with residues. If using sachets, suspend these from the sides of stacks but clear of the floor.

(g) Seal the remainder of the fumigation sheet to the floor using heavy sand snakes that overlap by at least one-third of their length.

(h) Leave the store and then lock the doors to prevent any unauthorized access.
5. Monitoring the fumigation

(a) On the fifth or seventh day of fumigation, a member of the pest control team, wearing a gas mask fitted with the appropriate phosphine filter, should enter the store to measure the concentration of phosphine from the two gas-sampling lines. As a safety precaution, a second member of the team should stand at the door to watch the one who is measuring the phosphine concentration. The phosphine concentration may be measured with an electronic phosphine meter or gas-detector tubes.

(b) The fumigation will be regarded as successful only if the phosphine concentration after 120 h (5 days) is at or above 150 ppm (0.1 mg/l) from both gas-sampling lines, or at least 100 ppm (0.066 mg/l) after 168 h (7 days).

(c) The fumigator should record the gas measurements and submit them as evidence that the job has been completed successfully.

6. Aeration

Careful planning is especially important at this stage to minimize dangers.

(a) Fumigation team members should open all doors and ventilators.

(b) They should enter the store, wearing gas masks fitted with the appropriate phosphine filters, and should remove all sand snakes.

(c) Pull back the sheeting from about one-third of the stack. Pull the corners of the sheet up onto the top of the stack using a rope. This should be done by two people climbing to the top of the stack, while a third person remains at the base.
(d) Fumigation team members should then leave the store for at least 2 h; ideally the store should be left overnight. After this time they may return wearing gas masks to check that the phosphine concentration is at or below 0.3 ppm. At this stage the use of gas-detector tubes is required for the verification of safe conditions in the warehouse, as these enable the accurate measurement of very low phosphine concentrations. Once safe conditions have been verified, gas masks may be removed and other staff allowed to enter the store.

(e) Fumigation sheets may now be removed from stacks, folded and taken out of the store.

7. Disposal of the residue

All phosphide residues, which are a fine grey dust, or used sachets must be removed from the store and disposed of safely, for example, buried to a depth of at least 500 mm. Dig a hole at a place away from public access and then fill in firmly.

8. Inspection of fumigation performance

Inspect stacks immediately after fumigation for signs of control failure.

Fumigations other than for bag stacks

Treatment of rail cars

Rail cars are very difficult to seal and when moving, fumigant will be drawn out by wind action. It is recommended that rail cars are fumigated only if they can be well sealed, for example, lined with polythene sheeting, and can be held stationary for the duration of a treatment.
Fumigating small quantities of commodity

Small quantities of commodity may be fumigated conveniently with phosphine. The commodity can be placed in small containers such as empty oil drums or dustbins, provided they are sound, uncorroded and can be properly sealed. Commodities can also be fumigated in sacks made from plastic film, or in woven sacks fitted with liners of plastic film.

Phosphine applied as tablets is the most effective and simple method of fumigation for small quantities of produce. The tablet or pellet is placed in a paper envelope, which is then pushed down into the commodity before sealing the container. If the container has a well fitting lid, it may be sealed with adhesive tape. Containers without lids can be sealed by placing a plastic sheet over the top and securing this tightly with tape.

A major problem with fumigating small quantities of commodity is that of obtaining appropriately small quantities of phosphine-generating formulation. The normal packages of tablets (20 or 30 tablets per tube) are too large to be used at once and cannot safely be re-sealed. Some manufacturers are marketing sealed packs of three or five tablets, while some tablets can be obtained in resealable flasks. Recently, sachets equivalent to 3 g phosphine have become available.

Ship and barge fumigations

Commodity fumigation on ships is a hazardous operation that is difficult to do successfully. Fumigation has to be done in compliance with the ship’s flag regulations and those applicable at the port of call or of destination. The Recommendations on the Safe Use of Pesticides in Ships issued by the International Maritime Organization (IMO) provide a useful framework and are incorporated into many national regulations, making them mandatory in most instances.

On-board fumigation must be supervised by a qualified fumigator who selects the treatment, determines which spaces of the ship, if any, are safe for occupancy during fumigation, and manages the process. The responsibility for the treatment lies with the fumigator except where fumigation will be conducted in-transit, in which case it rests with the ship’s master.

Not all ships can be considered for in-transit fumigation as not all ship designs can guarantee a safe confinement of the gas to the space to be fumigated. Bulk carrier and tanker-type ships are generally deemed to be the most suitable for in-transit fumigation, tween-deckers being less suitable. In any case, cargo holds should be tested for gas-tightness and a fumigation protocol should be approved by the ship’s master and the relevant port authorities before in-transit fumigation can be considered.

Another significant problem with fumigation is ensuring the adequate distribution of fumigant throughout the holds, and subsequently its complete removal from the ship.
Due to the considerable depth of grain in some of the larger vessels, some form of gas recirculation system may be required. If such systems are not used, then fumigation treatments will not be effective and may be regarded as only cosmetic. Depending on the depth of the grain, a variety of methods of applying phosphine are available. These are of two basic types. The phosphide preparation may be confined to an easily accessible location and the gas that is generated may then be circulated and recirculated by a fan. Alternatively, the preparation may be inserted into many locations at various depths in grain so that the gas will be distributed when it is generated. Failure to distribute the fumigant sufficiently throughout the cargo will reduce the efficacy of the treatment and, where phosphide tablets or pellets are used, could lead to the occurrence of visible powdery residues in or on the cargo. These residues could present problems for phytosanitary inspection and acceptance by the consignee.

In-transit ship fumigations should only be undertaken where it is expected that the duration of the voyage will be sufficient for the total release of the fumigant. Otherwise the ship might dock with undecomposed fumigant preparations present in the cargo. This outcome would be more likely to occur when cargoes such as grain are shipped at lower than normal moisture content. The result would be a failed fumigation and a serious hazard to health for anyone exposed to, or working with, the cargo. The IMO issued a circular in 2003 advising that ships carrying bulk cargoes under fumigation should notify the appropriate authorities prior to arrival and ensure that the ship’s hold and its cargo are gas-free upon berthing.

Barges of sound construction may be fumigated using the same technique of application for bag stacks. Hatches should be sealed during the course of the fumigation.

**Fumigation of shipping containers**

With the general increase in the use of shipping containers, this type of treatment is now becoming more common. In some situations, containers fumigated with phosphine may be loaded onto ships without opening; the ventilator seals being removed during the voyage. Containers ‘under gas’ are always carried on deck. Care is needed to ensure that fumigated containers are properly labelled.

Some containers have wooden floors which are not gas-tight, although they can be sealed. Due to their very nature, even well designed containers will become damaged when they are handled, so all containers should be tested for gas-tightness prior to fumigation. Options include pressure testing, smoke tests, and the Contestor (an automated system for pressure testing containers).
USE OF CONTACT INSECTICIDE IN STORES

Insecticide application

Details of the dosage rates and methods of dilution of contact insecticide concentrates are unlikely to be needed by food aid staff, but if these are necessary then reference can be made to the FAO Manual of Pest Control for Food Security Reserve Grain Stocks. To apply contact insecticides, a variety of spraying machines are available, some manually operated and others motorized.

Surface treatments

Insecticide is applied to the structure of store buildings, typically the floor and internal walls. Hand-operated sprayers are suitable for small applications, but in large storage buildings the motorized type is more suitable (Figure 13.12). To give coverage that includes cracks and crevices, it is important that the surfaces are sprayed until run-off. Hence insects on or in the fabric of the store will come into direct contact with the insecticide and be killed. This prevents them from moving into the bagged commodity.

Figure 13.12   Motorized knapsack sprayer in use
If the bags themselves are sprayed with an appropriate insecticide in accordance with the manufacturers' recommendations, there should not be a health hazard to the consumer. However, spraying bag stacks is not recommended because most of the pests infesting grain spend too little time on these surfaces to be lethally affected, and such treatments tend not to be cost-effective.

**Treatment of store spaces**

This type of treatment is really only effective for the control of flying (adult) insects, leaving other stages in the life cycle unaffected. For this reason this type of treatment is unlikely to be used in food aid stores. Flying insects are easily seen and, therefore, pose a serious problem in situations where there are strict rules against the presence of any insects. If even a few flying insects are observed then the commodity could be downgraded. Space sprayers may be electrically operated and produce a fine mist or aerosol. Battery-operated and petrol-driven misters allowing full portability are available. Some machines can be adjusted to produce a much coarser spray, and can be used to apply surface residual treatments. For the control of most flying insect pests, the optimum time for spraying is around dusk. An automatic sprayer linked to a clock is available which dispenses a small quantity of concentrated insecticide every day at dusk. By the beginning of the next working day the insecticide has dispersed, presenting no hazard to workers entering the building. Control of flying insect pests in storage buildings can also be achieved by the use of insecticidal fogs. These are produced by vapourizing heavy oil that then condenses, giving very fine droplets that completely fill any enclosure very rapidly (Figure 13.13). There is little deposition or wetting of surfaces by oil.

![Thermal fogger being used to apply a space treatment](image)
Important safety considerations when using contact insecticides

General advice

The grain products in stores should not come into direct contact with insecticides; the consumer should be at no risk. However, those applying insecticides to store surfaces should take appropriate precautions, as follows.

Toxicity and hazards vary for each chemical. Some pesticides can be mixed and applied with the only protection required being good hygiene. Other formulations require the use of protective clothing or even special breathing apparatus. Rather than rely on general advice which may be out of date or not applicable, the best strategy is always to advise people to read and follow the instructions on the label. Below are some broad issues which should always be considered, and some advice on the best protective clothing for tropical conditions which is not always covered on insecticide labels:

- always read the pesticide label and follow its instructions carefully
- wear clean and appropriate clothing and respirator when recommended
- never leave pesticides unattended in a place where security is poor
- never transfer pesticides to other containers, especially beer, soft drink or other beverage bottles, and never re-use empty pesticide containers
- never work alone when handling toxic pesticides
- never eat, drink, smoke, rub your eyes or touch your mouth while working with pesticides, and keep food, drink and tobacco separate from pesticides
- always have soap and plenty of water available, and a clean change of clothing
- always destroy heavily contaminated clothing and faulty protective clothing, especially gloves and respirators
- if spills and leaks occur, decontaminate immediately – remember to wash off the dribs of insecticide concentrate from the outside of drums so they can be handled safely later
- keep unauthorized persons, especially children, away from pesticides – store labourers should be kept out of a store until the sprayed surfaces have dried, and should be encouraged to wear shoes when walking on treated floors
- all electricity supplies to the store should be switched off before spraying begins.

Protective clothing and equipment

- People using protective clothing should understand the reasons why they are wearing it. Dirty, contaminated or defective protective equipment is a source of contamination, therefore, all safety equipment should be washed or cleaned after each day of use.
- Materials should be as light as possible and provide maximum air permeability. A pair of light, durable cotton overalls, which can be washed after use, or a long-sleeved cotton shirt and trousers, kept separate from other clothing, should be worn.
• Gloves should be worn wherever there is a risk of skin contamination. Gloves should be long enough to be worn under the sleeves. Neoprene, PVC or nitrile rubber are preferred. Natural rubber gloves are not recommended as they offer little protection against insecticide in certain formulations. Spills on gloves should be washed off immediately as insecticide can penetrate very quickly.

• Boots should be made of neoprene or nitrile rubber. Trousers should be worn outside the boot.

• A face shield will protect the eyes, face and mouth against pesticide spills, splashes and drift. However, shields give no protection against toxic fumes.

• If protective clothing is not available, wear sensible footwear, place a clean cotton cloth over the mouth and nose, wear a hat or scarf on the head. Wash all items carefully after each day’s use and destroy if items become heavily contaminated.

Contact insecticides used in grain stores

Different formulations of contact insecticide

Many contact insecticides are available in various formulations, and it is important to use not only the correct insecticide, but also the most appropriate formulation for each particular situation. There are several methods by which insecticides can be applied to control insect pests in food commodities. The following formulations are commonly available.

Dilute dusting powders ranging in concentration from 1–5% are mostly used for admixing directly with raw cereal and pulse crops. They are sometimes also used for application to horizontal surfaces such as floors in storage buildings, or to sack surfaces to control walking insects. Dust formulations are unlikely to find extensive use in food aid situations, although they might find application when sheets are placed over a stack to act as a physical barrier against invading insects. In this case the barrier is more effective if the interface between the edge of sheets and floor is dusted. Wettable (water-dispersible) powders are concentrated formulations intended for surface application as suspensions in water to store fabrics and for disinfesting railway wagons, trucks, ships’ holds, barges and other containers. They usually contain 20–80% by weight of the active ingredient.

Liquid concentrates are available in two types: emulsifiable concentrates (e.c.) intended for dispersion in water as an emulsion; and soluble concentrates (s.c.) which are diluted in a suitable solvent such as oil, to form a true solution. Emulsifiable concentrates are used generally for the same purposes as wettable powders, but in addition can be used for direct treatment of grain. Soluble concentrates are employed mostly for fogging, misting and other space treatments. Liquid concentrates may contain 20–80% active ingredient.

The choice between applying an emulsion or wettable powder for surface spraying should depend on the type of surface to be treated. In general, emulsions are considered most effective when applied to non-absorbent surfaces, such as metal, or
wood treated with oil-based paint. Wettable powders, however, are more effective than emulsions on absorbent surfaces such as concrete, brick and unpainted wood as they leave a white crystalline layer on the surface. On such surfaces, emulsions tend to leave less deposit so that little insecticide activity remains. In practice, however, there may be no choice as to which formulation is used, as emulsions are much more readily available than wettable powders. Emulsions are easier to mix and apply, and in addition have a wider field of application in agricultural crop protection generally.

Different types of insecticide

Commercial contact insecticides have at least two names, a chemical name, which is the scientific name and describes the chemical in the spray (e.g. pirimiphos-methyl), and a trade or brand name (e.g. Actellic, Syngenta) given to it by the chemical company. The same chemical, made by different companies will, therefore, have different names (one company may also use different names for the same chemical in different countries, or when presented as different formulations).

Organophosphorous insecticides

Most of the many organophosphorous insecticides that have been developed are of high or moderately high mammalian toxicity. Very few low or moderately low mammalian toxicity are suitable for use in food stores.

Pirimiphos-methyl (trade name Actellic, Syngenta)

Available as dusting powder, emulsifiable concentrate and ULV (ultra low volume) liquid, alone or in combination with permethrin (trade name Actellic Super, Syngenta) or with deltamethrin (trade name Sofagrain, Aventis CropScience). Pirimiphos-methyl is a fast-acting broad-spectrum insecticide with both contact and vapour action. It gives relatively long-lasting control of insect pests on inert surfaces such as wood, sacking and masonry in temperate conditions, and retains its activity when applied to stored agricultural commodities. Pirimiphos-methyl is useful against immature stages within the individual grains, and appears to be effective against many malathion-resistant strains. It can be used effectively against many beetles, especially *Sitophilus* and *Tribolium* spp., moths and mites, although it is not particularly effective against *R. dominica* and *P. truncatus*. The latter two species are more easily killed by synthetic pyrethroids such as permethrin or fenvalerate. To kill a broad range of pests, especially pest complexes where there are both *Sitophilus* spp. and *P. truncatus*, a mixture of actellic and a synthetic pyrethroid is used.

Chlorpyrifos-methyl (trade name Reldan, Dow)

Available as emulsifiable concentrate, ULV liquid and fogging concentrate.

Chlorpyrifos-methyl is a broad-spectrum insecticide of relatively low mammalian toxicity and moderate persistence with contact, stomach and respiratory action. Chlorpyrifos-methyl has a very similar spectrum of activity to pirimiphos-methyl, and controls a wide spectrum of storage pests including beetles, weevils, moths, mites,
and also several species with malathion resistance, although it is not effective against resistant strains of some bostrichid beetles.

**Fenitrothion (trade names Folithion, Bayer; Sumithion, Sumitomo; Accothion, BASF)**

Available as emulsifiable concentrate, wettable powder, granules, dusting powder, ULV liquid and aerosol. Fenitrothion is a broad-spectrum insecticide used worldwide against pests of field crops, public health, forestry and storage. Fenitrothion has been widely used for grain protection in a number of countries for at least 20 years. It is effective against most stored grain pests, although it is not fully effective against *R. dominica*. Fenitrothion is sometimes combined with pyrethrum or synthetic pyrethroids, for example, with fenvalerate.

**Dichlorvos (trade names Nuvan, Syngenta; Vapona, BASF)**

Available as emulsifiable concentrate, aerosol, granules, hot fogging concentrate, cold fogging concentrate, impregnated strips and oil-miscible liquid. Dichlorvos was introduced as an insecticide in the mid 1950s and has been widely used against stored-product, household, public health and field crop pests. It is an insecticide and acaricide (kills mites) with vapour, contact and stomach action, giving rapid knockdown. Dichlorvos is characterized by its high vapour pressure and its high insecticidal activity in the vapour phase. Dichlorvos can be applied as a space treatment in non-ventilated stores using a mist sprayer. The sprayer may be controlled by a time clock so that the treatment can be applied automatically to coincide with the time of maximum insect activity, usually early evening. Use of an automated timed application avoids the hazard of exposure to dichlorvos by operators and warehouse staff. It is useful for disinfesting grain brought into storage with live insects. Dichlorvos is very active against a wide spectrum of stored product pests, including larval stages within the grain and against moths. It has a short residual stability, particularly at higher temperatures and high moisture levels.

**Malathion (trade names Cythion, BASF; MLT, Sumitomo; Agrothion, Syngenta)**

Available as emulsifiable concentrate, wettable powder, dusting powder, ULV liquid and aerosol. Malathion has been widely used in many countries for over 30 years. It has been employed against a broad spectrum of pests in agricultural, forestry, public health and food storage situations. Although it is possibly one of weakest of all the organophosphorous insecticides against stored-product pests, it has been responsible for saving enormous quantities of grain and other stored products from destruction. Malathion is still important in many parts of the world despite the development of strains of some pest species that are resistant. In the tropics it has now been largely superseded by pirimiphos-methyl (Actellic).
Carbamates

**Carbaryl (trade name Sevin, Aventis CropScience)**

Available as wettable powder, dusting powder, bait, suspension concentrate, granules and oil-miscible flowable concentrate. Carbaryl is an insecticide with contact and stomach action and has been used to control moths, beetles and other insect pests on more than 120 different crops. Although carbaryl is not particularly effective against the full spectrum of stored-product pests, it gives good control of *R. dominica* and thus can be used in conjunction with approved organophosphorous insecticides. Carbaryl is cheap, readily available and has a low acute and chronic mammalian toxicity.

**Bendiocarb (trade names Ficam, Aventis CropScience; Garvox, Aventis CropScience)**

Available as granules, wettable powder, suspension concentrate, dusting powder, ULV liquid, aerosol and seed treatment. Bendiocarb is a contact and stomach-acting insecticide that has been used against a wide range of insects, including cockroaches, ants and flies in public health, food processing and handling, household, public transport and industrial situations. It is also effective against the major stored-product insects and is sometimes used as a surface treatment, but is not generally accepted for use on grain.

Natural pyrethroids

**Natural pyrethrum**

Pyrethrum is the oily extract from the flower of pyrethrum, *Tanacetum cinerariifolium*, and refers to the plant, flower or the crude, concentrated or refined extract. Pyrethrum has been known as a natural pesticide for many generations, having localized usage, and has been used for protecting grain and destroying grain pests for at least 50 years. Pyrethrum has a very low acute oral toxicity allied with a rapid knockdown action against a wide variety of insects. One disadvantage, however, is that insects that are rapidly immobilized by pyrethrum and ‘knocked down’ often recover after several hours, as they have the ability to detoxify the small amount of pyrethrum they receive. To overcome this, synergists such as piperonyl butoxide, or small amounts of other contact insecticides such as synthetic pyrethroids, are added to pyrethrum sprays to enhance their effect and reduce costs. A second potential disadvantage of pyrethrum is that it is not very stable and its insecticidal activity is rapidly lost from treated surfaces, particularly in the presence of direct or indirect sunlight. It is, however, useful for treating an active infestation and, if used in combination with a synergist or organophosphorous insecticide, can provide residual protection in bulk grain. Pyrethrum is effective against the spectrum of stored-product pests including moths and their larvae, although where the control of moths is the major requirement, unsynergized pyrethrum preparations are most cost-effective, for synergists do not improve the effectiveness of pyrethrum against moths.
Synthetic pyrethroids

*Permethrin (trade names Ambush, Syngenta; Talcord, BASF; Eksmin, Sumitomo)*

Available as emulsifiable concentrate, wettable powder, ULV liquid, aerosol, dusting powder and water-dispersible granules. Also available in combination with pirimiphos-methyl. Permethrin is a stomach and contact insecticide, effective against adults, larvae and eggs of insect pests, including those of field crops, public health, animal house and storage situations. Permethrin is used to control a wide range of stored-product pests, but it is most useful in conjunction with organophosphorous insecticides, as it is relatively weak against non-bostrichid beetle species. The combination of organophosphates and permethrin can be used to control insects that are tolerant or resistant to organophosphates. The efficacy of permethrin can be increased significantly by combining it with the synergist piperonyl butoxide.

*Deltamethrin (trade name K-Othrine, Aventis CropScience)*

Available as emulsifiable concentrate, wettable powder, ULV liquid, suspension concentrate, granules, dusting powder and fogging concentrate. Also available in combination with pirimiphos-methyl. Deltamethrin is used against pests of agricultural field crops, public health, forestry, animal houses and stored-product situations. Deltamethrin is one of the latest synthetic pyrethroids to be introduced, and is very stable. It is highly potent against the majority of stored product pests, being effective at low doses in the range of 1–2 mg/kg.

*Fenvalerate (trade names Sumicidin, Sumitomo; Fenkill, United Phosphorous; Sumitox, Aventis CropScience)*

Available as emulsifiable concentrate, ULV liquid and suspension concentrate. Fenvalerate is an insecticide and acaricide with contact and stomach action. It controls a wide range of pests on agricultural field crops and in public health situations, including those resistant to organochlorine, organophosphorous and carbamate insecticides. Fenvalerate is registered in many countries in Europe, Asia and the Americas, and also in Australia where it has undergone silo-scale field trials as a stored-grain protectant. Fenvalerate has been shown to be effective at low doses against *R. dominica* and at higher doses against most other storage pests. It is used in combination with organophosphorous insecticides (e.g. malathion or fenitrothion) and can be synergized with piperonyl butoxide.

*Bioresmethrin (trade name Isathrine, Aventis CropScience)*

This is available as emulsifiable concentrate, aerosol, ULV liquid and wettable powder. Bioresmethrin was one of the first successful synthetic pyrethroids developed in the 1960s. It is a potent contact insecticide producing rapid knockdown against a wide range of insect pests. It has been used against cockroaches, flies and mosquitoes in household and food premises and also as a grain protectant and disinfectant. Bioresmethrin is synergized by a factor of between two- and ninefold by piperonyl butoxide. It has proved particularly effective against *R. dominica*, and can
be used in combination with organophosphorous insecticides against grain pests, enabling the amount of organophosphorous insecticide applied to be reduced considerably. It is used mainly in Australia.

DEVELOPMENT OF RESISTANCE TO CONTACT INSECTICIDES AND FUMIGANTS BY PESTS

Within any pest population, susceptibility to contact insecticides or fumigants will vary from individual to individual. At the recommended dosage rate all individuals will be killed, but a suboptimal treatment will fail to kill those insects least susceptible. The survivors will quickly develop a population of less-susceptible individuals that will require, on average, a slightly higher dose to kill. In this way, repeated inadequate treatments may result in populations resistant to pesticides.

It is vital that pesticides are used correctly, as alternatives are either more expensive or not available.

From time to time pest control treatments will fail, and it may be claimed that the reason is that the insects are resistant. This is unlikely, and the most probable cause is that the treatments were not undertaken according to current recommendations. To check if resistance is the cause of the observed result you should:

(a) Check that all the procedures used in the treatment conform strictly to recommendations.

(b) If there are no obvious errors, samples of the insects should be cultured on the grain in question for at least 4 weeks to ensure all developmental stages are present in the grain. If the problem is an insecticide treatment, it will be necessary to proceed directly to (c). If a phosphine fumigation failed, a bioassay can be undertaken at the next fumigation. Some of the insect culture is placed in several porous containers such as finely woven cotton bags or fine metal mesh tubes. The containers are introduced into the fumigation enclosure at the start of fumigation. They are removed at the end and then monitored over sufficient time, typically at least 4 weeks, for any surviving larvae/eggs to emerge to indicate fumigation failure. It is important that gas concentration measurements are made during this fumigation.

(c) If complete kill is not achieved, the insect culture should be sent to a laboratory able to undertake a resistance test.

IMPORTANT MANAGEMENT CONSIDERATIONS TO ENSURE SUCCESSFUL AND COST-EFFECTIVE PEST MANAGEMENT IN BAG STORES

Enforce pest control rules

Contractors frequently undertake fumigations and insecticide spraying on behalf of store managers. It is important to ensure that they operate according to standards
laid down as part of their contract. Staff should check that the contractors meet these standards.

In the case of fumigation, the critical points to bear in mind are that there should be enough gas beneath the gas-proof sheet for long enough to kill 100% of all life stages of the pests. Anything less than 100% kill is a fumigation failure. For stocks held at about 25 °C and above, it is currently recommended that:

- the fumigation duration is not less than 5 days (120 h)
- the minimum gas concentration on the fifth day is at least 150 ppm.

This is a good standard and is achievable under normal bag storage conditions provided the fumigation contractor uses recommended procedures. The initial dosage rate of phosphine gas should be about 2 or 3 g per tonne of commodity (this is equivalent to two or three 3 g tablets of aluminium phosphide). Some contractors might be tempted to achieve the necessary minimum gas concentration on the fifth day by using a higher dosage rate at the start, hoping that this will compensate for a poor gas-tight enclosure. This would be counter-productive as excessively high initial concentrations of phosphine can induce a narcosis in the insects, resulting in a much lowered insect susceptibility, and hence survival.

Sometimes contractors suggest that the dosage rate should be varied according to the degree of pest infestation. This is a common misunderstanding. The dosage rate remains the same irrespective of the degree of infestation, as a minimum gas concentration is required for a minimum duration and the number of pests present does not affect these parameters.

In the case of insecticide spraying, it is important that the recommended dosage rate is used and that the volume applied to walls and floor is sufficient to give some run-off so that cracks and crevices are treated. Spraying should be done only as a hygiene measure in empty stores prior to the entry of new stock, or in association with a fumigation to prevent immediate re-infestation of stocks from insects hiding in the store fabric as soon as fumigation sheets are removed.

**Treat the whole store**

It is good practice to fumigate all the stock in a store at the same time. The reason for doing this is to avoid insects moving from untreated stacks onto those that have just been treated once the sheets are removed.

**Avoid fumigating lined bags**

Insects do not normally infest commodities held in polythene-lined bags, although damage to these sacks may allow their entry. Also, insects may hide in stacks of these bags when migrating from commodities held in unlined bags. Often, due to constraints of space, commodities in lined and unlined bags are held in the same stores. As a matter of good practice all stocks are fumigated at the same time; thus
the store manager is paying for the fumigation of lined and unlined bags even though the insect threat to lined bags is minimal. Avoiding the treatment of lined bags substantially reduces the need for fumigation, and can be achieved by placing lined bags in a separate store. Alternatively, stacks of lined bags could be covered with an insect-proof barrier as soon as they are built. Such barriers can be made of cotton or polythene sheeting secured around the base with sand snakes. To operate, this procedure will require stacks built to a standard shape and size so the covers can be prepared in advance.

Avoid fumigating bags of flour

Milled products such as flour are very compact, so it is difficult for phosphine to penetrate them. Also, being finely divided, they offer a huge surface area for adsorption so that much fumigant activity can be lost. For these reasons fumigation of flour is not recommended. Most finely divided products will, in any case, be in lined bags that prevent sufficient phosphine from entering for an effective fumigation.

Ensure floor joints are filled

Sometimes the floor joints in stores are not completely filled, so there are deep channels in the floor. During fumigation, these channels will allow gas to escape from the gas-tight enclosure. It is important that all floor joints should be filled with a bitumen/sand/cement mixture so that they are level with the floor surface.

Reduce the number of very large or very small stacks

Very large stacks (2000–3000 tonnes) can be very hard work for fumigation teams as they involve joining a number of fumigation sheets, often in constricted, awkward or precarious locations. Although a good fumigation team should be able to cope with this, the more difficult the fumigation, the greater the chances of it failing. Adopting a maximum stack size for unlined bags, in consultation with fumigation contractors, is a sensible precaution. Conversely, there may also be many very small stacks that are the residues of larger consignments. These are proportionally more expensive to fumigate than large stacks, and take up a disproportionate amount of space in store. Every effort should be made to reduce the number of small stacks.

Do not keep bags of grain dust

At the discharge of bulk grain from ships, dust is collected and bagged separately. The dust may then enter a store in the harbour area and remain there until it can be disposed of as animal food, or destroyed. During the period that it remains in store it is subject to fumigation. This poses two problems: first, being a dust and, therefore, highly compact, it is very difficult to achieve a fully successful fumigation. Second, dust stacks are usually about 5–10 tonnes and are, therefore, too small for stand-alone, cost-effective fumigation, unless they can be included with the fumigation of a larger stack. Instead, dust should be treated as waste, disposed of immediately after bagging and never enter a store. Alternatively, if this cannot be done, then dust
stacks should be covered with an insect-proof barrier (see ‘Avoid fumigating lined bags’ above) and maintained in this way without fumigation until they can be discharged.

**Do not fumigate in windy weather**

Windy weather is detrimental to fumigation. Wind moving across a store reduces the pressure within it. This has the effect of drawing the fumigant gas out from beneath the sheeted stack. Fumigations should not be undertaken in windy weather.

**Ensure good fumigation of locally purchased stocks**

Some stocks may be obtained from local suppliers. Such stock is frequently fumigated prior to delivery, although such fumigations have often been observed to be failures. The result is that stock will soon need to be re-fumigated at considerable cost. In order to reduce costs, it is recommended that the supplier should not undertake fumigation of the stock prior to delivery. Instead, an approved contractor should fumigate the stock, and the cost of this fumigation should be charged to the supplier.

**KEEPING GOOD RECORDS OF PEST MANAGEMENT**

Awareness of pest management problems often comes from a knowledge of the frequency of application of pest control procedures. All fumigations and insecticide spraying should be noted on the reverse side of the stack card of each bag stack. Several times each year, the frequency of pest management operations should be checked to ensure that pest control is being undertaken to an acceptable standard.

**FURTHER READING**


Food aid commodities in store are particularly vulnerable to attack by rats and mice, and to a lesser extent by birds. Most attention in this chapter is given to rodents, as they comprise the main vertebrate threat to stored produce.

Apart from the food eaten, spoiled or contaminated, there are additional ‘invisible’ losses such as the replacement or repair of packaging materials and the cost of re-bagging spilled food. Much of the spillage arises when rodents attack food packaging to obtain nesting material; stacks of heavily infested bagged foodstuffs may ultimately collapse. Rats and mice gnaw inedible materials including electrical wiring, so their presence in buildings can constitute a fire hazard.

Many different types of rodents are capable of transmitting diseases to people, but the three main commensal species (Table 14.1) are of particular public health importance because of their association with human settlements, their worldwide distribution, and the link they can provide between people and other carriers of infection. Rodent-borne diseases can be transmitted either directly by bites, through the air or the handling of rodent carcasses; or indirectly through contact with food and water contaminated with rodent droppings and urine, or by infected blood-sucking arthropods. Some of the diseases carried by rodents are given in Table 14.2, together with details of the causal organisms and the mode of transmission to people.

Rodent control is essential for public health, but can often be justified on the value of damage to goods. Most countries recognize the importance of controlling disease, but legislation for rodent control varies greatly and practical implementation is often lacking. For the control of rodents in food stores, the use of chemicals, trapping, proofing and improved hygiene are all necessary. The use of potentially dangerous rodenticides requires special care both for effectiveness and safety. It is important to remember that the objective for the control of rodents in stores is to obtain a 100% elimination of the target population. Lower levels of mortality will allow the residual population to recover rapidly to pre-control levels as a result of the high breeding potential of rodent populations. Any successful rodent management operation consists of four main components:

- surveying the problem
- management of the food store environment and rodent-proofing
RODENT BEHAVIOUR RELATED TO CONTROL OPERATIONS

An understanding of those aspects of rodent behaviour that relate directly to control and management is essential if cost-effective control is to be achieved.

Nocturnal activity

All the commensal rodent species are nocturnal, that is, they are largely active during the night, although some diurnal activity is present in most populations. This is relevant to control only insofar as it means that not seeing rodent activity during the day does not mean there is not a significant rodent population present. The assessment of the size and activity patterns of rodent infestations depends not on seeing the rodents, but on developing the skills to assess the infestation from the tracks and traces they leave behind. Thus developing surveying skills is an essential part of a control strategy.
### Table 14.2  Some important diseases of man transmitted by rodents

<table>
<thead>
<tr>
<th>Disease (and causal organism)</th>
<th>Primary carrier</th>
<th>Secondary carrier</th>
<th>Transmission</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viral haemorrhagic fever, e.g. Lassa fever (several viruses)</td>
<td>Many rodents, including commensals</td>
<td>None</td>
<td>Contact with infected rodents and their excreta, can be airborne, occasionally bites from infected insects and mites</td>
<td>Worldwide</td>
</tr>
<tr>
<td>Murine typhus (Rickettsia typhi)</td>
<td>Many rodents, including commensals</td>
<td>Fleas (notably Xenopsylla cheopis)</td>
<td>By way of flea faeces rubbed into fleabites or abrasions</td>
<td>Tropics and subtropics</td>
</tr>
<tr>
<td>Scrub typhus (Rickettsia tsutsugamushi)</td>
<td>Many rodents, including commensals</td>
<td>Larvae of the mite Leptotrombidium spp.</td>
<td>Though the bite of infected mites</td>
<td>S.E. Asia, East and S. Pacific</td>
</tr>
<tr>
<td>Rickettsial pox (Rickettsia akari)</td>
<td>Rodents, especially mice</td>
<td>Mite Allodermamyssus spp.</td>
<td>Through the bite of infected mites</td>
<td>Worldwide</td>
</tr>
<tr>
<td>Plague (Yersinia pestis)</td>
<td>Many rodents, including commensals</td>
<td>Fleas (notably Xenopsylla cheopis)</td>
<td>Through the bite of infected fleas, through broken or abraded skin when handling infected rodents</td>
<td>Worldwide</td>
</tr>
<tr>
<td>Tularemia (Francisella tularensis)</td>
<td>Many rodents, including commensals</td>
<td>Occasionally ticks</td>
<td>Handling infected rodents or contact with contaminated water</td>
<td>Worldwide</td>
</tr>
<tr>
<td>Leptospirosis/Weil’s syndrome (Leptospira spp.)</td>
<td>Many rodents, especially rats</td>
<td>None</td>
<td>In rat urine. Through broken or abraded skin. Stagnant water may be infective</td>
<td>Worldwide</td>
</tr>
<tr>
<td>Rat-bite fever (Spirillum minus)</td>
<td>Rats and some other rodents</td>
<td>None</td>
<td>Through the bite of infected rats</td>
<td>Worldwide</td>
</tr>
<tr>
<td>Food poisoning (Salmonella spp.)</td>
<td>Various animals</td>
<td>None</td>
<td>Commonly through contamination of food by rodents’ faeces</td>
<td>Worldwide</td>
</tr>
<tr>
<td>Trichinosis (Trichinella spiralis)</td>
<td>Norway rats</td>
<td>Pigs</td>
<td>Pigs are commonly infected through eating dead rats, or rat droppings, and man by eating infected pork</td>
<td>Worldwide</td>
</tr>
<tr>
<td>Tapeworm (Hymenolepis spp.)</td>
<td>Various rodents</td>
<td>None</td>
<td>Contact with rodent faeces through food or surroundings</td>
<td>Worldwide</td>
</tr>
</tbody>
</table>
Neophobia

Neophobia is the ‘avoidance or fear of new objects’. The most obvious neophobic responses are reported in Norway rats, where in the late 1940s neophobia was identified as being a major constraint to achieving effective control, and the technique termed ‘pre-baiting’ was identified as one method to overcome this problem. It has since become clear that even within Norway rats the response to new objects varies. This variation in response is related to a number of variables, the most important being the stability of the rat’s environment. For instance, Norway rats living on a rubbish tip where everything may change on a daily basis are likely to exhibit a much lower level of neophobia than those living around a grain store where activity and change may be minimal. This neophobic response has been used to explain differing levels of efficacy of anticoagulant baits, both in terms of rats’ reluctance to feed on the baits themselves, but also on their reluctance to enter bait containers with which they are not familiar. Thus neophobic responses in Norway rats affect the consumption and thus the efficacy of rodenticide baiting programmes.

Research on Norway rat feeding behaviour suggests that they tend to feed from a relatively few (three or four) feeding points during the night. Thus the establishment of familiar feeding points at which the rats are able to consume relatively large amounts of any rodenticide bait are more likely to achieve effective control. The house mouse, in contrast, shows generally low levels of neophobia. Mice like to investigate new objects in their environment, and appear to become bored very quickly, thus feeding very little from any one point. Typically, a house mouse is reported to feed from some 30 different feeding points in a night, consuming very little from any one feeding point.

In stores, which are generally very stable environments, it is essential when baiting for rodents to take into account both the concept of neophobia, and the variability between and within species. This requires the establishment of large numbers of bait points for house mice, and far fewer but more strategically placed bait points for rats. The most effective strategy for rat control might be to place baiting containers prior to the development of infestation, so that they are there when the rats arrive and do not initiate a neophobic response.

Hoarding and food removal

A characteristic shared by all the commensal rodents is their habit of removing food from where they find it and taking it to somewhere where they can feed on it more safely. This behaviour is often confused with hoarding, and may indeed be a part of hoarding behaviour. In many instances, however, it simply reflects the determination of a rodent to protect the food from being eaten or taken by other rats. The activity does have a significance for our control operations, in that removal of rodenticides by rodents and their subsequent placement in another area has the potential to both contaminate food in the store and give non-target species access to the rodenticide.
**Territoriality**
Commensal rodents live in small social or family groups. Norway rats live in groups of about 8–14, in which age is the primary determinant of dominance. House mice live in slightly smaller groups of about 5–8, in which a dominant male attempts to control the group. Each group will attempt to control the territory in which it resides and will exclude intruders. These territories are maintained by regular patrols and by scent marking with urine, faeces and excretions from scent glands. With this in mind, it is clearly essential to identify all areas where rodents may be active in and around a storage facility before applying baits and other control techniques. In this way, a thorough application of control measures should ensure all territories are adequately covered. Thorough mapping of activity assists this assessment.

**Communication**
In addition to the communication mentioned above associated with territory marking, communication between rodents is largely undertaken through ultrasonic ‘language’ whose frequency is outside the human hearing range. There may not be a great deal of sophistication associated with this sound, but basic sounds signifying fear and well-being are certainly communicated. The ability to communicate ultrasonically is reinforced by a very high sensitivity of hearing. Rodents have a sensitivity of hearing which is some three to four times more acute than humans, leading to their appreciation of approaching danger well in advance of our own.

**Taste and smell**
Rodents have a very acute sense of taste and smell and react to familiar and unfamiliar ones, reinforcing their ability to recognize new or old objects in their territory. They are also able to relate such tastes and smells with experiences that they may have experienced. For instance, if a food has caused pain or discomfort soon after its consumption, the same taste or smell will be avoided in the future. This is called ‘induced avoidance’ and can lead to what is called ‘shyness’ to foods, baits, poisons and other control techniques or experiences which may have caused discomfort, pain, shock or fright. The ability of rodents to avoid experiences that they have not enjoyed, but have nevertheless survived, reinforces their very strong learning ability. This leads to a learned avoidance of many active control techniques that are used in rodent control, particularly the acute rodenticides.

**SURVEYING THE PROBLEM**
Those undertaking control need to have a comprehensive understanding of the nature of the infestation with which they are dealing. The variability of rodent problems and the variety of possible control methods are such that the first essential task is a thorough survey. The objective of the survey must be to build up a picture of the infestation that is as complete as possible, and should ideally be recorded on a simple map. The subsequent application of environmental management and control techniques can then be specific to the areas of activity and the
susceptibilities of the environment. It is essential to remember that storage environments are, by their very nature, three dimensional, therefore, all survey and subsequent control must take account of the degree to which the three-dimensional habitat is being used by the species of rodent involved. It is perfectly possible for more than one or two species to be infesting the same storage facility. If this occurs it is usually because the species in question are not competing for resources, usually food, water or harbourage. If competition does occur, the larger and more aggressive species will usually exclude or even predate upon the weaker.

The survey should, if appropriate, extend to property adjoining the food store, to make sure the whole of any infestation present has been discovered and can be dealt with at one time. The survey needs to show what species of rodents are involved (Tables 14.1 and 14.3); the extent of the infestation; where rodents are living, feeding and drinking; and the routes they use in moving from one place to another. The control technique is so specific to the behaviour, biology and susceptibility of rodent species that successful control is unlikely to be achieved without this knowledge. The most reliable way of identifying rodent species will be through live or dead specimens; however, other signs and traces that rodents leave behind can also enable species identification (Table 14.3). The possible risks of contaminating foodstuffs with rodenticides and of poisoning other animals and people must also be assessed. All this information is needed for effective and safe rodent control, including the prevention of future trouble. For preventative measures such as proofing and improved hygiene to be fully successful, the existing and potential access routes and sources of re-infestation must be identified.

**Store location**

The chance of a food store becoming infested is partly determined by the size and proximity of neighbouring rodent infestations and the nature of the terrain between. A detached store, especially if surrounded by roadways, is less liable to infestation than one surrounded by other buildings. An urban store in the commercial or wharf area is particularly liable to infestation. These facts should be considered when a site for a new food store is being chosen.

With existing stores, some important improvements may be made in the immediate vicinity. All potential rodent harbourage, such as piles of unwanted building materials, damaged containers, packing cases, waste paper and floor sweepings, should be removed completely and their further accumulation prevented. An open area around a store, even if narrow, will act as a partial barrier to rodent movement and will facilitate routine inspection to ensure the building is kept free from rodent pests.

**Store management and hygiene**

The most important hiding places for rodents in food stores, apart from the fabric of the building, are within stacks of commodities. Canned foods are not vulnerable to rodent attack, and wooden boxes are also fairly resistant, but sacks made of plastic,
Table 14.3  Signs of infestation of the three main commensal rodents

<table>
<thead>
<tr>
<th>Sign of infestation</th>
<th>Rattus norvegicus (Norway/ship rat)</th>
<th>Rattus rattus (roof rat)</th>
<th>Mus musculus (house mouse)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Droppings</td>
<td>Large (up to 18 mm long) and normally pointed, often in groups.</td>
<td>Medium sized (up to 15 mm long) blunt and frequently curved, scattered.</td>
<td>Small (up to 3 mm long) and generally widely scattered but may be concentrated in favoured places.</td>
</tr>
<tr>
<td>Runways</td>
<td>Often clearly discernible outdoors over earth, through grass or undergrowth. Indoors, tend to be around walls.</td>
<td>Less evident than those of the Norway rat except at roof height inside buildings.</td>
<td>Only readily seen in dusty places unless the species is particularly abundant.</td>
</tr>
<tr>
<td>Urination pillars</td>
<td>None</td>
<td>None</td>
<td>Caused by mice urinating regularly on a particular spot. The pillars are indicative of intensive territory marking, particularly where immigration or invasion is likely.</td>
</tr>
<tr>
<td>Smears</td>
<td>Greasy marks most commonly indoors around walls near ground level but loop smears (which characteristically are unbroken) may be found beneath roof trusses.</td>
<td>Mainly found at ceiling height. Smears beneath roof trusses commonly appear as broken loops.</td>
<td>Found on frequently traversed objects. Smears near trusses are usually similar to those of the Norway rat, but smaller.</td>
</tr>
<tr>
<td>Foot and tail marks</td>
<td>Particularly evident outdoors in damp and muddy places. Commonly found inside buildings in dusty places.</td>
<td>Only commonly found indoors along the dusty tops of walls and rafters.</td>
<td>May be found, after diligent inspection, in dusty places or in finely divided foods.</td>
</tr>
<tr>
<td>Holes</td>
<td>About 75–100 mm in diameter leading into extensive burrow systems.</td>
<td>Prefers a climbing way of life but sometimes burrows underneath buildings and rocks, particularly in the absence of the Norway rat.</td>
<td>Small 20–30 mm in diameter and not usually obvious. Burrows inside stacked foodstuffs, in wall crevices and sometimes in earth.</td>
</tr>
<tr>
<td>Smell</td>
<td>Different rodent species generate their own particular smell. These smells are difficult to describe other than as ‘musty’ but are recognizable to those who have been undertaking rodent control for some time.</td>
<td></td>
<td></td>
</tr>
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paper or cloth and fibreboard cartons are easily penetrated. Rodent damage to packaging not only causes spillage losses, it also entails repair or replacement costs.

Foodstuffs that are liable to rodent damage should, where possible, be kept in relatively small stacks with sufficient space around to allow easy inspection. Where it is necessary to have large stacks, these too must have access all around. Stacks left undisturbed for very long periods are most likely to become a breeding ground for rats and mice.

Bulk storage of grain is advantageous in preventing damage by rodents, which find it difficult to burrow into, and live in, large masses of grain. Additionally, bulk storage structures are usually easier to make rodent-proof.

The floor around stacks of food commodities should be regularly swept and kept clear of spilled food and accumulated packing materials. When waste material cannot be disposed of immediately by burning or removal from the site, it should be stored temporarily in rodent-proof containers such as metal dustbins.

**Rodent-proofing**

Rats and mice can often be completely excluded from a food store by blocking all unnecessary openings that are accessible to rodents with materials that are proof against gnawing, such as sheet metal and concrete, and by covering all necessary openings, such as ventilators and windows, with suitable gauge wire netting or expanded metal. The exclusion of mice requires special care because an adult house mouse can work its way through a crack only 10 mm wide. To be certain of keeping out mice, no opening in excess of 6 mm should be left unsealed.

The need to block all openings can sometimes be avoided by placing barriers on rodent access routes. For example, where rodents are entering a store beneath the eaves and can reach the top of the wall only by means of an overhead cable, it is much simpler to attach a rodent guard to the cable than to screen all the space under the eaves. Most of the points where rodents can enter a building will be revealed by a careful survey of the exterior, but rodents may live within the building fabric itself, so it is also necessary to examine the building from the inside.

Modern stores are generally more easily proofed than old buildings, because the points where rodents can enter are usually fewer and because modern structures have fewer places for rodents to live within the building fabric. Newly built stores should be made rodent-proof from the outset, as the incorporation of proofing during construction costs much less than proofing done after the building is complete. The attention of architects and builders should be drawn to the need for rodent-proofing at the design stage of any new food store.
Points of entry

Where large areas of the store interior are made of materials that are easily attacked by rodents, such as earthen floors and wooden walls, the points of entry may be numerous and the necessary proofing expensive (Figure 14.1). There may be a need to concrete the floor and line parts of the walls with sheet metal. A concrete curtain wall some 100 mm thick, extending not less than 600 mm below ground with the base turned out some 300 mm away from the building in the shape of an ‘L’, should prevent rodents from digging under a building. Badly fitting or rotting hinged doors may allow mice or even rats to squeeze underneath (Figure 14.2), or the apertures may soon be enlarged by their gnawing. This can be prevented by fitting a metal kick plate to the base of the door (Figure 14.3). Kick plates should be made from 0.9 mm galvanized iron sheet (not aluminium) approximately 300 mm high, fixed to the outer face of wooden doors and finishing within 6 mm of the threshold or step. Plates should also be fixed to any exposed wooden door frame. Sliding doors are particularly difficult to proof unless they are made very close-fitting, but the erection of a movable metal barrier, 1 m high, inside the doors will prevent the rodents that get through the sliding doors from entering the store itself (Figure 14.4).

Windows, ventilators and eaves are common points of entry, particularly for the roof rat. Expanded metal screens should be permanently fitted to windows and ventilators and the eaves should be sealed with concrete (Figure 14.5). As an added precaution, rats and mice can be prevented from gaining access to the upper part of a building by fitting metal baffles to all pipes and cables that lead to the roof or window level. Baffles should be made of 0.9 mm galvanized iron sheet and should project at least 250 mm from the wall, pipe or cable to which they are fixed.

Figure 14.1 Common points of rodent entry into buildings

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Figure 14.2  Badly fitting or rotting hinged doors

Figure 14.3  Fitting a metal kick plate to the base of the door
Figure 14.4 Movable metal barrier inside doors prevents rodents from entering the store

Figure 14.5 Expanded metal screens permanently fitted to windows and ventilators
Horizontal pipes and cables running between buildings at high level should be proofed with circular metal guards projecting at least 230 mm. All electrical and telephone cable access points must be proofed, and where these are aerial they should be proofed with a cone guard. The holes through which pipes and cables pass into a building can be closed with either concrete or metal plates. Possible entrances from sewers, broken drains or drain covers should also be blocked. Brick or other rough-walled buildings should be proofed by a band of gloss paint on a smooth mortar rendering all round the exterior below window level but at least 1 m above the ground. This makes a barrier too smooth for rodents to climb (Figure 14.4). Paint bands should be at least 150 mm in depth. One coat of primer should be applied prior to two undercoats and a final top coat of hard gloss. Light coloured paints allow easy detection of any marks made by rodents. A trench of at least 300 mm deep and 200 mm wide should be dug around all exterior walls and filled with fine pea gravel – rats will not be able to dig a burrow through the gravel because it will collapse. The trench should be kept free of vegetation.

In all cases, good store hygiene will help reduce rodent immigration into a store. All food spillage should be removed immediately. All potential water sources must be proofed, turned off, isolated or otherwise removed. If this is not possible they need to be regularly monitored for rodent activity.

Some temporary stores are made almost entirely of rubber or soft plastic and are, therefore, readily penetrated by rats and mice. They should be sited well away from possible sources of infestation and, where necessary, should be completely surrounded by a rodent barrier at least 1 m high.

**RODENT CONTROL**

All possible steps should be taken to prevent rodents entering food aid warehouses, because attempting to control them once they are inside presents significant difficulties. The use of chemicals which are toxic to mammals in a food store requires a very high standard of warehouse management and could still carry the risk that some of the food stocks could be contaminated. If management decides it is necessary to use poison baits in a food warehouse, it must contract the services of a reputable company that is able to provide the necessary safety assurances.

The diversity of behaviour within a single rodent population makes the use of several control methods desirable. When it can be seen that a particular method is not very effective, the possible reasons for its failure should be appraised and an alternative method used. Rodent control must always be an adaptable procedure, and a succession of different techniques or combinations of techniques may be required for complete success.
Types of rodenticides

Rodenticides are of two main types: acute and chronic (Table 14.4). Acute rodenticides, such as zinc phosphide, are effective after a single dose. The onset of poisoning symptoms is rapid and death may occur within less than one hour, but any survivors that did not take a lethal dose may display ‘poison shyness’ and subsequently refrain from ever eating the same rodenticide or bait that was used. The success of using acute rodenticides depends on inducing the animals to eat the poisoned bait as rapidly as possible at the first feeding (by pre-baiting) and then using a different method to eliminate any survivors.

A minor class of rodenticides, called the subacute poisons, such as ergocalciferol, are similar to the acute poisons but differ in that the symptoms appear more slowly. Hence a lethal dose need not necessarily be consumed in a single feed, and feeding may continue for 24 h or more. A period of anorexia may be induced in animals that have taken both lethal and sublethal doses. This ‘stop–feed’ action is only a benefit if a lethal dose has been consumed, otherwise death will not occur.

Chronic rodenticides take much longer to act, and they can be taken repeatedly over a period of several days without the development of poison shyness. This type of rodenticide is safer to use than the acute type as it is used at low concentrations in the bait. The chronic rodenticides are anticoagulants, a group of chemicals that prevent blood from clotting and eventually cause death from internal haemorrhage. The chief advantage of a chronic rodenticide is that the rodent eats a lethal dose long before it becomes too ill to feed. Provided all the rodents eat enough bait, a complete kill is assured. Exceptions have been found in species where individual animals are more or less resistant to certain anticoagulants. In practice, it is sensible to assume the absence of resistance until evidence is found to the contrary. For reasons of comparative safety, effectiveness and ease of use, one of the anticoagulants should be the first choice before contemplating the use of an acute poison.

Using anticoagulant rodenticides

There are considerable differences in toxicity between the anticoagulant rodenticides available, but in practice they all take about the same length of time to eradicate rodent populations. The earliest anticoagulants, of which the best known is warfarin, became widely used in the 1950s, probably to the exclusion of other rodenticides in many countries. Ready-to-use baits containing anticoagulants such as warfarin have been marketed, but they are comparatively expensive, and do not allow for a change in bait type to suit local circumstances. For this reason it has often been preferred to use a master mix (concentrate) with which to prepare baits locally. A further disadvantage associated with the so called ‘first generation’ of anticoagulants is the large quantity of bait necessary to obtain effective control. Excess bait must be maintained throughout a control campaign, a technique usually referred to as saturation baiting.
### Table 14.4 Chronic and acute poisons used in rodent control

<table>
<thead>
<tr>
<th>Chronic poisons</th>
<th>Sub-acute poisons</th>
<th>Acute poisons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warfarin</td>
<td>Calciferol</td>
<td>Zinc phosphide</td>
</tr>
<tr>
<td>Diphacinone</td>
<td>Bromethalin</td>
<td>Alphachloralose</td>
</tr>
<tr>
<td>Pindone</td>
<td></td>
<td>Sodium monofluoroacetate</td>
</tr>
<tr>
<td>Coumatetralyl</td>
<td></td>
<td>Fluoroacetamide</td>
</tr>
<tr>
<td>Coumachlor</td>
<td></td>
<td>Thallium sulphate</td>
</tr>
<tr>
<td>Chlorophacinone</td>
<td></td>
<td>Red squill</td>
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<tr>
<td>Difenacoum</td>
<td></td>
<td></td>
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<tr>
<td>Bromadiolone</td>
<td></td>
<td></td>
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<tr>
<td>Difethialone</td>
<td></td>
<td></td>
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<tr>
<td>Brodifacoum</td>
<td></td>
<td></td>
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<tr>
<td>Flocoumafen</td>
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</table>

**Chronic poisons**
- **Warfarin**: First generation anticoagulant (LD$_{50}$ = 186 mg/kg for *R. norvegicus*). Mixed with dry bait. Soluble sodium compound used in drinking water.
- **Diphacinone**: First generation anticoagulant.
- **Pindone**: First generation anticoagulant.
- **Coumatetralyl**: First generation anticoagulant (LD$_{50}$ = 16.5). Mixed with dry bait or in powder form as a rodenticidal dust. Not always effective against warfarin-resistant rats.
- **Coumachlor**: First generation anticoagulant.
- **Chlorophacinone**: First generation anticoagulant (LD$_{50}$ = 20.5).
- **Difenacoum**: Second generation anticoagulant (LD$_{50}$ = 1.8). Usually effective against Norway rats which are resistant to other anticoagulant poisons.
- **Bromadiolone**: Second generation anticoagulant (LD$_{50}$ = 1.13).
- **Difethialone**: Second generation anticoagulant.
- **Brodifacoum**: Second generation anticoagulant (LD$_{50}$ = 0.26). High potency used with pulsed baiting.
- **Flocoumafen**: Second generation anticoagulant (LD$_{50}$ = 0.25). High potency used with pulsed baiting.

**Sub-acute poisons**
- **Calciferol**: A naturally occurring fat soluble vitamin. In high doses promotes the absorption of calcium and this leads to calcium deposition in the kidneys and cardiovascular system and death through hypercalcaemia. This process can be slow, taking 2–3 days.
- **Bromethalin**: A pale yellow crystalline solid that works by uncoupling oxidative phosphorylation in cells of the central nervous system causing tremors, paralysis of the hind limbs and convulsion. Relatively rapid acting with death usually occurring in 24 hours.

**Acute poisons**
- **Zinc phosphide**: The most commonly used and most effective of the acute poisons. Usually available as a greyish powder and smelling of garlic. It works through the liberation of phosphine in the stomach causing heart failure and organ damage.
- **Alphachloralose**: A narcotic that slows metabolic processes, resulting in death from hypothermia. Most effective in smaller rodents (mice) and at low temperatures (below about 14 °C).
- **Sodium monofluoroacetate**: Highly toxic to rodents by blocking the tricarboxylic acid cycle resulting in the accumulation of citric acid and respiratory or circulatory failure. Due to its high toxicity and absence of any antidote, its use is strictly regulated in most countries.
- **Fluoroacetamide**: Very similar to sodium monofluoroacetate but slightly less toxic.
- **Thallium sulphate**: A tasteless powder that seems not to induce bait shyness. Its high toxicity and lack of antidote has restricted its use.
- **Red squill**: An extract of a plant, *Urginea maritima*. Causes death by convulsion and banned in some countries. Available in a purified form as Silmurin but both unpalatability and bait shyness reported.
By 1958 the continued use of warfarin led to the development of resistance in Norway rat. This led to the development of other more potent rodenticides which are often referred to as ‘second generation’ anticoagulants. The relatively high toxicity of second generation anticoagulants has caused manufacturers to market them mainly as ready-to-use baits and rarely as master mixes, although liquid concentrates can be found for a number of second generation compounds in some countries. These rodenticides are claimed to be very palatable to rodents and are usually available in granular form, in some cases on a wheat base, or as wax blocks which are primarily intended for outdoor use.

The high potency of the newer anticoagulants means there is no need for saturation baiting techniques. Instead, a pulsed baiting technique should be employed in which the rodenticide is laid in small quantities at more sites than used in the saturation technique, and it is not renewed until after a period of 7 days. This pulsed baiting technique requires fewer servicing visits, and economizes on the quantities of rodenticide used.

Dry situations, as found in food stores, are ideal for presenting specially formulated anticoagulants in drinking water. The poisoned water should be made available to the rodents, preferably from a dispenser to make frequent servicing unnecessary (Figure 14.6). Every effort should be made to prevent access to alternative supplies of water.

Some anticoagulants can also be obtained as a 1% dust, specially formulated to stick to rodents’ feet and fur. The dust should be blown into burrow entrances by a dusting machine and sprinkled along runs in patches about 2 mm deep and 500 mm long. Rodents running over these patches pick up the dust and later ingest it during grooming. Anticoagulant dust is particularly useful when there is a possibility that baiting difficulties may occur, but it must not be used if there is any risk of contaminating foodstuffs. Similar to poisoned bait and water, dust patches should be renewed during the course of a treatment.

Baits for use with anticoagulant master mixes are of two main types. The first and simplest is any readily available dry, ground or crushed cereal which distributes evenly with the master mix. Baits like this are adequate in most situations, provided they are renewed before they become stale or rancid. Second, there are baits that are more attractive, but less easy to prepare. These can be used if the first type of bait has failed, or if experience suggests that it will fail. Such baits include coarse-ground cereals to which has been added a little vegetable oil to make it more attractive and improve the adhesion of the rodenticide to the bait, but this increases the likelihood that the bait will eventually become rancid and unpalatable. Another useful attractant is sugar, which should be mixed in at about 5% by weight. A bait that has often proved very effective consists of whole wheat grains, soaked overnight, drained of excess water and added to the master mix. There are a large number of possible ingredients that can be used successfully in baits, and it is often worthwhile trying out new combinations of locally available materials.
Anticoagulant bait should be placed in piles located so that the rodents will find and eat them before reaching their normal food. Initially, the amount of bait put in each pile should be about 100–200 g for rats and 25 g for mice. Thereafter a surplus should be maintained at all points by revisiting every few days and laying more bait as necessary (Figure 14.7). If the amount needed at any point has been underestimated and the bait has all been eaten, it should be replaced with at least double the quantity.

After about a week of using anticoagulants, the amount of bait eaten should rapidly decline as rodents begin to die, and ultimately should stop altogether. This should occur within 3 weeks for Norway rats, 4 weeks for roof rats, and 5 weeks for house mice, although much will depend on the situation. A few days after feeding has stopped, a fresh survey should be made. If some rodents have not been killed a different bait should be tried, the number of baits and drinking points should be increased, a different rodenticide should be used, and the need for using or extending the use of a dust should be considered.

In some circumstances the bait may continue to be taken by rodents long after the periods given above. This could indicate continuous re-infestation of the site, and evidence of this will generally be visible. Clear signs are fluctuations in the distribution and amount of rodent activity and of newly poisoned rodents on the site, together with evidence of neighbouring infestations. In this situation the proper course of action will be to continue the treatment until it is possible to prevent further
re-infestation by proofing. If feeding on the bait and other rodent activities continue at a gradually increasing level, it is likely that the rodents are physiologically resistant to the anticoagulant. The circumstances should be reported to the appropriate national authority. If no follow-up investigation by a research organization is possible, the survivors should be treated with ergocalciferol or an acute rodenticide. In some cases a more active anticoagulant may be successful. The multi-dose is very effective against rodents, including those resistant to anticoagulants.

Ergocalciferol should be used in the same way as anticoagulants. However, it is even more important to avoid ‘complete takes’ of bait during the first 2 or 3 days of treatment. Baiting should, therefore, be generous and the baits checked daily for the first 3 days. This is necessary because ergocalciferol acts faster than anticoagulants. Any initial shortage of bait may prevent some rodents from eating a lethal dose and hence the possibility that survivors will be poison shy. Rat bait takes should stop after 7–10 days, and mouse takes should be finished within 3 weeks.

**Using acute rodenticides**

These are an obvious choice for rodents found to be resistant to the available anticoagulants. Acute rodenticides may also be needed in situations where speed rather than maximum effectiveness is required. In buildings where inattention to rodent control has led to the build-up of large populations attacking stored food,
further damage will be halted most quickly by using acute rodenticides. However, any advantage gained may very soon be lost if the acute treatment is not rapidly followed by one using anticoagulants for the survivors.

Acute rodenticides, like anticoagulants, are usually mixed with a bait, but they differ from anticoagulants in that best results are generally obtained if unpoisoned baits are laid for 4–8 days before placing poisoned baits. This technique, called pre-baiting, allows the rodents to get used to feeding at a particular place on a particular bait, so that when rodenticides are added they are likely to feed on it readily and rapidly. Rapid feeding can also be encouraged by using moistened bait and avoiding all disturbance in the treatment area.

Of the acute rodenticides listed in Table 14.4, zinc phosphide is probably the most widely used. Sodium fluoroacetate and fluoroacetamide are among the most effective of the acute poisons but are more hazardous than the others and should only be used by experts. There is no advantage in making acute rodenticides available to rodents for long periods; one or two nights is generally sufficient, particularly after pre-baiting. After it has been removed, a few days should be allowed for any rodents that have taken a sublethal dose to become active again, and the area should then be surveyed and unpoisoned baits of a different type laid. When the new bait is being taken, poisoned bait should be laid using a different rodenticide, and this process of pre-baiting and poisoning should go on until full control is achieved.

Mice are sometimes more difficult than other rodents to eradicate. Mice can survive for some time in the absence of drinking water, so the use of poisoned water may not be effective. Control is most often successful when a large number of baiting points are used, because mice prefer to eat from many different sources.

**Fumigation**

Rats and mice are more susceptible than insects to fumigants, and treatments with phosphine which are designed to control insect pests will also kill rats and mice. Fumigation of bag stacks under gas-proof sheets will control rodents, but is usually not cost-effective if used solely for that purpose. Rodents living in burrows outside food stores may be controlled using solid preparations of aluminium phosphate which liberate phosphine in the burrow. Not more than 2 g phosphine (two tablets) should be used in each burrow because of the risk of explosion if the soil is very wet. Each hole should be blocked with soil after application of the fumigant. Any holes re-opened by rodents should be blocked and re-fumigated, this process being repeated until no further re-opening occurs.

**Trapping**

Traps are rarely completely effective by themselves, but may be useful to eliminate a few survivors of a rodenticide treatment or for operation in areas where poisons are not allowed. Break-back traps with a treadle are the best type and should be laid
across runs rather than along them (Figure 14.8). To control rats, they should be left unset for a few days until the rats are running freely over them. Traps for mice can be baited and set immediately. Live traps are less effective than break-back traps because most rodents are reluctant to enter the cage, and their use should be discouraged. Glue or sticky traps are another option that can be effective, particularly in relatively inaccessible areas. Rodents will, however, learn to avoid the glue, and many countries have banned the technique on the grounds of humaneness. Traps have a clear part to play in the control of rodents in the food storage environment, if for no other reason than that they are non-toxic and will not contaminate the food. They will be most effective when they are used intensively and placed carefully in areas where rodents are active and carefully integrated with poison campaigns.

**Other non-chemical methods**

Predators such as cats are of little use for rodent control as predation rarely leads to significant reductions in prey populations. Other forms of biological control, such as bacterial preparations (e.g. Biorat based on *Salmonella* spp.) for rodent control, are available in some countries but they are not effective and may give rise to human food poisoning. Such commercial products should be strongly discouraged in food stores.

Several commercial devices emitting ultrasonic noise are available. As rodents communicate in ultrasonic frequencies, these devices claim to drive rodents away from an area. However, there is no evidence that any of these devices work. Other devices that emit electromagnetic fields can also be found that claim to deter...
rodents, but again these devices have not proven effective and their use should be discouraged.

SAFETY PRECAUTIONS

Protection against disease

People carrying out rodent control continually come into contact with rodents and with rodent-contaminated surfaces from which they could be infected with disease. They should, therefore, protect themselves carefully. In particular, live or dead rodents should not be handled unless gloves are worn. All scratches and abrasions need to be treated and kept covered until healed. Local medical officers should be consulted on the advisability of taking further precautions such as immunization against particular diseases.

Protection against rodenticides

Anyone mixing or laying rodenticides needs to be protected. It is recommended that such work be restricted to trained or experienced personnel. Acute poisons and fumigants can be very dangerous if used incorrectly. Actual contact with rodenticides should be avoided at all times. Most can be dangerous if inhaled and a dust mask should be worn when mixing or applying powdered rodenticides. However, a dust mask does not provide protection against poisonous gases. Baits containing zinc phosphide, which gives rise to phosphine gas, should always be mixed in the open air. Plastic or rubber gloves should be worn when mixing rodenticide baits and should be washed before being removed. There should be no smoking and eating in places where rodenticides are stored or prepared for use.

To protect other people, all poisoned baits and the more concentrated forms of rodenticides should be stored in a locked place and, when baits containing acute poisons are laid, everyone should be excluded from the treatment area. All poisoned baits should be clearly marked as dangerous and must not be placed where they may contaminate foodstuffs if displaced or upset. Bait containers like those shown in Figure 14.7 are especially necessary to prevent discovery and consumption by domestic animals or small children.

When treatments are finished, all uneaten poisoned baits should be collected and burnt or buried deeply along with any rodent corpses. If possible, a local medical authority should be informed of the rodenticides being used, so that they can act quickly if cases of accidental poisoning do occur.

Emergency treatment for anticoagulant poisoning

Signs and symptoms of poisoning include diarrhoea, bleeding from nose and gums, blood in excretions, and internal bleeding leading to shock and coma. Anticoagulants act through inhibition of blood clotting. To restore blood clotting, 10–20 mg of vitamin K should be administered by oral, intramuscular or intravenous routes. The daily dose should not exceed 40 mg. Therapy may need to continue for several weeks to
return clotting time to normal. Treatment after poisoning may be necessary even in the absence of symptoms because of the increased tendency to bleed.

**Prevention of re-infestation**

One of the most important and perhaps least applied aspects of rodent control is the monitoring of rodent control operations, and the recording of data which goes with this monitoring. Stores that are rodent-proofed and cleared of infestation can still be re-infested by rats and mice entering through open doors or concealed in consignments brought into the store. There remains a need for alertness and monitoring on the part of workers in the store, to detect and report promptly any signs of new infestations. Regular inspections are necessary to check for signs of re-infestation and to ensure that high standards of hygiene and proofing are being maintained. The extent and degree to which monitoring is necessary will depend on the nature of the problem. Monitoring the activity of rodents in an infestation will provide evidence relating to the progress of the control operation, and starts with the initial survey of rodent activity. The problem with some forms of monitoring is that it may not provide the information required. For example, rodents may not be eating bait from a bait point, but the absence of a bait take does not mean there are no rodents. The baits may not be in the correct place, or the rodents may simply not want to feed on the baits. Similarly, failure to catch rodents in traps does not mean there are no rodents. For these reasons, it is essential that visual surveys continue throughout the treatment, including the use of a secondary method of survey such as tracking plates. A good method of monitoring for rodents is to use dust, such as sand or chalk dust. Rodents may not have to eat baits or go into traps, but they do usually have to move around. If the dust is placed carefully in rodent runways, they will show footprints or other marks if the rodents move over them. This technique can be used easily when monitoring stacks of food. Bands of dust can be laid around the base of the stack, and any movement into or out of the stack will be evident. If tracks or any other traces are found, efforts should be made to eliminate the rodents before they become established.

If re-infestation is frequent, because of difficulty in proofing the store satisfactorily or the presence of an uncontrolled nearby infestation, a system of permanent rodenticide baiting should be maintained. Anticoagulants should be placed permanently at appropriate sites to attract any newly arrived rodents. In addition, baits should be laid outside the store along routes that migrating rodents are most likely to take, and on any nearby sites that are likely sources of infestation. Permanent rodenticide baiting should monitor for the development of resistance, and rotating different anticoagulant compounds may help reduce the chances of resistance developing.

Effective monitoring permits those managing the control to know how the operation is progressing. Changes can then be made to improve the situation if the control is not working satisfactorily.
BIRDS

Birds are occasional invaders of warehouses, particularly those containing grain. Species that roost or perch within the store, such as pigeons and sparrows, are the major bird pests. However, birds are often seen as more of a problem than they actually present.

Birds cause damage by spillage, consumption and contamination of grain, although the latter is likely to be more of a problem than direct consumption. However, in some instances, sparrows and finches can cause serious problems when small grains such as rice are stored in jute sacks. The birds pick out the grains through the open weave of the sack. Because they tend to prefer those parts of the stack that are well lit by sunlight, their activities are often concentrated on specific parts of the stack. The result is that after several weeks some bags can become slack as a result of continued grain removal, and stack slippage and collapse have been recorded. Droppings and shed feathers may spread diseases such as salmonellosis.

Birds are very effective at exploiting store environments because they are mobile, have a high reproductive rate and learn quickly. In addition, they are often small and, therefore, difficult to exclude, and are active during the day when the food store is open and working. Stores are frequently sited near urban areas which provide a source of birds that migrate readily from the surrounding area into the warehouse. The size of the bird population in a store is directly related to the amount of food available. Thus, controlling the access to food is the primary objective in bird pest management.

Bird control

Before attempting control measures, a good understanding of the nature of the problem should be obtained. Knowledge of bird identity, the nature and extent of the loss or damage, and the cost implications of the damage and control regime are valuable in determining which, if any, control options are appropriate.

Options for control include store and environmental management, culling, exclusion, anti-roosting techniques and scaring. They may be used singly or preferably in combination to achieve the maximum benefit. However, all these methods have advantages and disadvantages, as shown in Table 14.5.

As the size of the bird population depends on food availability, control of the food source is the most effective measure in limiting bird problems. Thus high levels of hygiene that promptly clear all spillage, and exclusion measures that prevent the access of birds to the store, will considerably reduce bird damage. If management is maintained at a high level, significant bird problems should not occur.
Table 14.5 Options for bird control in warehouses

<table>
<thead>
<tr>
<th>Option</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Advice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poisons (avicides)</td>
<td>Fast-acting, lethal, easy to apply</td>
<td>Toxic to non-target species, danger of secondary poisoning if dead birds are eaten, prebaiting increases the amount of food available, immigration*, do not address reasons why birds were present</td>
<td>Not recommended</td>
</tr>
<tr>
<td>Chemosterilants</td>
<td>Easy to apply</td>
<td>Expensive, continuous application needed, danger to non-target species, immigration</td>
<td>Not recommended</td>
</tr>
<tr>
<td>Trapping</td>
<td>Useful for identifying target species</td>
<td>Danger to non-target species, food in traps increases the carrying capacity of the store, immigration, not all species will enter traps, labour is expensive, legislation may restrict use of traps</td>
<td>Useful in some cases but trapping period must be extensive and prolonged</td>
</tr>
<tr>
<td>Shooting</td>
<td>Specific to target species, lethal</td>
<td>Risk of damage to store, immigration, legislation may restrict use of guns</td>
<td>Useful in some cases, but short-term gains may not be sustainable</td>
</tr>
<tr>
<td>Exclusion (blocking holes, netting, curtains)</td>
<td>Blocking is cheap and permanent, netting and curtains usually cost-effective</td>
<td>Nets must have the appropriate mesh size, birds may learn how to get through curtains</td>
<td>Can be very useful</td>
</tr>
<tr>
<td>Anti-roosting (wires, spikes, repellent gels)</td>
<td>Effective against medium-sized birds such as pigeons, wires and spikes are permanent</td>
<td>Not effective against small birds (sparrows) and large birds (seagulls, crows), expensive, gels lose effectiveness when dirty, need skilled labour to install</td>
<td>Wires and spikes can be very useful</td>
</tr>
<tr>
<td>Scaring (visual, acoustic, distress calls)</td>
<td>Relatively inexpensive</td>
<td>Effect short-lived</td>
<td>For maximum benefit scarers must be used unpredictably to prevent acclimation, ultrasonic scarers are not effective, distress calls more reliable if used for short periods</td>
</tr>
<tr>
<td>Predators</td>
<td>Cheap</td>
<td>Effect short-lived</td>
<td>Not recommended</td>
</tr>
</tbody>
</table>

*Dead birds are replaced by immigrants from outside the store.
**FURTHER READING**


CEREALS
Cereal grains such as wheat, rice, sorghum, millet, maize and barley comprise 85% by volume and 50% by value of World Food Programme (WFP) food aid shipments. They are frequently the staple foodstuff and thus of great importance to the beneficiaries in recipient countries. It is necessary, therefore, to ensure all commodities are procured to the most appropriate quality specifications. This is particularly important for the increasing proportion of local or regional purchases. If commodities were not procured to the most appropriate quality standards, they would be difficult to maintain in good condition and would require more intensive management from field logistics staff.

Field staff are advised to check that the procurement quality standards of commodities supplied by donors are suitable for the relevant management systems in place in the receiving country. This will require all appropriate documentation to be available for review. An early examination of the documents relating to grade, pest control and phytosanitary condition will alert field staff to any potential problems associated with acceptability to local government officials and any need for special warehouse management. In particular, where consignments have moisture contents that exceed locally accepted norms, it could be necessary to upgrade the available management skills to ensure that consequent warehousing difficulties are minimized.

Local or regional procurement offers many advantages, not least that it is more likely to provide varieties of food that are more familiar to the recipients, and that it supports developing agribusiness systems. However, it can pose a challenge to quality assurance. Local or regional quality assurance and inspection procedures are likely to be less rigorous than those found in the established international food trade. Additionally, local procurement can result in the bulking of numerous small lots, resulting in a consignment that has an increased risk of heterogeneity for important quality factors. Hence greater vigilance is required when these consignments are received into store.

Maize (Zea mays)
Maize varieties are classified mainly by colour – yellow or white – and by the nature of the endosperm. ‘Dent’ maize has a depression in the crown of the grain caused
by natural shrinkage. ‘Flint’ maize has a harder endosperm layer in this area, which shrinks uniformly during drying so that no depression is formed.

In large-scale roller milling processes the maize grain is degermed before undergoing a gradual reduction process to produce a variety of milled products. The removal of the germ or embryo, which contains a considerable quantity of easily oxidized oil, reduces the development of rancidity which shortens the shelf-life. Whole-grain maize meal processed in hammer mills does not have such good keeping qualities because the embryo and endosperm are mixed thereby facilitating enzymic action and fat oxidation.

Maximum safe storage moisture contents for maize and other commodities are given in Chapter 4.

**Rice (Oryza sativa)**

Rice varieties are generally classified by the shape of the grain and behaviour on cooking. The two principal subspecies are *indica* and *japonica*. The grains of the former are typically longer and more slender than those of the latter. Both subspecies include varieties characterized by glutinous (sticky) and non-glutinous kernels.

The harvested and threshed grain, known as rough rice or paddy, differs from other major cereals in retaining its abrasive husk (approximately 20% of the whole grain by weight). The husk is removed during milling, before whitening, or as a preliminary operation to reduce the shipping volume of grain traded as brown or cargo rice. During the whitening operation, the bran layers and germ are removed to produce a kernel which, in the well milled state, consists almost entirely of endosperm. As the bran contains a relatively high proportion of vitamins, protein and fat, a reduction in the nutritional value occurs in the milling process. This reduction is minimized if rice is parboiled before milling.

In the parboiling process, paddy is soaked in water and is then boiled or steamed before being dried and milled. Water-soluble nutrients, particularly vitamin B₁ (thiamine), diffuse from the bran into the endosperm, improving its nutrient content. Parboiling physically affects the internal structure of the grain, making the kernel tougher and more resistant to milling forces. Consequently, it increases the yield of unbroken kernels.

**Sorghum (Sorghum spp.)**

Most types of sorghum are hybrid varieties which have grains of various sizes, ranging in colour from white to dark brown. Whole-grain sorghum flour does not keep well for the same reason as whole-grain maize flours; domestically, sorghum is normally milled as required. On a larger-scale, sorghum may be decorticated and degermed prior to milling so as to give a flour with a longer shelf-life.
Wheat (*Triticum* spp.)

There are many cultivated species of wheat, with many varieties generally classified by colour and texture. Common wheat (*Triticum vulgare*) includes varieties that give a ‘strong’ flour, suitable for bread-making, and others that give a ‘weaker’ flour, more suitable for pastry, biscuits and cakes. ‘Strength’ relates to the quantity and quality of the protein, mainly gluten, in the flour. *Triticum durum*, known as durum wheat, has a very hard, translucent endosperm and is used in the manufacture of pasta products. Hard wheats are often expensive, and mixtures of hard, medium and soft wheats are commonly milled together to produce the required flour.

Wheat grains are much more easily transported and stored than wheat flour. However, for those programmes that have processing constraints, it can be more appropriate to supply wheat as flour.

**PROCESSED CEREAL PRODUCTS**

Processed cereals and oilseeds such as maize meal, wheat flour, bulgur wheat, pasta and soyabean meal are more easily prepared for consumption by the beneficiaries than are whole grains. However, they are much more susceptible to biological and chemical deterioration because activities such as milling permit interaction between enzymes and fats with other grain constituents and spoilage processes. Processing generally makes the product more susceptible to insect attack. Therefore, these commodities have a shorter shelf-life than whole grains.

Several processed cereal products, particularly those from the USA, may be fortified with minerals and vitamins such as A and B. In instances where the agency distributing the processed grain has control over the local milling process, there are increasing opportunities in-country to fortify the flour with micronutrients that would otherwise be deficient in the local diet.

Bulgur wheat is made from wheat that has been soaked in water, boiled or steamed, then dried. The gelatinous grain is subsequently pearled, cracked and screened to remove most of the bran. Bulgur wheat is fortified with vitamins and minerals which make it comparable to parboiled rice in nutritive value, with similar cooking properties. It has a role as a rice substitute.

Rolled oats are generally made by dehusking the grains which are then moistened and rolled. Some rolled oats may also have been cooked or toasted.

In general, it is easier to store cereals as whole grains for subsequent local milling. The storage of milled or processed products frequently requires a far higher standard of storage management to ensure minimum losses. Commodities with low bulk densities (calculated by dividing weight by volume) require large storage capacities per tonne (Table 15.1). Bulk density will vary depending on whether the commodity is bagged or in bulk, and the nature of the packaging or handling practice.
PULSES

Pulses are a better source of protein than cereals. However, their utilization depends on careful preparation to make them acceptable, safe and digestible. A wide variety of pulses are commercially available, but beneficiary preference is important. The dried pulses that are commonly handled by WFP include peas and many types of beans, including black beans, butter beans, cowpeas (black-eye beans), grams, haricot beans, horse beans, pinto beans and lentils. They are different in size and shape but their basic structure is similar. The outer protective seed coat is indigestible and has little food value. It encloses the two cotyledons and the embryo which contain the sources of energy and nutrition.

Bulk densities of pulses do not vary greatly, normally being in the range 800–900 kg/m³.

Split peas (green and yellow), lentils and grams, from which the seed coat and (usually) the embryo have been removed, are more susceptible to insect and mould attack than are whole pulses. However, as the seed coat has little food value, transportation and storage of split pulses may be more economical. Less prolonged cooking is required, so nutrient and vitamin losses during cooking are reduced. Biological and chemical deterioration are accelerated by milling, hence pulse flours should not be stored for long periods.

Pulses that are stored very dry – below 12% moisture content for beans, and below 11% for peas and lentils – are more likely to break because the seed coat will become brittle and will easily crack. Prolonged storage will generally result in excessive hardness, making cooking more difficult and increasing fuel requirements. Extended preparation time will tend to increase losses of nutrients during cooking and may impair digestibility and acceptability.

Pulses have a calorific value comparable to cereals, but contain more minerals (especially iron) and vitamin B, and are a much better source of protein. This protein lacks certain essential amino acids which have to be supplied by other foods if pulse proteins are to be best utilized. Generally, cereals and pulses are considered to be complementary in the diet.

Table 15.1 Bulk densities of some cereals and cereal products

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Bulk density</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg/m³</td>
<td>lb/US bushel</td>
</tr>
<tr>
<td>Maize</td>
<td>640–750</td>
<td>50–58</td>
</tr>
<tr>
<td>Milled rice</td>
<td>800–900</td>
<td>62–70</td>
</tr>
<tr>
<td>Sorghum</td>
<td>650–780</td>
<td>51–61</td>
</tr>
<tr>
<td>Wheat</td>
<td>680–830</td>
<td>53–64</td>
</tr>
<tr>
<td>Wheat flour</td>
<td>490–560</td>
<td>38–43</td>
</tr>
</tbody>
</table>
BLENDED AND PROTEIN-FORTIFIED PROCESSED FOODS

Various fortified and blended foods have been formulated using cereals, pulses, dried skimmed milk and vegetable oils. One of the first to be developed was corn soya milk (CSM). The protein and vitamin-fortified processed foods, such as soya-fortified cornmeal, are designed for general use in feeding programmes which serve older children and adults in need of additional protein. Several blended foods have been specially designed to provide protein supplements for weaning infants and young children. Comparative energy and nutrient values of some selected food commodities are given in Table 15.2.

The following data are drawn mainly from the USAID Commodities Reference Guide.

- **Corn soya blend (CSB)** – 69.9% processed maize meal, 21.8% defatted toasted soya flour, 5.5% soya oil, 0.1% vitamin premix, 2.0% tricalciumphosphate, 1.0% salt/mineral premix.
- **Corn soya milk (CSM)** – 63% processed gelatinized maize meal, 23.7% defatted toasted soya flour, 5.5% refined deodorized stabilized soya oil, 5% non-fat spray-dried milk, 2.7% mineral premix and 0.1% vitamin anti-oxidant premix.
- **Soya-fortified bulgur wheat (SFBW)** – 85% cracked bulgur wheat, 15% defatted toasted soya grits, minerals and vitamins.
- **Soya-fortified corn meal (SFCM)** – 85% degermed maize meal, 15% defatted toasted soya flour, minerals and vitamins.
- **Soya-fortified sorghum grits (SFSG)** – 85% dehulled degermed sorghum, 15% defatted toasted soya grits.
- **Wheat soya blend (WSB)** – 52.9% bulgur wheat, 20% defatted toasted soya flour, 20% wheat protein concentrate, 4% stabilized soya oil, 2.7% salt/mineral premix, 2% tricalciumphosphate, 0.1% vitamin premix.

Most blended food aid commodities originate from the USA, but others have been developed in Europe. European products consist of a blend of flours (maize, oats, wheat or rice) generally including vitamins and minerals, and may be enriched by soya proteins, milk or vegetable oil. Increasingly, some blended foods originating from African or Asian countries are used in the producing country itself or on a regional basis.

Production of such high-energy protein supplement foodstuffs should be encouraged where feasible and cost-effective. There are many examples:

- **Zambian Heps** consists of a mixture of 58.5% maize flour, 27% soya flour, 9.5% sugar and 5% dried skimmed milk. Manufacturers claim a shelf-life of 3 months. ‘Golden soy’ is a variant with a higher content of soya flour.
Table 15.2 Comparative energy and nutrient values of selected food commodities

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Approximate nutritional value of selected commodities per 100 g edible portion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Energy (kcal)</td>
</tr>
<tr>
<td>Cereals</td>
<td></td>
</tr>
<tr>
<td>Bulgur wheat</td>
<td>350</td>
</tr>
<tr>
<td>Maize</td>
<td>350</td>
</tr>
<tr>
<td>Maize meal</td>
<td>360</td>
</tr>
<tr>
<td>Rice</td>
<td>360</td>
</tr>
<tr>
<td>Rolled oats</td>
<td>380</td>
</tr>
<tr>
<td>Sorghum</td>
<td>335</td>
</tr>
<tr>
<td>Wheat</td>
<td>330</td>
</tr>
<tr>
<td>Wheat flour</td>
<td>350</td>
</tr>
<tr>
<td>Pulses</td>
<td></td>
</tr>
<tr>
<td>Groundnuts</td>
<td>330</td>
</tr>
<tr>
<td>Peas and beans</td>
<td>335</td>
</tr>
<tr>
<td>Blended foods</td>
<td></td>
</tr>
<tr>
<td>Corn soya blend</td>
<td>380</td>
</tr>
<tr>
<td>Soya-fortified bulgur wheat</td>
<td>350</td>
</tr>
<tr>
<td>Soya-fortified corn meal</td>
<td>360</td>
</tr>
<tr>
<td>Soya-fortified rolled oats</td>
<td>375</td>
</tr>
<tr>
<td>Soya-fortified sorghum grits</td>
<td>340</td>
</tr>
<tr>
<td>Soya-fortified wheat flour</td>
<td>360</td>
</tr>
<tr>
<td>Wheat soya blend</td>
<td>365</td>
</tr>
<tr>
<td>Milk</td>
<td></td>
</tr>
<tr>
<td>Dried skimmed milk</td>
<td>360</td>
</tr>
<tr>
<td>Dried whole milk</td>
<td>500</td>
</tr>
<tr>
<td>Oils and fats</td>
<td></td>
</tr>
<tr>
<td>Butter oil</td>
<td>860</td>
</tr>
<tr>
<td>Margarine</td>
<td>735</td>
</tr>
<tr>
<td>Vegetable oil</td>
<td>885</td>
</tr>
<tr>
<td>Meat and fish</td>
<td></td>
</tr>
<tr>
<td>Canned meat</td>
<td>220</td>
</tr>
<tr>
<td>Canned fish in oil</td>
<td>305</td>
</tr>
<tr>
<td>Dried salted fish</td>
<td>270</td>
</tr>
<tr>
<td>Fish protein concentrate</td>
<td>390</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td></td>
</tr>
<tr>
<td>High protein biscuits</td>
<td>450</td>
</tr>
<tr>
<td>Iodized salt</td>
<td>0</td>
</tr>
<tr>
<td>Pasta</td>
<td>365</td>
</tr>
<tr>
<td>Protein-enriched ration</td>
<td>450</td>
</tr>
<tr>
<td>Sugar</td>
<td>400</td>
</tr>
</tbody>
</table>
• *Faffa* is an Ethiopian supplementary blend consisting of 57% wheat flour, 18% defatted soya, 10% chickpea, 8% sugar, 5% dried skimmed milk, 1% iodized salt, 1% vitamins and minerals.

• In Malawi, *Likuni phala* comprises 80% ground maize, 10% beans and 10% groundnuts which may be substituted by soyabean.

• ‘Unimix’, which is based on maize, is commonly produced and consumed in increasing quantities in East and southern Africa. ‘Indiamix’, which is primarily 75% wheat and 25% soyabean, has been successfully promoted by WFP in India. Current production is around 25 000 tonnes.

High warehousing temperatures over long periods can reduce the nutritive value of these products, especially the added vitamin content. Flavour and colour may also be affected, and this may influence acceptability. Fortified foods are normally produced to order, thereby avoiding the need for long storage periods. These foods are highly susceptible to attack by insects, although milling and blending processes limit the range of species concerned.

The handling of these commodities, especially those packed in multi-wall paper sacks, requires special care. It is essential to maintain the integrity of the package. Unloading from ships is best carried out using a pallet with a spreader bar. This is preferable to cargo nets. Double- and single-rope slings should not be used. Cargo hooks should not be used on any of these commodities; they should be handled with care and never thrown down when unloading or loading.

The avoidance of wetting during unloading, in transit or in store, is very important. However, experience has shown that with polyethylene-lined paper sacks, even when these have been wetted and the paper badly moulded and rotten, the contents are sometimes sufficiently protected by the plastic liner. Where sacks have become wet they should be dried as quickly as possible, and an examination made to find out whether the contents have been affected by the water. If the contents are mouldy the sack should be rejected and disposed of in an appropriate manner.

**DRIED MILK**

Milk powders are nutritionally valuable as food aid and are readily available from donors. They are usually very dry when packed, and are not normally attacked by insects or micro-organisms provided they remain dry. Storage life is largely determined by the technology of manufacture and the standard and type of packaging.

Milk products are a rich source of protein and supply calcium and certain vitamins. For dried milk powders, compositions similar to those of fresh milk and fresh skimmed milk can be obtained by mixing 100 g whole milk powder or 145 g skimmed milk powder with 1 l of water.

The bulk density of spray-dried powders is related to particle size and air content. It varies greatly between powders from different manufacturers. The usual range is...
0.4–0.9 g/ml, so that a container with a usable volume of 0.0278 m³ holds 25 kg of the heaviest powder, but not much more than 11 kg of the lightest.

The moisture content of milk powders immediately after manufacture is usually in the range 1.5 to 2.5% for drum-dried powders and 2.0 to 3.5% for spray-dried powders. If exposed to damp air they rapidly absorb moisture until, at equilibrium relative humidities of 40–50% (5–7% moisture content), the glassy lactose begins to crystallize. The water liberated by crystallization will further raise the relative humidity within the commodity, causing a greatly increased rate of non-enzymic browning. Crystallization usually also causes the powder to cake into a very hard mass.

Although milk powders do not normally undergo any form of biological deterioration during storage, they are susceptible to chemical changes brought about by fat oxidation and non-enzymic browning.

**Fat oxidation**

Butter fat present in whole milk powders readily reacts with oxygen during storage; a rancid condition (usually described as ‘tallowiness’) develops, and the product will become unacceptable. Low-heat spray-dried whole milk powders have a storage life under temperate conditions (15 °C) of 4–12 months, but under tropical conditions (30 °C) tallowy flavours can develop in 2–6 months. Some of the variation in keeping quality results from undefined differences between batches of powder from different sources. High-heat, spray-dried whole milk powders have a longer storage life, up to as much as 2 years under temperate conditions and perhaps 6–9 months under tropical conditions. Drum-dried whole milk shows a similar increased stability to fat oxidation. The storage life of both these products is not sufficiently long, when packed in air, to guarantee that they will reach the recipient in good condition. The storage life of whole milk powders can be increased by adding anti-oxidants or by packing in gas-tight cans filled with nitrogen. Gas-packaging, although costly, has been adopted in most countries, to avoid adding chemical substances to milk used principally for infant feeding. The use of dried skimmed milk avoids many of these difficulties.

**Non-enzymic browning**

Non-enzymic browning results from the reaction of lactose with protein in the milk. During storage this causes a gradual loss of solubility in the powder, coupled with the production of a stale flavour (variously described as gluey, like burnt feathers or caramelized) and brown in colour. When the powder becomes seriously browned, a loss of nutritional value amounting to 40% of the available lysine may have occurred. These changes may appear in all kinds of milk powder but are most serious in drum-dried and spray-dried skimmed milk powders, although the effects are sometimes masked by tallowiness due to oxidation. Browning proceeds at a rate dependent on moisture content and temperature. It is most rapid when the moisture content exceeds 5% at about 30 °C. The storage life of milk powder, as measured by
browning, is almost entirely dependent on the manner in which the product is packed and protected from moisture absorption. With good packaging, for example, for skimmed milk packed under nitrogen, a storage life of 2 years under tropical conditions is possible. Otherwise the storage life may be as short as 6 months.

The ideal package for milk powder excludes oxygen, water vapour and light. In practice it is difficult and costly to meet all three requirements. Hermetically sealed and gas-packed tins of 0.5–1 kg capacity are generally used for whole milk powders to prevent oxidative deterioration. However, gas-packaging is too costly for skimmed milk powder, which mainly needs protection from water vapour. For family distribution, polythene bags or paper/foil/plastic bags holding about 2 kg of powder are convenient. For distribution to school feeding projects and for community feeding, 25 kg paper sacks are more usual. These vary a great deal in construction and in the protection they afford during transportation and storage. Sacks with a polythene liner of at least 0.1 mm thickness are essential if moisture uptake is to be prevented. Paper sacks without polythene liners provide only a poor water barrier and possess very little wet strength.

**FATS AND OILS**

Oils contain a high proportion of unsaturated fatty acids and consequently are liquid at tropical ambient temperatures; whereas fats, which are composed of predominantly saturated fatty acids, remain solid unless exposed to high ambient temperatures.

The vegetable oils most commonly donated as food aid are soyabean oil, rapeseed oil (canola) and refined palm oil (palmolein). The oil of animal origin most regularly donated as a food aid commodity is butter oil. Some oils may be enriched with vitamin A.

All oils and fats, when initially extracted, contain colouring materials, free fatty acids and other impurities. In this unrefined state they are termed ‘crude’. Refining processes remove colour, free fatty acids and the impurities.

Solid cooking fats, such as margarine, can be obtained from vegetable oils by the process known as ‘hardening’ which converts the unsaturated fatty acids to their more saturated chemical analogues by hydrogenation. This process also reduces susceptibility to decomposition and rancidity. Solid edible fat produced from fish oil makes a substitute for other edible oils or locally produced ghee.

Spoilage in oils and fats is recognized by the development of rancid off-flavours. Keeping them in good condition is mainly a matter of excluding air (oxygen), light (particularly ultraviolet), micro-organisms, moisture, high temperatures and metallic catalysts such as copper and iron. Therefore, properly prepared, pure oil or fat sealed in an air-free opaque container (can or drum) and stored below 20 °C will readily keep for more than a year without deterioration.
DRIED FISH

There are many types of dried fish. Those processed in warm climates will frequently be salted and sun-dried, while the stockfish product of Scandinavia and Canada will be unsalted and wind-dried.

In salted fish, the preservative effect is due mainly to withdrawal of water from the tissues, so that insufficient moisture is available for the growth of micro-organisms. Almost certainly other factors are involved, such as the inactivation of tissue enzymes and the antibiotic effects of high salt concentrations on most bacteria. If the product remains dry there is no danger of microbial spoilage, but dry salt fish takes up moisture very readily, and at relative humidities above 75% the moisture content increases rapidly. Deterioration is mainly due to mould growth, but salted fish can also suffer severe damage due to halophilic bacteria which cause red discoloration and rapid disintegration of the flesh.

Discoloration in fatty fish is commonly due to oxidation of oils present in the fish.

Unsalted, dried fish is readily attacked by both insects and rodents, but hard-cured, dried salt fish is less attractive to these pests. However, dried fish must be regarded as very susceptible to spoilage in warm, damp climates. Fish packed in fibreboard cases without moisture-proofing, or in jute bales, will deteriorate more rapidly than fish packed in well sealed wooden cases. In extreme circumstances the shelf-life could be as short as 3 months. Dried fish should be supplied, where possible, only to countries with climatic conditions favourable for its storage, and canned fish should be reserved for the hot, humid areas. Unfortunately, dried salt fish is often most popular in areas unsuitable for its long-term storage. Rapid distribution is the best solution; otherwise the fish may need to be unpacked, re-dried and re-packed. Dried fish should be separated from other foodstuffs during storage because of its strong smell. A ventilated store that is dry and cool is required. Wooden boxes of salt fish should be kept sealed to prevent moisture uptake unless it is apparent that spoilage has already begun. If the fish has become damp but not spoiled it should be re-dried, if possible, by spreading it in the sun on a suitable rack or platform. It should be re-stacked and covered at night to prevent uptake of moisture.

BISCUITS

Biscuits are sometimes used in feeding programmes involving vulnerable groups or children. The ingredients are basically wheat flour with sugar, vegetable shortening, malt, ammonium and sodium bicarbonate. Vitamins and some minerals may also be added depending on the source. Biscuits may be imported, but are now more commonly baked locally to approved recipes.

A typical analysis would be 9–13% protein, 6–20% fats, and 60–80% carbohydrates. High-protein biscuits may have a 20% protein content.
EMERGENCY RATIONS

Compressed or compact dehydrated food rations for use in emergencies were developed for military purposes, but are now available commercially for food aid. Emergency rations are normally used at the beginning of operations and often comprise vacuum-packed bars of dried food with around 5% moisture.

A recent report by the Institute of Medicine in the USA took the initial premise that a cost-effective emergency ration bar for displaced people in emergency situations should meet the following criteria:

- satisfies all nutrient requirements for a population of all ages over 6 months
- appropriate for use as the sole source of subsistence for up to 15 days
- acceptable to people of any ethnic and religious background
- can be eaten on the move without preparation
- can be pre-positioned in harsh environments for at least 3 years
- can be airdropped.

These commodities typically contain a range of dry or lyophilized (freeze-dried) products which, although expensive, may be useful because of their long shelf-life and low transport costs. Lyophilization involves dehydration of frozen food under vacuum. No chemical additives are used, but the lack of water ensures microbiological safety. Reconstitution is by simple addition of water. The high cost normally limits their use to emergency operations.

An example is the BP-5 compact food ration which provides a nutritionally complete bar of compressed food, based on soya protein and wheat protein, which contains all necessary vitamins and minerals in addition to sufficient energy and protein to restore or retain normal body functions. A 20-foot container can hold 18 tonnes (36 000 units) sufficient to provide a minimum diet, except for water, for 10 000 adults for 1 week. It can be eaten from the packet as a biscuit or mixed with water to form porridge.

FURTHER READING


www.usaid.gov/hum_response/crg/
Canned foods form a small but an important – and expensive – part of food aid distribution. Often they are readily accepted in the diet of the recipients. But a number of problems may arise during their transportation and storage, and these occasionally cause considerable losses.

Canning, as a means of food preservation, is applied to a whole range of products. It involves heating the food to destroy micro-organisms, and the elimination of subsequent contamination by enclosing the product in an airtight container.

As it is the can that protects the food from post-process spoilage, it must be reliable, of good quality and handled with care after processing. The normal material of the container is tin-coated mild steel, but inorganic coatings are now also employed – both are often further covered with lacquers to limit contact between the can and its contents. Aluminium containers are sometimes used, for example, with canned fish. Aluminium cans are corrosion-resistant but not very strong and are, therefore, more easily damaged than tin-coated containers.

Consignments of canned goods should be examined as soon as possible after receipt. There are two objectives:

- to ascertain whether they are fit for human consumption
- to decide whether they can be stored or should be distributed quickly.

Each consignment should be examined according to a sampling plan that, of necessity, will be a compromise between the risks involved in overlooking a defective can, and the work involved in performing a more extensive examination.

Because some canned foods, if improperly processed or damaged, can be much more dangerous than others, two sampling plans are described for the different classes of canned goods. Whichever sampling plan is used, cans that are leaking must be removed (and not distributed), and soiled cans must be cleaned, dried, and re-packed in clean, clearly marked cartons.

Even though damaged cans should not be included deliberately in a random sampling plan (their selection would not be random), any indications of more widespread problems that the damaged cans might give should not be ignored.
For food aid purposes, food in cans can be classified into three broad groups which carry different risks and, therefore, require different handling.

**COOKING OIL AND DRIED PRODUCTS**

No microbial action should occur in cooking oil and dried products because there is insufficient water present to sustain the life cycles of micro-organisms. Oil rancidity, which sometimes occurs, is objectionable because it renders the food unpalatable. Oil in leaking cans should be re-packed into dry cans, which should be completely filled to reduce the presence of air. Excluding water and air helps reduce the development of rancidity.

**CHEESE**

Processed cheese is susceptible to spoilage by spore-forming bacteria (*Clostridium* spp.). The spores are not destroyed by the heat treatment given to the milk or the subsequent processing into cheese. During storage at high temperatures, these spores may germinate. The vegetative cells multiply and produce large quantities of gas. Cans of affected cheese become swollen and, when opened, the contents may smell foul or have a rancid odour depending on the nature of the causative bacteria. Cheese affected by these gas-producing bacteria must not be distributed, and the cause of spoilage should be fully investigated.

Nisin, an antibiotic produced by certain strains of the bacterium *Streptococcus lactis*, which occurs naturally in milk, inhibits the germination of bacterial spores. Its use in food is permitted in many countries. The commercial preparation is added to the cheese during processing at the rate of about 1 g per 10 kg, giving approximately 2.5 ppm of nisin. There is a gradual loss of activity during storage, but this concentration is usually sufficient to prevent *Clostridium* spoilage and is recommended for processed cheese destined for tropical countries.

Processed cheese should be kept as cool as possible. It should not be stored near roof level, or anywhere else where temperatures may be high. Vacuum and headspace difficulties are not common with canned cheese, so swollen cans usually indicate bacterial spoilage.

**FISH AND MEAT**

These products are usually given a far more extensive heat treatment than other foods and are considered ‘commercially sterile’. Cans that are badly rusted or perforated (holed) should be viewed with great suspicion unless the perforations may reasonably be attributed to an identifiable sharp object. Unless clearly due to denting, high altitude (low pressure) or excessive temperature, swollen cans must be treated with great caution.

It is imperative that any canned food that appears defective or in anyway spoiled should not be consumed or even tasted.
MICROBIOLOGY AND CANNED FOODS

Probably the most important bacterium in the canning industry is *Clostridium botulinum*, which must be assumed to be present in all raw materials. It is an anaerobic organism (it can grow in the absence of oxygen, a condition prevailing in canned foods), and on germination and subsequent growth it will produce a virulent toxin characterized in those who ingest it by botulism, an illness that is rare but when, it occurs, often fatal. Modern canning practice demands that there should be a probability of *C. botulinum* spore survival in not more than one in a million million (1 in $10^{12}$).

Fortunately there are a number of conditions that ensure *C. botulinum* spores will not germinate even if they are present after processing. The main one is acidity. *Clostridium botulinum* (and most other pathogenic and spoilage organisms) cannot survive below a pH of 4.5. Very high concentrations of dissolved sugars (as in jams) and rather lower concentrations of certain curing salts (common salt, and combinations of nitrates and nitrites) are effective. There are also various other chemicals that inhibit germination of spores, in particular nisin, the antibiotic used in canned cheese. Spices, smoking and certain fats also give some measure of protection.

Different micro-organisms produce different effects in foods. Many produce gas, but not all do so. Some micro-organisms affect the texture of food, but again, not all do so. Some just produce unpleasant tastes. Whatever the symptoms, toxins are not necessarily present. Conversely it is theoretically possible, but most unlikely, to have toxins present without any sensory indications that the food is spoiled. This increases the need to inspect cans to establish whether the opportunity for spoilage may have occurred.

STORAGE PRACTICE

Proper storage will not make good damage caused by earlier bad handling, but will assist in reducing or preventing further deterioration of the food. Ideally, cans should be kept cool and dry.

Temperature is most important in the storage of cans. Most instances of spoilage of canned goods are due to chemical action, and every 8–10 °C rise in temperature doubles the rate at which chemical reactions occur. The nutrients in the food break down at different rates, but generally these rates increase with temperature. Specific components of the food react to cause various deteriorations in quality. Acids react with the tin-plate, first dissolving the tin and then attacking the food. Nitrate or nitrite will dissolve tin and accelerate this process. These reactions produce hydrogen gas which results in swollen or distorted cans.

High temperatures will also increase the rate of microbiological spoilage. The non-pathogenic, thermophilic (heat-loving) spores that survive processing may germinate at high storage temperatures and cause spoilage. Below 25 °C the risk of germination is minimal, but over 30 °C the risk rises rapidly with increasing temperature.
Temperatures of over 50 °C have been recorded in the centre of cans stacked near the roof in uninsulated stores in the tropics. A further source of spoilage at this temperature is excessive cooking of the can contents. Under humid conditions, high-temperature storage will also cause increased rusting on the outside of cans. At the other extreme, if cans freeze this will affect the colour, flavour and texture of food. Freezing may also distend or burst the seams leading to leaking and spoiled cans.

Water on the outside of cans will lead to rapid external corrosion and ultimately result in perforation and spoilage. Cans that are kept dry will not rust during long periods of storage. In contrast, wet cans may develop visible signs of rusting in as little as 4 h if the storage temperature exceeds 25 °C. Corrosion may begin before the canned goods are received if cans have been exposed to salt spray during shipment. Salt accelerates rusting. This effect may be apparent when cans are stored in warehouses near sea coasts, even several kilometres inland.

The most likely source of moisture on cans is condensation from moist air. Whenever moist air is in contact with cans that are cooler than the air, condensation can be expected. Even in dry climates, it is possible for the air in enclosed spaces to become moist. This can happen with cans stored in polythene wraps. Steady storage temperatures are, therefore, important to minimize movement of moisture. Anything that can be done in practice to reduce temperature fluctuations will help.

Where there is condensation on cartons that contain cans, the cartons themselves are weakened and may burst. Where cans are packed in cases made of unseasoned wood, and such cases are held in large stacks, drying of the container proceeds very slowly in the centre of the stack and the humidity around cans can be high for a long time. Some adhesives employed to stick labels on to cans may absorb water. This can lead to extensive rusting under the label.

It is always preferable to stack cans in cartons rather than stacking them loose. Loose cans will be damaged much more easily and will also accumulate dirt and dust. Correct stacking of cartons will also minimize damage. Cartons of cans are best stacked on pallets up to six or seven layers high. Pallets may be stacked three or four high, giving a height of 20–30 cartons in the stack.

**POINTS TO NOTE IN WAREHOUSE STORAGE**

In order of priority:

1. Every consignment of cans should be examined as soon as possible after receipt. Any damaged or spoiled cans or cartons must be removed before a stack is constructed. Thereafter, there should be a regular inspection of the cans at monthly intervals. Immediate action must be taken if leaking or burst cans are found in the stack or if the stack becomes hot or wet.

2. The warehouse should be dry to minimize rusting of cans.
3. Warehouses should be well ventilated and as cool as possible. Extremes of hot and cold should be avoided, as this leads to condensation. If the warehouse is near a sea coast, it should be constructed and ventilated so that a minimum of air currents from the sea enter the store. A building with a flat roof exposes the interior more fully to outside temperatures than an otherwise similar building with a peaked roof. The risk that drops of condensation water will fall on to the contents is greater in a building with a flat roof.

4. Cartons should never be stacked directly on the floor of the store. They must be on wooden strips or pallets to permit airflow underneath and through the stacks.

5. Cartons should not be stacked against walls because this will reduce the airflow around them, and moisture may migrate from the wall to the cartons and to the cans inside.

6. Stacks of cans should not be higher than necessary. The lower the stack, the easier it will be to make regular inspections.

7. The risk of physical damage to cans must be minimized by always handling canned goods very carefully. The risk of damage may also be reduced by cross-stacking cartons to bind the stack so that it is less likely to collapse.

8. The floor should be strong enough to support heavy loads.

**SHELF-LIFE OF CANNED FOOD**

Food in cans is not inert, and may suffer from either chemical or microbial activity. Both are accelerated at the higher temperatures commonly encountered in tropical climates.

The shelf-life that is probably of most interest to a field officer is the residual shelf-life – the difference between the original shelf-life on completion of the canning process, and the dissipated shelf-life resulting from storage conditions to date. However, in practice neither can be determined with any degree of accuracy.

The original shelf-life of a canned food is affected by its initial quality, the type of food, and the consumer’s requirements and expectations.

The amount of the original life dissipated before receipt by the user is largely the result of the storage time and temperature conditions to which the can has already been exposed. It is unlikely that there will be any record of these. For example, the stowage of cans near to the boiler room of a ship can cause thermal damage to canned food and a drastically reduced shelf-life.
Residual shelf-life

This is also greatly influenced by the conditions to which the food will be exposed in future storage and handling, hence it is difficult to calculate, even if optimum prior handling is assumed. Different foods have different stabilities, and the following gives recommended shelf-lives for properly prepared cans held in temperate storage (about 20 °C). However, the food will retain much of its nutritive value long past these times, and may appear different only through a slight loss of flavour or texture.

2 years  Fish in tomato sauce  
         Fats  
         Tomatoes  
2.5 years Processed cheese  
3 years  Fish in oil  
         Meat  
         Vegetables  
4 years  Corned beef  
         Corned mutton

The best method of assessing the residual life of a canned food is to examine the food when received. If it appears overcooked but is otherwise good, it is best distributed quickly. Otherwise, it may be assumed that it has been favourably treated up to the time of inspection and may be stored if necessary.

In hot climates, every effort must be made to distribute and consume the food within half the shelf-life indicated. When it is possible to choose between canned goods, for storage or distribution, remember that canned cheese is more easily damaged by heat than most other canned goods and may need distributing before other canned commodities.

Black stains, rust, and detinning of the can body are all quite harmless, although they may well be the source of objections. Even if the stains or rust enter the food, there is no danger to the person eating the food.

FURTHER READING

Absorb/absorption The uptake of moisture (water) into a hygroscopic material (such as grain).

Acceptable daily intake (ADI) The daily intake of a chemical which, during an entire lifetime, appears to be without appreciable risk on the basis of known facts.

Acquired qualities Qualities of grain that are additional to the normal complement of intrinsic qualities, the result of changes in intrinsic qualities or the consequence of certain intrinsic qualities being lost or not attained.

Active ingredient The biologically active component of a formulated pesticide.

Adjunct Non-essential additive.

Adjuvant A compound added to a pesticide to increase its efficacy.

Aerobe An organism needing free oxygen for growth.

Ambient Referring to the outside air in the atmosphere as opposed to that in the store or between the commodity.

Anaerobe An organism able to grow in the absence of oxygen.

Angle of repose ‘Natural’ angle between the sloping surface of a heap of grain and the flat surface on which it is placed.

Anisidine value (AV) In an oil, the anisidine value indicates the level of secondary oxidation through measurement of the secondary oxidation products. The secondary compounds are detected by the $p$-anisidine test. Effectively, the AV indicates an oil’s oxidation history (see also Totox).

Anti-nutritive factors (ANFs) In cereals, those components that prevent the uptake of certain nutrients or breakdown by the body’s enzyme system, or make eating a food unpleasant.

Arbitrage The movement of supplies between one place and another until prices come into balance, taking into account transport and financing costs.

Botulism An often fatal disease caused by the ingestion of botulinum toxin produced by the bacterium Clostridium botulinum, which grows in the absence of oxygen, a condition prevailing in canned foods.
Brewers’ grains  The grains of barley which have undergone malting and hot washing, and are used in animal feed formulations.

Buffer stock  Stocks, usually government controlled, built up by purchasing when supplies are ample and prices low, and sold when supplies become scarcer and prices are higher, with the goal of stabilizing prices.

Bulk density  The density (kg/m³) of the grain mass – the grains and air spaces between them.

Bulk handling  The product is moved or held loose as opposed to in sacks or other packaging.

Bulk sample  See Composite sample.

Calibration  The comparison of a meter’s reading to that which is known to be correct in order to determine the meter’s accuracy. In the case of grain moisture meters, the comparison is normally to samples analysed using a laboratory oven.

Calorie  A unit of heat defined as the energy required to raise the temperature of 1 g of pure water by 1 °C. In nutrition, a unit called the diet calorie is used. This unit is equivalent to 1000 calories, or 1 kilocalorie. In the metric system, the kilojoule replaces the kilocalorie (commonly called just calorie) and 1 kilocalorie equals approximately 4.3 kilojoules.

Carbohydrate  Any member of a large class of chemical compounds that includes sugars, starches, cellulose and related compounds. Carbohydrates are produced naturally by green plants from carbon dioxide and water.

Codex Alimentarius Commission  Created in 1963 by FAO and WHO to develop food standards, guidelines and related texts such as codes of practice under the Joint FAO/WHO Food Standards Programme. The main purposes of this programme are protecting health of the consumers and ensuring fair trade practices in the food trade, and promoting co-ordination of all food standards work undertaken by international governmental and non-governmental organizations.

Commodity  The material being transported or stored – grain, fresh or preserved produce.

Composite sample  Sample consisting of mixture of primary samples (may be referred to as a bulk sample).

Condensation  Formation of moisture on a surface, deposited by the air. Occurs when saturated air (100% relative humidity) is further cooled, resulting in the air having to release some of its moisture.

Contaminant  As distinct from foreign matter, a substance that cannot be readily removed from grain.

Crude fat  A total measure of the fat content from all components of the material under study.
Crude fibre A total measure of the fibre content from all components of the material under study.

Crude protein A total measure of the protein content from all components of the material under study.

Decortication Removal of the outer covering of oilseeds or some cereals.

Dehulling Removal of the outer covering of oilseeds.

Dehumidify Remove moisture from the air.

Density General term used to indicate the weight of a commodity for a given volume (kg/m³).

Desorb/desorption The release of moisture (water) from a hygroscopic material.

Dewpoint The temperature to which a sample of air is cooled to become saturated; further cooling will result in moisture being lost from the air.

Dockage A term used primarily in the USA and Canada to describe non-grain material that can be removed from grain using approved cleaning equipment.

Dry basis (d.b.) One method of calculating the moisture content of grain; ratio of weight of water to the dry weight of the grain (see also Wet basis).

Dry-bulb temperature Actual temperature of the air.

Dunnage Any material, such as pallets or wooden poles, that is used to lift a stack off the floor to enable air movement beneath the commodity and prevent ground moisture rising up into the stack.

Endosperm Tissue containing reserve food substances in grains.

Equilibrium relative humidity (e.r.h.) For a sample of grain at a fixed moisture content, the e.r.h. would be reached when moisture in the air is in equilibrium with the grain, i.e. there is no net movement of moisture from or to the grain.

Essential amino acid An amino acid which has an important role to play within a living organism but which cannot be produced by that organism and must, therefore, be ingested in the diet.

Fair Average Quality (FAQ) The condition of a single reference sample which is considered to be representative of a stock of grain. It is a temporary and subjective grading procedure, useful when fairly wide variations in quality can be tolerated.

Fat An organic compound composed of glycerol and fatty acids.

Fatty acid One of a series of acids with the general formula CₙH₂₀O₂, of which some members are found in natural fats.

Feed A formulation of various raw materials given to livestock to provide nutrients and minerals, but which may not necessarily contain all the essential ingredients in the correct proportions.
Glossary

**File sample** Sample set aside in the laboratory to be analysed at a later date in case of dispute over the first analytical results.

**Fish meal** Animal food made from finely crushed fish.

**Foreign matter** Any matter mixed with grain that does not answer to the type description of the grain itself.

**Frass** Insect waste consisting of excrement, faeces, cast skins and sometimes also dead insect bodies.

**Full fat soya** Refers to products made from whole soyabeans which have been processed to rupture their internal oil-containing cells.

**Fumigant** A chemical, for example, a pesticide, that is toxic in its volatile form.

**Gluten** The water-insoluble protein complex extractable from cereal grains.

**Glycerol (= glycerine)** A sweet, viscous liquid compound, a molecule of which forms the ‘backbone’ of fat molecules.

**Grading** Sorting products by size or other quality features in accordance with their appearance, physical condition or market value.

**Haemaglutenins** Blood-clotting agents present in raw soyabeans.

**Halophile** A salt-loving organism that tolerates saline conditions.

**Hermetic** Airtight storage.

**Hydrolysis** Splitting of a compound substance by interaction with water.

**Hygrometer** An instrument used to measure the relative humidity of air.

**Hygroscopic** A material that is capable of absorbing and desorbing water (taking in and releasing moisture).

**Hysteresis** The slight difference in an isotherm depending on whether the grain moisture contents were being increased or decreased at the time the e.r.h. was recorded.

**Impurities** All elements that are considered undesirable in a sample or batch of commodity.

**Infrastructure** Facilities and services, for example, stores, roads, transport, banking and communications services.

**Intergranular** Relating to the air spaces between grains.

**Intrinsic qualities** Qualities possessed by the whole, unblemished fresh commodity.

**Inventory** A record of stocks and supplies in hand.

**Inventory credit** Obtaining finance against stocks of a stored commodity held in an approved and independently managed warehouse.
ISO (International Organization for Standardization) A network of national standards institutes from 145 countries working in partnership with international organizations, governments, industry, business and consumer representatives.

Isotherm The relationship between the moisture content of the grain (in equilibrium with the surrounding air) and the relative humidity of the air at a constant temperature; usually depicted by a graph.

Judgement sample See Purposeful sample.

Laboratory sample Sample extracted from a bulk sample for analysis in the laboratory. In some instances it is the same as the submitted sample.

LD$_{50}$ Lethal dose of a compound which will kill 50% of individuals. This is usually calculated for rats and then expressed as an LD$_{50}$ per kg body weight.

Limiting amino acid That (essential) amino acid which is present in the diet, but in insufficient quantity so as to limit the rate of protein production.

Macro-nutrient A substance providing nourishment which is required in relatively large quantities.

Maximum residue limit (MRL) The maximum amount of insecticide that is allowed on the commodity and is expressed in parts per million (ppm).

Mesophile Organisms that grow at temperatures from 25 to 40 °C – between psychrophilic and thermophilic organisms.

Micro-nutrient A substance providing nourishment which is required in relatively small quantities.

Middlings Grade of commodities, such as flour, of secondary quality or fineness.

Mineral Element or compound occurring naturally as a product of inorganic processes.

Moisture Alternative name for water. Usually relates to water contained on or in a commodity, whereas ‘water’ is used to describe ‘free’ water – rainfall, puddles, etc.

Moisture capacity A measure of how much moisture an object could hold.

Moisture content (m.c.) A measure of how much moisture an object actually holds. Usually expressed as a percentage (see also Dry basis; Wet basis).

Moisture diffusion/diffusivity A measure of how easily moisture can move through something.

Mycelium (pl. mycelia) A mass of agglomerated fungal cells or hyphae.

Mycotoxin Fungal metabolite which when ingested, inhaled or absorbed through the skin causes lowered performance, sickness or death in man and animals.

Non-essential amino acid An amino acid which can be produced within the body and, therefore, does not need to be ingested as part of the diet.
**Glossary**

**Oilcake (oilseed cake)** The product of expelling oilseeds to yield oil.

**Oilseed** Seed of a legume which is grown for its oil content.

**Oilseed meal** The product of expelling and solvent extraction of oilseeds, or the result of grinding oilseed cake after expelling.

**Organoleptic properties** Those properties of a foodstuff or food ingredient which are perceived in the mouth during consumption. The properties include taste, mouth-feel, consistency, texture, chewability, stickiness, etc.

**Pasteurization** The heating of every particle of a product to a specific temperature for a specified period of time without allowing recontamination of the product during the heat-treatment process, followed by rapid cooling.

**Peroxide value (PV)** In an oil, indicates the level of primary oxidation through measurement of the primary oxidation products. Effectively, the PV indicates the current oxidation state of the oil (see also Totox).

**Primary sample** The initial sample obtained from the primary unit. If samples are taken to determine the extent or distribution of insects, the samples should be kept separate. However, primary samples for the determination of quality are usually mixed together to form the bulk sample.

**Protein** A class of organic compounds composed of amino acids, containing carbon, hydrogen, oxygen, nitrogen (and sometimes sulphur); forming an important part of all living organisms and the essential nitrogenous constituent of food for animals.

**Psychrometric chart** A chart illustrating the various properties of air (such as dry-bulb and wet-bulb temperatures, relative humidities, absolute humidities, etc.) at a given atmospheric pressure.

**Psychrophile** An organism that thrives in cool conditions. Optimum growth is typically at 15–20 °C, but some growth may be possible near freezing.

**Purposeful sample** A sample taken from a restricted part of a lot, rather than being representative of the whole lot.

**Quality assurance** Achieving and maintaining agreed expectations or specifications.

**Relative humidity** Measure of the quantity of moisture held by air, expressed as a percentage of what the air could hold at that temperature. Defined as the ratio of the partial pressure to the saturation pressure.

**Representative sample** A sample that is representative of the whole lot, such that analyses of the sample will allow valid conclusions to be drawn as to the condition of the whole lot.

**Safe moisture content** Moisture content with a corresponding e.r.h. of 70% or below – the lower limit for mould growth.
**Sample** A part of a lot removed from the lot for the purpose of quality analysis (see also Primary sample). The sample should be representative of the lot. The sample may be subdivided or reduced on site to the required number of submitted, final lot or laboratory samples. In the laboratory, the submitted sample may be further divided or reduced to one or more working samples. Sometimes duplicate samples may be set aside as file or reference samples which may be analysed at a later date if there is a dispute over the first set of results.

**Saturated air** Air that is unable to pick up any more moisture, that is, air at 100% relative humidity.

**Saturated fat** Fat that has no double bonds within its structure.

**Silo** A vertical store in which grain is held in bulk, as opposed to in sacks.

**Specific density** The density (kg/m$^3$) of the individual grains, not including any air spaces between the grains.

**Standard** An established specification of size and other quality factors.

**Standardization** Arranging for products, or containers, weights and measures, etc., to conform to an established set of size, shape and form specifications.

**Starch** A carbohydrate occurring widely in plants, especially cereals and potatoes, which forms an important part of the diet of humans and livestock.

**Sterilization** The destruction of all micro-organisms in an environment.

**Stockout** Lack of specific stock in an inventory.

**Store** The building in which a commodity is to be kept.

**Stowage factor** The quantity of space occupied by 1 tonne of the commodity (m$^3$/kg). Reciprocal of the bulk density.

**Submitted sample** Sample comprising or extracted from a bulk sample for analysis in the laboratory. In some instances it is the same as the laboratory sample.

**Synergist** A compound added to a pesticide to improve its efficacy, for example, piperonyl butoxide added to pyrethrum sprays.

**Tender** An offer to buy or supply a designated quantity of a product in response to an announcement inviting such offers.

**Thermal capacity** A measure of the ability of an object to store heat.

**Thermal conductivity** A measure of the ability of an object to conduct heat.

**Thermophile** Micro-organisms whose optimum growth temperature is warmer than that seen with most micro-organisms. Such organisms can grow at temperatures above those that denature proteins in most organisms (typically 50 °C), and sometimes up to the temperature of boiling water.

**Thiamine** Vitamin B$_1$, vital for normal development, growth, reproduction, healthy skin and hair, blood production and immune function.
**Toast** The process of heating soyabeans to inactivate their anti-nutritive factors.

**Totox** A measure of the rancidity of an oil. It is derived from the anisidine value (AV) and the peroxide value (PV), which are combined (AV + 2PV) to give the Totox value (TV). TV is an overall indicator of rancidity, and is considered by many investigators to be a useful indicator of oxidation because it combines evidence of the past history and present state of the oil. Acceptable Totox values vary depending on the type of oil, but a figure of about 10 is generally accepted by the oil trade as the upper limit for vegetable oils considered fit for human consumption.

**Trace element** An element that is required in very small quantities.

**Transnational** An enterprise operating in several countries at the same time.

**Trypsin inhibitors** Proteins found in soyabeans and other pulses, which prevent the digestion of soyabean proteins in the intestine.

**Unsaturated fat** A fat that has one or more double bonds within its structure.

**Vitamin** One of a number of substances essential for growth and nutrition, occurring in certain foodstuffs or produced synthetically.

**Warehousing** Provision of a guaranteed storage service in return for a fee. Under an approved warehousing system, a negotiable certificate of storage can be provided under independent supervision. This is acceptable collateral for credit from a bank (see also Inventory credit).

**Water activity (A_w)** Ratio of the water vapour pressure of the food to the water vapour pressure of pure water under the same conditions. It is expressed as a fraction.

**Wet basis (w.b.)** One method of calculating the moisture content of grain; ratio of weight of water to the total weight of the grain (see also Dry basis).

**Wet-bulb temperature** The temperature indicated on a wet bulb of a wet-and-dry thermometer (lower than the dry-bulb temperature as water evaporating from the wet bulb cools the thermometer slightly).

**Wheat feed** A mix of middlings and fine bran for feed use.

**Working sample** A subdivision of a submitted sample which may be too large for analysis.

**Xerophile** An organism able to grow in very dry conditions.
Annex 1

A sampling plan case study

A donor sent 2600 tonnes of cereal grain in bags into a tropical country, which showed evidence of fungal spoilage during inspection at the port. The grain was condemned by the Ministry of Health as unfit for the purpose of food aid and its importation was not allowed. However, the donor was not persuaded that all of the consignment was affected, and so was compelled to enter negotiations with several stakeholders to resolve the impasse and agree a course of action that would hopefully permit some at least of the grain to enter the recipient country.

All parties agreed that samples would be taken that were representative of the whole lot; that these samples would be subdivided between the stakeholders; that the subsamples would be assessed at three different laboratories for a range of quality defects, including insects, fungi, yeasts, moisture content and mycotoxins; and, most importantly, that a clean bill of health for part of the consignment would be accepted as evidence of that part’s fitness-for-purpose, thus allowing part salvage. The stakeholders also agreed the quality criteria (levels of mycotoxins, numbers of insects, etc.) against which the results would be judged.

After advice from the Natural Resources Institute, the parties agreed on a sampling plan. Table 9.1 was used as a guide. The cereal was on pallets, and had been separated into ‘damaged’ and ‘clean’ lots. As the cereal was in piles of 30 bags on pallets, there were about 1733 pallets.

1. The pallets were divided into five parcels of 347 each, and each parcel was given an identification letter for future reference (A–E). Each parcel weighed about 520 tonnes.

2. The primary unit was a bag.

3. 130 g of cereal was taken from one randomly selected bag from every pallet within parcel A, using a sampling spear.

4. The 130 g samples were combined to give a primary sample of about 45 kg.

5. This process was repeated for parcels B–E.
6. A subsample of 4 kg was taken from the primary sample in each parcel by coning and quartering.

7. This was further subdivided to give 4 x 1 kg samples, one for each of the three laboratories and one retained in case additional tests were requested. These samples were used for assessment of insects, moisture content and quality parameters.

8. The balance of the primary sample (41 kg) was subdivided to give 4 x 10 kg samples, again one for each of the three laboratories and one retained in case additional tests were requested. These samples were used for assessment of fungi, yeasts and mycotoxins.

9. Thus every laboratory received 1 kg of grain and 10 kg of grain for each parcel.

The results of the sampling exercise revealed the presence of some insects and mycotoxins, but these were below the levels set by the stakeholders, so most of the consignment was allowed into the recipient country. Only those bags that showed signs of heavy mould growth, which would have been rejected by beneficiaries on the grounds of appearance, were diverted to animal feed.
Annex 2

Pesticide toxicity and maximum residue limits

If pest control operations result in stored food being contaminated with pesticide, it is important to know what residues are acceptable. In some circumstances insecticide is admixed with stored food. However, this is not normal practice for food aid shipments, which would be expected to be nominally free of any pesticide residues. However, in the tropics subsistence farmers are sometimes encouraged to admix pesticides, so that it is possible for locally purchased grain to carry pesticide residues.

Information on the toxicity of an insecticide to insects and to mammals is often available. Ideally, an insecticide should have very high toxicity to the target insects and zero toxicity to everything else. In practice, there is often a compromise between these objectives and other desirable properties of contact insecticides. Three commonly used ways of expressing how toxic insecticides are to mammals are as follows.

- **LD$_{50}$** – lethal dose which will kill 50% of individuals. This is usually calculated for rats and then expressed as an LD$_{50}$ per kg body weight (Table A1). This gives a measure of the relative toxicity of different insecticides, and is one consideration when calculating the other measures given below. The higher the number in the table, the safer the insecticide is to humans.

- **Maximum residue limit (MRL)** – this is the maximum amount of insecticide allowed in the commodity, and is expressed in parts per million (ppm) (Table A2). This measure takes into account the processing of the commodity that will occur before it reaches the end consumer, and the amount of commodity likely to be eaten by the consumer. Thus whole grains are often allowed a higher MRL than flours, as insecticides on the surfaces of whole grains are largely confined to the bran during flour production. Note that residues of stable pesticides can remain in the commodity from pesticide applications made when the crop was in the field. It is even possible for very persistent pesticides, such as DDT, to contaminate a crop grown in soil where treatments were applied to a previous crop. Another possible source of contamination is from other uses of pesticides, such as vector control (control of disease carrying insects). Blanket spraying against vectors, however, such as spraying mosquitoes with DDT, is in decline because of concerns about residues.

- **Acceptable daily intake levels (ADI)** – this refers to the total amount of insecticide that a human can consume every day during an entire lifetime that appears to be without appreciable risk (Table A2). This is calculated on the basis of known facts. As new knowledge is acquired, ADIs can go either up or down.
Greater awareness of the significance of pesticide residues in recent years has increased legislation regarding the use of pesticides. This has also affected the trade of food commodities between countries, as MRLs can be used to limit what is acceptable for import. It is essential that exporters are aware of the legislation of the importing country, and that they know the history of any commodity being exported. Every 2 years a committee of experts from the FAO (Food and Agriculture Organization of the United Nations) and the WHO (World Health Organization) meet to consider submissions for the use of particular pesticides on particular foods. This meeting is called the Joint Meeting on Pesticide Residues (JMPR). This committee reviews data on the toxicology of pesticides and the residues arising from good agricultural practice, so that it can make recommendations on acceptable MRLs. Toxicological data reviewed can include studies on the long-term impact of chemicals on reproduction in rats, and assessments of nerve activity and brain structure. The JMPR makes its recommendations to the Committee on Pesticide Residues of the Codex Alimentarius Commission.

Table A1  \(LD_{50}\) for insecticides associated with protection of stored products (some are now not registered with Codex)

<table>
<thead>
<tr>
<th>Insecticide</th>
<th>Acute oral (LD_{50}) (rats) (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organophosphorus group</td>
<td></td>
</tr>
<tr>
<td>Bromophos</td>
<td>3750–8000</td>
</tr>
<tr>
<td>Chlorpyrifos-methyl</td>
<td>1630–2140</td>
</tr>
<tr>
<td>Dichlorvos</td>
<td>56–80</td>
</tr>
<tr>
<td>Etrimfos</td>
<td>1600–1800</td>
</tr>
<tr>
<td>Fenitrothion</td>
<td>570–800</td>
</tr>
<tr>
<td>Iodofenphos</td>
<td>2100</td>
</tr>
<tr>
<td>Malathion</td>
<td>2800</td>
</tr>
<tr>
<td>Methacrifos</td>
<td>678</td>
</tr>
<tr>
<td>Phoxim</td>
<td>1976–2170</td>
</tr>
<tr>
<td>Pirimiphos-methyl</td>
<td>2050</td>
</tr>
<tr>
<td>Tetrachlorvinphos</td>
<td>4000–5000</td>
</tr>
<tr>
<td>Carbamate group</td>
<td></td>
</tr>
<tr>
<td>Bendiocarb</td>
<td>40–156</td>
</tr>
<tr>
<td>Carbaryl</td>
<td>850</td>
</tr>
<tr>
<td>Pyrethroid group</td>
<td></td>
</tr>
<tr>
<td>Natural pyrethrum</td>
<td>584–900</td>
</tr>
<tr>
<td>Bioresmethrin</td>
<td>&gt;2500</td>
</tr>
<tr>
<td>Deltamethrin (decamethrin)</td>
<td>128</td>
</tr>
<tr>
<td>Fenvalerate</td>
<td>451</td>
</tr>
<tr>
<td>Permethrin</td>
<td>4000–6000</td>
</tr>
<tr>
<td>(d)-Phenothrin</td>
<td>&gt;10 000</td>
</tr>
<tr>
<td>Insect growth regulators group</td>
<td></td>
</tr>
<tr>
<td>Methoprene</td>
<td>&gt;34 600</td>
</tr>
</tbody>
</table>
Some chemicals that are sometimes used on stored food, but are not recommended for this purpose by the JMPR, include phoxim, tetrachlorvinphos, bendiocarb and fenoxycarb.

Quantification of toxicity and regulations for the use of grain protectants are generally limited to commercially available products. Natural products such as botanicals are often thought to be non-toxic or inherently safer. This is not necessarily the case, and it is important that the toxicity of all grain protectants is assessed to avoid unnecessary health risks for those applying such materials and for the consumer.

Contact insecticides approved for use with food aid commodities generally combine high toxicity to insects with low toxicity to mammals, but they all have a measurable mammalian toxicity. The acute oral toxicities to rats (Table A1), expressed as the acute LD$_{50}$, are the figures most frequently quoted. They are a useful guide to toxicity to humans, and are particularly useful in assessing the dangers of handling or applying particular insecticides. Those with low acute LD$_{50}$ values (e.g. less than 100 mg/kg body weight) must be handled with special care, or preferably avoided.

Many countries have their own established limits for residues of insecticide permitted in foodstuffs and these levels must not be exceeded. Food aid staff need to be aware of any such local regulations. Only where local standards and residue limits have not been specified should the FAO/WHO limits be used, and even then they must be regarded as guidelines subject to the approval of the national government.

### Table A2  Maximum residue limits (mg/kg or ppm of commodity) and acceptable daily intake levels (mg/kg or ppm of consumer’s body weight) based on the April 2000 edition of the Codex Alimentarius (FAO–WHO)

<table>
<thead>
<tr>
<th>Insecticide</th>
<th>Maximum residue limits</th>
<th>ADI*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cereal grains</td>
<td>Raw wheat bran</td>
</tr>
<tr>
<td>Carbaryl</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>Chlorpyrifos-methyl</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Deltamethrin</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Fenitrothion</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Fenvalerate</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Malathion</td>
<td>8</td>
<td>20</td>
</tr>
<tr>
<td>Methoprene</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Permethrin</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Pirimiphos-methyl</td>
<td>10</td>
<td>20</td>
</tr>
</tbody>
</table>

*Acceptable daily intake (ADI) of a chemical is the daily intake which, during an entire lifetime, appears to be without appreciable risk on the basis of known facts. Some chemicals that are sometimes used on stored food, but are not recommended for this purpose by the JMPR, include phoxim, tetrachlorvinphos, bendiocarb and fenoxycarb.
Annex 3

Recommended warehouse equipment

Warehouses may not need all items if, for example, they are sited near major towns with access to commercial pest control companies, or can share equipment with other warehouses on the same site.

Table A3  Recommended warehouse equipment

<table>
<thead>
<tr>
<th>Item</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Storage and handling</strong></td>
<td></td>
</tr>
<tr>
<td>Platform scales, Avery 500 kg non-digital</td>
<td>Good for transit centre; too large for extended delivery points (EDPs), not good for reconstitution</td>
</tr>
<tr>
<td>Platform scales, 300 kg</td>
<td>Better size, cheaper for EDPs, better for reconstitution</td>
</tr>
<tr>
<td>Salter scales (hanging 100 kg)</td>
<td>Portable, widely used, good for reconstitution</td>
</tr>
<tr>
<td>Forklifts</td>
<td>Electric/diesel 2.5–3 tonnes</td>
</tr>
<tr>
<td>Hand jacks</td>
<td>Hydraulic</td>
</tr>
<tr>
<td>Wheelbarrow</td>
<td></td>
</tr>
<tr>
<td>Pallets</td>
<td></td>
</tr>
<tr>
<td>Plastic sheeting in rolls</td>
<td></td>
</tr>
<tr>
<td>Storage tents</td>
<td></td>
</tr>
<tr>
<td>Containers</td>
<td></td>
</tr>
<tr>
<td>Tarpaulins</td>
<td></td>
</tr>
<tr>
<td>Ladders</td>
<td></td>
</tr>
<tr>
<td><strong>Reconditioning/salvage and reclamation</strong></td>
<td></td>
</tr>
<tr>
<td>Empty bags, 50 kg polypropylene</td>
<td></td>
</tr>
<tr>
<td>Empty bags, 25 kg plastic</td>
<td>For blended foods, e.g. corn soya blend</td>
</tr>
<tr>
<td>Empty bags, 100 kg jute</td>
<td>Depends on region</td>
</tr>
<tr>
<td>Bag stitcher/sewing machine</td>
<td>Must have adequate spares and manuals</td>
</tr>
<tr>
<td>Buckets</td>
<td>Reconstitution equipment should not be used for general cleaning</td>
</tr>
<tr>
<td>Brooms</td>
<td></td>
</tr>
<tr>
<td>Shovels</td>
<td>Snow shovels in some countries</td>
</tr>
<tr>
<td>Needles</td>
<td></td>
</tr>
<tr>
<td>Thread</td>
<td></td>
</tr>
<tr>
<td>Funnels</td>
<td></td>
</tr>
<tr>
<td>Jerry cans</td>
<td>5, 10, 20, 25 l</td>
</tr>
<tr>
<td>Sieves/screens</td>
<td>Sack sieve, hand sieves</td>
</tr>
<tr>
<td>Scoops</td>
<td></td>
</tr>
<tr>
<td><strong>Inspection/quality control</strong></td>
<td></td>
</tr>
<tr>
<td>Sampling spear</td>
<td></td>
</tr>
<tr>
<td>Torches</td>
<td></td>
</tr>
</tbody>
</table>

Note: Good for transit centre; too large for extended delivery points (EDPs), not good for reconstitution.
<table>
<thead>
<tr>
<th>Item</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture meter</td>
<td></td>
</tr>
<tr>
<td>Sample bags</td>
<td></td>
</tr>
<tr>
<td>Vacuum cleaner</td>
<td></td>
</tr>
<tr>
<td>Waste disposal/garbage drums</td>
<td></td>
</tr>
<tr>
<td>Cleaning equipment</td>
<td>Not to be used for reconstitution – brooms, dust pan, etc.</td>
</tr>
<tr>
<td>Paint and paint brushes</td>
<td></td>
</tr>
<tr>
<td>Dust mask</td>
<td></td>
</tr>
<tr>
<td>Sealing tape</td>
<td></td>
</tr>
<tr>
<td>Safety/security equipment</td>
<td></td>
</tr>
<tr>
<td>Generator (5–32 kVA)</td>
<td>For lighting and bag stitcher</td>
</tr>
<tr>
<td>Heaters</td>
<td></td>
</tr>
<tr>
<td>Water tank with hand pump</td>
<td>500–1000 l</td>
</tr>
<tr>
<td>Fuel tank</td>
<td></td>
</tr>
<tr>
<td>Hand pump for fuel</td>
<td></td>
</tr>
<tr>
<td>Security alarm</td>
<td>Battery powered</td>
</tr>
<tr>
<td>Padlocks</td>
<td>Heavy duty</td>
</tr>
<tr>
<td>Spotlights</td>
<td></td>
</tr>
<tr>
<td>Razor wire</td>
<td></td>
</tr>
<tr>
<td>Mobile toilets</td>
<td></td>
</tr>
<tr>
<td>First aid kits</td>
<td>Include stretchers, backboard, eyewash</td>
</tr>
<tr>
<td>Smoke detector</td>
<td></td>
</tr>
<tr>
<td>Fire extinguishers</td>
<td>ABC type</td>
</tr>
<tr>
<td>Empty drum</td>
<td>To fill with water/sand for firefighting</td>
</tr>
<tr>
<td>Tools</td>
<td></td>
</tr>
<tr>
<td>Measuring tape</td>
<td>50–100 m</td>
</tr>
<tr>
<td>Tool box</td>
<td>Basic with pliers, hammer, etc.</td>
</tr>
<tr>
<td>Electric drill</td>
<td>For repairing pallets</td>
</tr>
<tr>
<td>Electric saw</td>
<td>For repairing pallets</td>
</tr>
<tr>
<td>Machetes</td>
<td>Brush/foliage clearing</td>
</tr>
<tr>
<td>Bolt cutter</td>
<td>For opening container seals</td>
</tr>
<tr>
<td>Pest control</td>
<td></td>
</tr>
<tr>
<td>Fumigation sheets</td>
<td>Various sizes, 20 x 30 m and smaller sizes</td>
</tr>
<tr>
<td>Sand snakes</td>
<td>In sufficient numbers to seal fumigation sheets</td>
</tr>
<tr>
<td>Phosphine meter</td>
<td>Electronic</td>
</tr>
<tr>
<td>Gas detector tubes</td>
<td>For phosphine</td>
</tr>
<tr>
<td>Gas sampling line</td>
<td>For phosphine meter</td>
</tr>
<tr>
<td>Gas face masks</td>
<td></td>
</tr>
<tr>
<td>Gas face mask filters</td>
<td></td>
</tr>
<tr>
<td>Aluminium phosphide tablets</td>
<td>For phosphine fumigation</td>
</tr>
<tr>
<td>Pirimiphos-methyl</td>
<td>For treatment of store surfaces by trained staff</td>
</tr>
<tr>
<td>Knapsack sprayers</td>
<td>For insecticide treatment of store surfaces</td>
</tr>
<tr>
<td>Mousetraps/rat traps</td>
<td>For use by trained staff</td>
</tr>
<tr>
<td>Rat poison</td>
<td>For use by trained staff</td>
</tr>
<tr>
<td>Overalls/protective clothing</td>
<td></td>
</tr>
<tr>
<td>Rubber gloves</td>
<td></td>
</tr>
<tr>
<td>Rubber boots</td>
<td></td>
</tr>
</tbody>
</table>
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