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Introduction

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In this chapter traditional methods of storing grain at producer level and in entrepreneurial warehouses are briefly reviewed. The greater part of the chapter is devoted to describing 'improvements' or developments of grain storage at these levels.

It is often stressed that traditional storage methods are the product of decades, if not centuries of development, perhaps by trial and error, but certainly as a result of experience of the users and their ancestors. This maxim must, in general, be upheld as true and would-be 'developers' should employ utmost respect for traditional practices when endeavouring to introduce 'improvements'. Traditional storage methods at producer level are usually well adapted to both the types of grain for which they are intended, and the environment in which they are employed. Consequently, storage losses are often already minimal and it is difficult to justify interference with the established system.

However, for a number of reasons, this is not always the case. In the first instance, it is well known that rural communities are very conservative in their attitude towards change. Thus, if such a community is uprooted, perhaps as a result of conflict, and is forced to move into an environment which is very different both climatically and geographically from that to which they are accustomed, it may take them a long time to adapt or change their grain storage practices accordingly. This is almost certainly the case in central and eastern parts of Zambia (author's personal experience), where the 'traditional' basket type of store is not the best form of grain container for local climatic conditions).

Secondly, a growing shortage of the materials traditionally used for the construction of grain stores (usually caused by extended use of such materials) may force rural people to seek alternative means of storing grain. This is the case in the Anatolia region of Turkey, and in Lesotho where ancient grain storage practices have virtually disappeared, because of the depletion of supplies of suitable timber and/or grass.

Thirdly, but by no means unimportant, the introduction of high-yielding varieties of grain (which are usually more susceptible to infestation by insects than traditional varieties) and the spread of exotic insect pests of grain (e.g. Prostephanus truncatus) through trade or aid have disrupted erstwhile effective storage practices, to the extent that they have had to be abandoned or at least considerably modified with outside assistance.

Traditional grain traders throughout the world have tended to depend upon fairly rapid turnover of stocks as a means of minimising losses due to pests and other factors. Consequently, their storage facilities vary in quality and condition. With the advent of Government intervention and the establishment of quasi-government grain marketing organizations in many countries, especially during and immediately after the Second World War, the importance of good grain storage facilities and management became apparent. Most of the 'improvements' in warehouse design are associated with such enterprises. The recent tendency to revert to private grain marketing and storage has high-lighted the need for improving the standards of storing and managing grain stocks at this level. Hopefully, the suggestions and recommendations for improving warehouses given in this chapter will help in this regard.

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Such methods are quite often associated with the drying of the crop, and are primarily intended to serve this purpose. They assume the function of storage only if the grain is kept in place beyond the drying period.

(i) **Aerial Storage** (Ref: FAO,1987, fig.6(a))

Maize cobs, sorghum or millet panicles are sometimes tied in bundles, which are then suspended from tree branches, posts, or tight lines, on or inside the house (Figure 6.1). This precarious method of storage is not suitable for very small or very large quantities and does not provide protection against the weather (if outside), insects, rodents, or thieves.

(ii) **Storage on the ground, or on drying floors**

This method can only be provisional since the grain is exposed to all pests, including domestic animals, and the weather. Usually it is resorted to only if the producer is compelled to attend to some other task, or lacks means for transporting the grain to the homestead.

(iii) **Open Timber Platforms**

A platform consists essentially of a number of relatively straight poles laid horizontally on a series of upright posts. If the platform is constructed inside a building, it may be raised just 35-40 cm above ground level to facilitate cleaning and inspection. Platforms in the open may be raised at least 1 metre above ground level. They are usually rectangular in shape, but circular or polygonal platforms are common in some countries.

Grain is stored on platforms in heaps, in woven baskets or in bags. In humid countries fires may be lit under elevated platforms, to dry the produce and deter insects or other pests.

Instead of being horizontal and flat, the platform may be conical in shape, the point at the bottom. Up to 3 metres in diameter, such platforms facilitate drying because of their funnel shape: at the top they consist of a frame of horizontal poles which is square, circular or polygonal in shape, against which the timbers which form the cone rest; these timbers meet at the bottom on a wide central supporting post (Figure 6.2).

Platforms with roofs (but no walls), of whatever shape or form, may be regarded as transitional types between temporary and long-term stores. In southern Benin, Togo and Ghana, for example, maize cobs in their sheaths are laid in layers on circular platforms with their tips pointing inwards. The platforms are usually between 2 and 3 metres in diameter, but some may be more than 6 metres wide, with a maximum height of 2.5 metres at the centre and 1.5 metres at the periphery. In Ghana such a granary is called an "ewe" barn (Figure 6.3).

Long-term Storage Methods

(i) Storage baskets (cribs) made exclusively of plant materials

In humid countries, where grain cannot be dried adequately prior to storage and needs to be kept well ventilated during the storage period, traditional granaries (cribs) are usually constructed entirely out of locally available plant materials: timber, reeds, bamboo, etc. (Figure 6.4.). Under prevailing climatic conditions most plant material rot fairly quickly, and most cribs have to be replaced every two or three years - although bamboo structures may last up to 15 years, with careful maintenance.

Basically similar to the outdoor type of platform described above, in all its variations, the traditional crib differs in always having a roof and wall(s). It may even be elevated at least one metre above ground level, with a fire maintained underneath to assist drying of the contents and, allegedly, to reduce insect infestation. However, such cribs (especially the larger ones) are more commonly raised only 40 to 50 cm above ground level.

Access to the interior of a crib is gained usually over the wall. This may involve raising the roof, but some cribs have a gap between the top of the wall and the roof to facilitate entry. Relatively few cribs have sealable gaps in the wall or floor for the removal of grain.

(ii) Calabashes, gourds, earthenware pots

These small capacity containers are most commonly used for storing seed and pulse grains, such as cowpeas. Having a small opening, they can be made hermetic, by sealing the walls inside and out with liquid clay and closing the mouth with stiff clay, cow dung, or a wooden (cork?) bung reinforced with cloth.

If the grain is dry (less than 12% moisture content) there there is usually no problem with this kind of storage.

(iii) **Jars**

These are large clay receptacles whose shape and capacity vary from place to place. The upper part is narrow and is closed with a flat stone or a clay lid: which is sealed in position with clay or other suitable material. Generally kept in dwellings, they serve equally for storing seeds and legumes. So that they may remain in good servicable condition, they should not be exposed to the sun and should not be either porous or cracked.

(iv) **Solid wall bins**

Such grain stores are usually associated with dry climatic conditions, under which it is possible to reduce the moisture content of the harvested grain to a satisfactory level simply by sun-drying it. Solid wall bins are therefore traditional in the Sahel region of Africa, and in southern African countries bordering on the Kalahari desert.

The base of a solid wall bin may be made of timber (an increasingly scarce resource), earth or stone. Earth is not recommended because it permits termites and rodents to enter. The better base is made of stone.

Mud or clay silos are usually round or cylindrical in shape, depending on the materials used (Figure 6.5). Rectangular-shaped bins of this type are less common, because the uneven pressure of the grain inside causes cracking - especially at the corners. Clay, which is the basic material, varies in composition from one place to another. That most commonly used for such construction work is obtained from termitaries, because the termites add a secretion which gives it better plasticity. To give it added strength, certain straw materials such as rice straw may be mixed with it; while, in some countries, nr juice is added to make it almost as durable as concrete. The diversity of materials used explains why the capacities of such silos can vary from 150 kg to 10 tonnes.

In West Africa, when only clay is used, the walls are 15 to 20 cm thick: the shape is then more or less cylindrical and the construction is similar to the walls of a house. However, when the clay is strengthened as described above, the bin is usually rounder in shape and resembles a jar; with walls only 2.5 to 5 cm thick, but very strong, so that it is possible to climb on top to enter the silo for regular withdrawal of grain. The interior is often compartmented by vertical internal walls, joining at the centre on a central column which serves to support the foot when one enters the silo. The walls are rendered as smooth as possible, inside and out in such a way as not to offer refuge for insects and their larvae; fissures are sealed with liquid clay before each loading. Similarly, the angles formed by the internal partition walls and external wall are rounded for the same reasons.

In southern Africa, where the bins are commonly rectangular in plan, internal compartments are usually covered with mud-plastered timber ceilings and are accessed via sealable 'windows'. These face a short corridor leading to the exit, which may be fitted with a standard lockable door.

The roof is usually made of thatched grass, with a generous overhang to protect the mud wall(s) from erosion. Where a side door or a detachable 'cap' is not provided, the roof has to be lifted for access to the bin. Such silos can serve for 30 or even 50 years.

(v) **Underground Storage**

Practised in India, Turkey, sahelian countries and southern Africa, this method of storage is used in dry regions where the water table does not endanger the contents. Conceived for long term storage, pits vary in capacity (from a few hundred kilogrammes to 200 tonnes). Their traditional form varies from region to region: they are usually cylindrical, spherical or amphoric in shape, but other types are known (Gilman and Boxall, 1974). The entrance to the pit may be closed either by heaping earth or sand onto a timber cover, or by a stone sealed with mud (Figure 6.6. Vertical section of a Cyprus village underground grain store.).

The advantages of this method of storage are:

- few problems with rodents and insects;

- low cost of construction compared to that of above-ground storage of similar capacity;
- ambient temperatures are relatively low and constant;
- hardly visible, and therefore relatively safe from thieves;
- no need for continuous inspection.

The disadvantages are:

- construction and digging are laborious;
- storage conditions adversely affect viability; the stored grains can only be used for consumption;
- the grain can acquire a fermented smell after long storage;
- removal of the grain is laborious and can be dangerous because of the accumulation of carbon dioxide in the pit, if it is not completely full;
- inspection of the grain is difficult;
- risks of penetration by water are not small, and the grain at the top and in contact with the walls is often mouldy, even if the rest of the stock is healthy.

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It is recognized that, although temporary storage methods are the least desirable, there are circumstances in which they are unavoidable. The following suggestions and recommendations for improving such storage methods are offered, on the understanding that more permanent solutions to problems should be sought wherever possible.

Little can be done to improve **aerial storage** except, perhaps, to suggest that the bundles of cereals may be safer if suspended in a well ventilated part of the house; or above a fireplace where insects may be deterred and the moisture content of the grain may be reduced.

As far as **storage on the ground, or on floors** is concerned, the grain is less exposed to risk if it is placed on wattle mats or the like laid on the ground or floor. Drying floors could be improved by making them of concrete; or by stabilising the earth chemically or with natural material such as nr juice. Larger animals are less likely to spoil the grain if such floors are constructed near the house, where they can be better guarded.

If the grain is stored on the floor in a part of the house, it is best to ensure that the floor is clean and stabilised. To prevent the translocation of moisture through the floor to the grain, a plastic sheet should be placed upon it first (or better, embedded in the floor during its construction). The room should be rodent proofed as far as possible (including wire mesh screens fitted to windows), and the grain should be treated with insecticide. Before each new harvest the room should be cleaned, to remove any residual insect infestation.

Open timber platforms may be improved by fitted rodent barriers around the supporting posts. Furthermore, the posts should be driven at least 60 cm into the ground, to withstand pressures caused by wind, uneven loads, or even animals leaning against them (some animals will rub against trees to relieve itches!). To protect them against termites, posts should be coated with bitumen or used engine oil, or superficially charred after having the bark removed. Alternatively, since termites do not attack fresh, healthy wood, green wood which will sprout and grow may be used as poles.

The central post of a **conical-shaped platform** should be at least 80 cm high to prevent rodent attack and, like the poles supporting the upper frame, should be fitted with a rodent barrier. The poles or large bamboos comprising the cone, while being sufficiently strong, must not fit so tight together as to impede the passage of air and retard drying. One solution is to cover the timbers with enough loosely woven wattle (sorghum stems for example), to prevent cobs falling between the timbers, to pass the weight of the grain to the wood and allow air to pass at the same time.

Long-term Storage Methods

The upright poles which support the platforms of **traditional storage baskets** (cribs) should be at least 80 cm high, and protected against termites as described above. They should also be fitted with rodent barriers in similar fashion (Figure 6.7). The poles should be as thick as possible, in order to reduce the number needed and therefore the amount of metal sheet which has to be purchased for making the rodent barriers.

Where it is customary to raise the roof (or part of it) when removing grain from the crib, then the possibility of incorporating a small framed door near the bottom of the wall should be considered. This will prevent damaging the roof and help maintaining its waterproofness. When the platform is conically shaped, an opening in the side of the cone could be practical. If the walls are woven, a trapdoor could be fitted into the platform for access from underneath the crib.

In a dramatic break-away from traditional crib design, while retaining the important principle of using locally available materials as much as possible, the African Rural Storage Centre (ARSC) based at IITA in Ibadan, Nigeria, has developed a crib which optimises both the drying and storage of maize under humid tropical conditions (FAO, 1987).

Such a crib consists basically of two parallel frames between which the grain, mainly cob maize, is stored. The supporting posts are driven 50 to 60 cm into the ground one metre apart and protected from termites with sump oil, tar or scorching. They are then fitted with rodent barriers.

The walls of the ARSC crib may be constructed of wire netting or local material, such as rafia, bamboo or wooden lattice, and should be 1.5 to 2 metres high. The floor, which should be fixed at least 80 cm above ground level, is made of straight poles; if possible removable to facilitate emptying. The roof may be covered with corrugated metal sheet or thatch, which should overhang a long way to protect the cobs from rain: an overhang of 0.6 to 1 metre is recommended.

The various components of the crib are nailed together, or can be bound together with lianas or bark string.

In very humid areas where maize is harvested at 30-35 % moisture content, the recommended width for the crib is 60 cm. In drier zones with a single rainy season, maize is harvested at about 25% moisture content and the width may be increased to 1 metre. In very dry places the crib could be 1.5 metres wide.

The length of the crib is a function of the quantity to be stored. Given that 500 kg of maize cobs with their sheaths removed, and a moisture content of 30%, (equivalent to 300 kg of shelled maize at 14% mc) occupy approximately one cubic metre: if a crib is 60 cm wide and 1.7 metres high, it will need to be 5 metres long to contain the cob equivalent of 1,500 kg of shelled maize at the quoted moisture contents.

If it is possible, the crib should be erected across the direction of the prevailing wind and, if this is strong, the supporting posts should be reinforced to resist it. The crib should be located in a ventilated area and not constructed along a wall or next to a windbreak of trees.

Calabashes, gourds, and earthenware pots can be rendered virtually airtight by treating the exterior surfaces with varnish or with dry oil such as linseed oil (McFarlane, 1970). The mouth may be carefully sealed with wax; or covered with a doubled plastic sheet tied firmly in position.

If an absolutely air-tight seal cannot be guaranteed, the grain should be treated with insecticide.

Jars should be treated like small containers (see above) to make them airtight. Very large and immobile jars could be provided with outlets in their bases, for the easy removal of grain. Such outlets could, for example, be metal tubes fitted with lockable caps for greater security. If the cap is well designed it would ensure both security and airtightness.

The following suggestions are made for improving traditional solid wall bins

a. Where the base consists of a layer of stones, these should be set in concrete or clay mixed with a hardener such as nr juice, to prevent the base becoming a hiding place for rodents (and snakes). An alternative is to make a hollow base with an opening, in which to house chickens (see Figure 6.5.). A solid concrete base could also be made, but the cost is often too high.
b. When clay is used alone, it is very friable and must therefore be protected. Rendering with pure cement is not recommended, because it resists movements of the walls (expansion, contraction, settling), cracks and becomes detached within a short time. It is preferable to use a mixture of earth and cement (one part cement to ten of earth) or earth mixed with lime (one part lime to five parts of earth) or earth stabilised with a natural product such as guava juice, karit butter, cow dung, opuntia (cactus), flour (in the form of a paste, made by mixing 15 litres of flour with 220 litres of water, which is added to the earth), euphorbia latex, nr juice, etc.
c. Traditional solid wall bins can be made more secure against thieves by providing each compartment with a

lockable outlet at its base. If a mud-plastered ceiling (under the thatch roof) is also provided, with sealable entrance(s) for loading, such an improved bin can be made reasonably airtight.

Underground storage pits may be improved in a number of ways, several of which are already employed locally but are worth adopting elsewhere (Boxall, 1974).

a. In the first instance, it is very worth while extending the neck, or collar, of the pit above ground level - with clay or even a concrete slab - to minimise the risk of rainwater pentrating at this point. This risk can be further reduced by digging simple drainage trenches around and away from the pit, to remove rainwater from the area as quickly as possible. Such precautions may interfere with the security of the pit, by revealing its presence to potential thieves; so the fitting of a lockable lid should be considered. Alternatively, the pit can be located under a lockable shed, or even under the floor of a room in the house.
b. The floor of the pit may be strengthened with stones, stabilised earth or even concrete; and the walls may be solidified with cow dung, or chicken wire mesh plastered with cement. A double layer of concrete, each layer about 5 cm thick, with chicken wire (for strength) and bitumen (for waterproofness) sandwiched between, is probably the best type of lining that can be recommended.
c. Plastic sheeting could be applied to the walls and the floor, but this is not easy and it is probably more practical to put the grain into plastic sacks and stack these in the pit.

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Alternative storage technology at farm/village level

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Sacks

Wherever grain is grown on a commercial basis, buying agencies often issue empty sacks to producers so that they may be filled on the farm. The buying agency may then collect the bagged grain from the farm, or the producer has to deliver it to the nearest collection point. In either case, the producer has to store the sacks of grain for some time before they are sold. During this period precautions have to be taken to ensure the safety of the grain and maintain its quality.

At the very least, the bagged grain must be kept off the ground to prevent spoilage by translocating water and/or termites. Low platforms, tarpaulins or plastic sheeting may serve this purpose; but if there is a risk of damage by rodents or other animals, high platforms fitted with rodent barriers should be used. If there is a risk of rain during the temporary storage period the bags should be covered with waterproof sheeting (but not all the time if the grain has a moisture content much in excess of 12%). Alternatively, the sacks of grain should be stacked on dunnage or waterproof sheeting, away from walls, in a rodentproofed barn. The need for chemical methods of pest control should not arise if the storage period is short.

Where sacks are used for domestic grain storage, similar conservation measures should be adopted. However, it will be necessary to employ some form of insect pest control (see Chapter 8). Second-hand sacks must be thoroughly cleaned and disinfested before use.

Metal or Plastic Drums

Drums are often used as storage containers in the house and serve notably for the storage of cereal seeds and pulses.

Plastic drums are used intact or after having the upper part cut off to facilitate loading and unloading. Otherwise, plastic lends itself poorly to adaptation because it is relatively weak: at most, a lockable outlet can be added. If the lid is tight fitting and the drum is completely filled with grain, any insects present will deplete the oxygen in the drum and die.

Metal drums can be adapted for domestic grain storage in a similar way. A removable lid permits easy loading; but it is also possible to weld half of the lid to the rim of the drum, and provide a riveted hinge on the remaining half of the lid so that it alone can be opened.

Fitted with a padlock, such a modified drum is more secure. To make a store of greater capacity, two metal drums can be welded together end to end and fitted out as described above. Well modified and/or fitted with gaskets, metal drums can also be made airtight.

Inaccessible to rodents, efficient against insects, sealed against entry of water, drums make excellent grain containers. However, they should be protected from direct sunshine and other sources of heat to avoid condensation by being located in shaded and well ventilated places.

Alternative Solid Wall Bins

In some countries grain storage workers, rather than modifying traditional storage structures, have developed significantly different storage bins. A few examples of these are described below.

(i) The "Pusa" bin.

Developed by the Indian Agricultural Research Institute (I.A.R.I.), these silos are made of earth or sun-dried bricks; they are rectangular in shape and have a capacity of 1 to 3 tonnes.

A typical "Pusa" bin has a foundation of bricks, compacted earth, or stabilised earth. A polyethylene sheet is laid on this, followed by a concrete slab floor 10 cm thick. An internal wall of the desired height (usually 1.5 to 2 metres) is constructed of bricks or compacted earth, with a sheet of polyethylene wrapped around it. This sheet is heat-sealed to the basal sheet, and the external wall is then erected. During the construction of the wall an outlet pipe is built into its base.

The concrete slab roof is supported by a wooden frame and, like the floor, is constructed of two layers separated by a polyethylene sheet. During its construction, a man-hole measuring 60 x 60 cm is built into one corner.

The "Pusa" bin (Figure 6.10. The "Pusa" bin.) has been widely adopted in India, and has been demonstrated in some African countries. It gives good results when loaded with well dried grain.

(ii) The "Burkino" silo

Based on a traditional dome shaped type of bin, this silo is constructed with stabilised earth bricks (Figure 6.11. The "Burkino" bin.). Various models and capacities are available.

The base is made of stabilised earth resting on the ground or on concrete pillars. The domeshaped roof is also made of stabilised earth bricks, using special wooden formers. The technique of making a dome-shaped roof is not easy to master, and usually has to be done by skilled masons. A variant has been developed with the roof resting upon a wooden frame, which can be erected by unskilled farmers.

(iii) The "USAID" silo

This silo is based on the "Burkino" silo and examples have been erected in Nigeria; holding one tonne of maize grain, the silo rests on stone or concrete pillars supporting a reinforced concrete slab 1.5 metres in diameter. The walls are made of stabilised earth bricks and are plastered inside and out with cement reinforced with chicken wire mesh. The top is domeshaped with a central round opening, and covered with a cone-shaped earthen cap. This is plastered with cement, and rests on bamboos or on a metallic drum base. An outlet door, consisting of a 15 x 30 cm plate 1.5 mm thick which is smeared with grease for easy sliding, is let into the base concrete slab.

(iv) Concrete/cement silos

Such silos are 'cement rich', and often include other materials which normally have to be imported into developing countries. Therefore they are potentially (and usually) expensive structures, which can be seriously considered only when improvements to traditional storage bins cannot be practically applied. Their redeeming feature, given that they are properly constructed and used, is that they are robust and should give many years of satisfactory service.

The Ferrocement Bin ("Ferrumbu")

Developed in Cameroon (stergaard, 1977), and tested in a number of African countries, this bin is similar to the "Burkino" bin in shape but consists mainly of chicken wire plastered inside and out with cement mortar. Details of its construction may be found in Bodholt and Diop (1987).

The wall varies in thickness from 3.5 cm for a bin of 0.9 m3 capacity, to 6 cm for one of 14.4 m3 capacity.

The "Dichter" stave silo

This cylindrical silo (Figure 6.12. The "Dichter" concrete stave bin.) was developed in Benin, and is constructed with trapezoidal section concrete blocks (staves) supported externally by tightened steel wire. Both internal and external surfaces are rendered smooth with cement, and the outside may be treated with coaltar to ensure water-proofness. The floor and cover slab consist of reinforced concrete cast in situ, and the whole structure is raised off the ground on four concrete block pillars. A manhole is located in one side of the cover slab, and an 'anti-theft' outlet is built into the bottom of the wall. Construction details may be found in Dichter (1978).

Other types of ferrocement or concrete block bins have been designed and tested, notably that developed in Thailand for rice storage (Smith and Boon-Long, 1970) (Figure 6.13. Ferrocement bin for rice, Thailand.). However, as far as is known, none has enjoyed more than local popularity.

A principal technical difficulty with such bins is that they are poorly insulated, which encourages the development of moulds if the moisture content of the grain is higher than 13%. This means that the bins must be constructed indoors, or at least protected by shelters with a wide overhang to reduce extreme variations in temperature. With tall bins, such as the larger Ferrumbu, this is not very practical.

(v) Metal Silos

Economically valid for storing large quantities (over 25 tonnes), metal silos are often regarded as too costly for small scale storage. Nevertheless certain projects have been successful in introducing small metal silos, of 0.4 to 10 tonne capacity, at farm/village level in developing countries: Swaziland (Walker, 1975), Bolivia (Anon, 1982), India (Anon, no date), to mention just a few. Metal silos are reported to have been used on farms and in villages in Guatemala for over 50 years (Breth, 1976) and in Swaziland, on a small scale, for possibly longer.

Such silos are made of smooth or corrugated galvanised metal, and are cylindrical in shape with a flat metal top and, usually but not always, a flat metal bottom. A man-hole with a cover, which may be hinged but is nevertheless lockable, is located, usually to one side, in the top panel; and an outlet pipe provided with a padlock is fitted at the base of the wall.

Metal silos should be placed on platforms or plinths, to facilitate emptying. Large capacity silos are usually constructed without base plates on raised concrete slabs. In this case, bitumen or cement mortar is plastered around the base of the wall to prevent penetration by water and pests.

As with concrete silos, it is essential to provide cover, to avoid excessive variations in temperature and moisture translocation (Figure 6.14).

(vi) Synthetic Silos

Various attempts have been made to develop small scale storage bins, using synthetic materials such as butyl rubber (O'Dowd, 1971) and high density polyethylene (CFTRI, 1975). However, such bins proved to be either too expensive (Figure 6.15. 500 kg butyl rubber/weldmesh silo for cowpea storage, Nigeria.) or prone to damage by pests. Also the management level required by such storage facilities is probably too high for most rural situations.

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Traditional private grain trader storage

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As implied in the Introduction to this chapter, the requirements of private grain traders have tended to be neglected in favour of the development of storage facilities for government or quasi-government grain marketing organizations. Consequently, references to private trader storage facilities are scattered and almost inconsequential. This section is therefore brief and based almost entirely on the author's observations.

Most private grain traders never have more than a few tonnes of grain in store at any given time; their operating principle being to dispose of stocks as quickly as possible, thereby minimising losses associated with pest infestation and avoiding the extra expense of pest control. With few exceptions, therefore, their storage facilities are small (200 tonnes capacity or less) and absolutely basic in design. Typically consisting of nothing more than a single large room, with bare brick or mud plastered walls, an earth floor, a corrugated metal roof supported by many pillars, and poorly fitting swing doors; a grain store is often one of several traders' stores in a long building sharing a common roof.

The existence of many roof supports in such a primitive store makes it impossible to build large stacks of bagged grain free of obstructions (a necessary prerequisite for effective fumigation). However the traditional 'banco' store in Mali, with its flat mud roof supported by many pillars, has lent itself well to the 'whole store' fumigation technique using phosphine (Webley and Harris, 1979) (see Chapter 8).

In production areas of Somalia and Sudan some grain traders are known to hold stocks of grain in large underground pits ('baker' or 'matmura' respectively). When trading conditions are favourable these stocks are transferred to urban wholesale or retail stores not unlike those briefly described above.

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Modern warehouses

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The Purposes of Warehouses, and Basic Requirements

Warehouses are intended for the storage and physical protection of goods. In the context of grain storage, 'goods' primarily refers to bagged grain. It may also include materials and equipment required for the packaging and handling of bagged grain, and storage pest control; although, in an ideal situation, such items should be stored separately. The distinction is made between warehouses and flat stores, which are designed rather differently for the storage of grain in bulk and are discussed in Chapter 7.

Locating a Warehouse

The approximate location of a proposed warehouse for grain storage will have been decided already. However, the determination of its exact siting is a matter for engineers. If a large warehouse is planned, it is always prudent to involve local Civil Engineers at this stage.

Several factors need to be considered in selecting a suitable site. In the first instance the topography of the area has to be studied. It is preferable to erect the warehouse on level ground, ideally slightly raised above the surrounding area, which is well drained and not prone to flooding. Low locations must be avoided. If it is difficult to find a level area then the least undulating or sloping area should be selected, and the site should be oriented along contour lines, in order to minimise the amount of levelling and filling in to be done.

It is then important to determine the characteristics of the soil: its load-bearing capacity, resistance to compaction, and drainage characteristics. Never build on black cotton soils, because these are weak and do not have sufficient soil-bearing capacity even for small warehouses. The warehouse and the approaches to it will need to be protected from running water by an effective drainage system, and the site should be able to accommodate such a system.

For easy access and movement of stocks, the warehouse should be sited as near as possible to a main road. It is also important to ensure that the approaches to the warehouse will permit easy movement and manoeuvring of vehicles around it. This means that, in addition to the area to be occupied by the warehouse, there should be plenty of usable space around it. Also, looking to the future, there should be sufficient space for the erection of additional warehouses and utility buildings.

In tropical countries it is very important that the long axes of warehouses are oriented East-West as nearly as possible. This way, the side walls are least exposed to the sun and temperature variations inside are minimised. If the warehouse cannot be oriented EastWest, some benefit may be derived from siting it across the direction of the prevailing wind. The interior can then be effectively cooled by opening all doors and windows at appropriate times.

Finally, bearing in mind that grain in the warehouse will probably be fumigated with gas lethal to human beings (see Chapter 8) from time to time, it is important that the site chosen must be a safe distance from dwelling houses, shopping centres and other working areas.

Standard Warehouse Design (for information on fumigable warehouses, see Annex 4)

All warehouses consist of a floor, walls, a roof, and one or more entrances. However, they can vary considerably in the detailed composition and construction of these basic components; and may include others, such as ventilators, windows, artificial lighting, etc. The various combinations of features possible have to be considered very carefully, together with other factors relating to location, intended use, etc., when planning the construction of a warehouse.

Paramount importance should be attached to ensuring that the quality of the commodity to be stored will not be affected by physical factors such as moisture and heat. Wherever possible and practical, the design of the warehouse should incorporate features which will protect its contents from attack by rodents and birds, and facilitate the use of insecticides.

The warehouse should also be easy to clean and maintain (there is no point in using components which are not readily replaceable or repairable); and it should provide good working conditions.

(i) Foundations and Floor

Unstable clay soils and areas which have been filled in should be avoided wherever possible, because they involve the risk of subsidence. In all cases, it is necessary to dig down to a point where the soil-bearing pressure is 150 kN/m2 or better.

The floor must be able to bear the weight of the grain which will be stacked upon it, and it must also be impermeable to ground water. For these reasons the floor should consist of a slab of reinforced concrete laid upon well compacted hard core, with a moisture barrier sandwiched between the two. This moisture barrier should consist of a layer of bitumen or asphalt, bitumen felt, or a polyethylene film.

The reinforced concrete slab must be made with expansion joints, to prevent cracking (which makes storage hygiene difficult). It should be covered with a cement cap a few centimetres thick, which is rendered smooth and hardened (to prevent powdering). Ideally, the concrete slab should be laid after the roof has been completed: to prevent direct sunshine drying it too rapidly, and possibly causing it to crack.

The floor level must be sufficiently above ground level to ensure that water will not enter the warehouse, even after the heaviest rainfall that can be expected. Consideration could be given to erecting the warehouse on a plinth raised about 1.2 metres above ground level, to facilitate loading and unloading of vehicles; but this alternative is expensive and can add 40% to the cost of construction.

(ii) Walls

Most modern warehouses are constructed with a framework, usually of reinforced concrete. The supporting pillars are linked together by lower tie-bars, which are themselves secured to the floor slab, and by upper tie-bars, which hold the frame firmly together. It is essential that all joins are secure and accurate, and that the reinforcing rods are well covered with concrete. The walls of the warehouse are built between the supporting pillars.

If the supporting posts are thicker than the walls, it is important that the extra thickness is on the outside of the building so that the internal surfaces of the walls are smooth and free from projections. This facilitates cleaning of the store, and avoids interference with other operations as well.

The walls may be made of breezeblocks, or stabilised earth bricks 15 to 20 cm thick, and should be rendered smooth on both sides. They should be painted white, on the inside to facilitate the detection of insect pests, and on the outside to help keep the warehouse as cool as possible. Alternatively, the walls may be made of a lightweight material such as fibro-cement, galvanised metal sheet, or aluminium sheeting. However, walls of this kind are easily damaged, have poor insulating properties, and are sometimes prone to erosion.

A vapour-proof barrier should be incorporated into the base of the walls, to prevent damp rising and causing damage to the warehouse structure and its contents. Also, a concrete strip about 1 metre wide should be laid around the outside of the warehouse, to prevent rain from eroding the base of the walls below the damp course.

(iii) Roof

Internal pillars supporting roof frames should be avoided because, as previously stated, they can interfere with pest control and other stock management procedures. Instead, roof frames should be designed so that they transfer the weight of the roof to the supporting columns (in framed buildings), or to the walls if the warehouse is small.

Modern engineering techniques allow very wide 'free-span' roofs (i.e. roofs without internal supporting pillars) to be constructed. However, such roofs are very expensive and rarely used in warehouse construction. A steel portal frame should be used if the span is to be greater than 15 metres. Warehouses less than this width may have reinforced concrete roof frames.

Roof frames made of wood or bamboo are only suitable for warehouses not more than 4 or 5 metres wide. The wood used must be well dried and treated with a preservative.

Roof cladding may be of galvanised steel or aluminium sheeting, or asbestos cement; the latter being more fragile but having better insulating properties. Tiles are not recommended, especially for large warehouses.

The roof should overhang the gables by 0.7 to 1.0 metres, and the eaves by at least 1 metre. This ensures that rainwater is shed well clear of the walls; and obviates the need for guttering and drainpipes, which may become blocked or assist rodents entering the warehouse. The overhang also helps to keep walls cool and protects ventilation openings from rain.

(iv) Ventilation

Ventilation openings are necessary for allowing the renewal of air and reducing the temperature in the warehouse, they also allow some light to enter it. If such openings are

located too low down they can be the source of numerous problems: entry of water, rodents, thieves, etc. These problems are avoided when ventilators are placed under the eaves. They should be fitted on the outside with anti-bird grills (20 mm mesh) and on the inside (10 cm behind the grills) with 1 mm mesh screens (removable for cleaning) which will deter most insects.

(v) Doors

The number of doors will vary according to the size of the warehouse. If possible there should be at least two doors, so as to be able to rotate stocks on a 'first in, first out' basis. Hoever, this may not be possible or practical in a very small warehouse.

Double sliding doors are recommended. Preferably made of steel, or at least reinforced along their lower edges with metal plate as protection against rodents, they should be sufficiently large (at least 2.5 x 2.5 m) and close fitting. If swing doors are fitted they should open outwards in order not to reduce the storage capacity of the warehouse. It is recommended that the doors be protected from rain by an extension of the roof or a separate cover.

(vi) Illumination

Adequate light in a warehouse is an important factor as far as the safety of workers inside it is concerned. However, there can be problems in providing sufficient natural light while satisfying other technical aspects at the same time.

Many warehouses are fitted with translucent sheets in the roof. However this is considered inadvisable, because it may involve the risk of spot heating of produce in the top layers of stacks underneath. Other warehouses are reasonably well lit by daylight filtering through ventilation gaps left along the tops of side walls. This source of illumination is impaired by the installation of bird-proofing. Non-opening windows set high up in walls may solve this problem; although their sills could harbour pest-infested grain residues, unless they are specially sloped to prevent this happening.

Most warehouse managers find that leaving several doors wide open during the hours of intense sunlight in tropical countries provides adequate illumination of the interior. This is probably the most practical solution when all open doorways are in active use. Otherwise, it does invite the risk of theft, or furtive access by rodents.

Artificial lighting is justified only in warehouses which are regularly worked in during hours of darkness.

Determining the Dimensions of a Warehouse

Before calculating the dimensions of a warehouse it is important to identify the function it is intended to perform. If it intended to be a transit store, and bagged grain will be moved through it quickly, stacks are likely to be low and plenty of working space will be needed. If, on the other hand, it is to be used for the storage of reserve stocks, stacks will need to be as high as possible and only minimum working space will be required.

The dimensions of a warehouse are calculated mainly from:

i. the Specific Volume of the principal product to be stored;
ii. the Maximum Tonnage of this product which it is desired to store;

iii. the Maximum Stack Height desired;
iv. the extent to which Separation of Lots is desired.

An example of how the dimensions are calculated, using these parameters, is given on page 162.

(i) The Specific Volume of the Product

This is defined as the volume occupied by 1 tonne of the bagged grain. The term Specific Volume may be similarly defined for grain stored in bulk, which is the subject of the next chapter.

Engineers find it more convenient to use Specific Volume rather than Bulk Density (see Chapter 3) in their calculations. However, even now, there is a tendency to use bulk density data in determining specific volumes for products. This tendency is queried (Clancy (1977) and Hayward (1981a)) because large quantities of bagged grain in stacks or bulk grain in silos become compacted, and occupy less space than bulk density calculations indicate. Clancy found that bulk wheat can pack by 1% or more, while Hayward discovered that the average density of bagged millet exceeded quoted bulk density figures by up to 40%.

While Specific Volume is regarded as a valid parameter, it is recommended that engineers responsible for designing warehouses should collect as much information as possible on the specific volumes of locally important products to guide their calculations. For what it is worth, Table 6.1. gives the specific volumes of a number of products for which warehouse accommodation is frequently required.

Table 6.1. Specific volumes of some bagged grains and grain products.

Commodity	**Specific Volume (m/t)**
Bulrush millet	1.25

Beans, peas, lentils	1.30
Wheat, milled rice, coffee	1.60
Maize, sorghum, decorticated groundnuts, palm seed	1.80
Soybeans, cocoa	2.00
Wheat flour, maize meal	2.10
Cotton seed	2.50

(ii) Maximum Tonnage

This parameter will depend upon the purpose for which the warehouse is required. The quantity calculated should also take long-term projected requirements into account.

(iii) Stack height

This also depends, in part, upon the purpose for which the warehouse is required (see above). The nature of the commodity and the type of sack to be used are additional factors to be considered.

Some commodities, notably palm seed and cocoa, cannot be stacked very high because they compact easily. Sacks made of woven polypropylene have a tendency to slide on each other, and therefore should not be stacked more than 3 metres high. Jute sacks bind together better, and may be stacked up to 6 metres above the floor.

The height of stacks should not exceed the height of the walls, and a space of at least 1 metre should be allowed between the tops of stacks and roof frames.

(iv) Separation of lots

Maximum use of the warehouse is gained by storing products in one stack. However, it is usually necessary to separate lots; and, for better stock control, gangways have to be provided between and around stacks. Spaces 1 metre wide should be left between stacks and between stacks and the walls. Also, it is customary to provide one or more areas at least 2 metres wide, in which incoming or outgoing stocks can be handled.

Ancillary Buildings and Structures

Warehouses are often constructed without consideration being given to how the storekeeper, equipment and consumable items (empty sacks, pesticides, etc.) are to be accommodated. The storekeeper is then obliged to section off parts of the warehouse as his 'office' and storage areas for equipment and other items. Apart from thus wasting valuable space, this practice is also hazardous when stocks of grain have to be fumigated. It is always better, therefore, to include an office and other ancillary buildings, adjacent to the warehouse but a safe distance from it, right from the early planning stages.

The provision of toilets and washing facilities for workers is a statutory requirement in many countries, but often overlooked. Larger grain storage installations may also require quality control laboratories, workshops and garages for vehicles, and so on. An incinerator for the destruction of spoiled grain and combustible waste material would complement other pest control measures, and reduce rubbish disposal costs.

In order to make maximum use of the storage space inside a warehouse, it is often advantageous to

extend the roof at one end (Figure 6.18. Standard warehouse with a working area at one end.), or along one side, to provide a covered working area for the handling of stocks being received or despatched.

For further detailed information see FAO (1985),

Example of how the dimensions of a warehouse are calculated

In this example it is assumed that a warehouse is required for the storage 1000 tonnes of maize in jute sacks in 4 separate lots. It is also assumed that the warehouse will be rectangular in plan, with the length approximately twice the width. Prom the specific volume of maize (Table 6.1), the total volume of the stock will be:

1000 (t) x 1.8 (m^3/t) - 1800 m^3

If the sacks of maize are to be stacked 5 metres high, the floor area required will be:

$$\frac{1800}{5} = 360\ \text{m}^2$$

If length (L) = 2 x width (W), when:

$2W^2 = 360$ m^2, or W = 13.4 metres

Keeping the example simple, let W = 12 m; then, the area being 360 m^2, L = 30 m.

If the stock is to be kept in four separate lots, each measuring 6 x 15 metres, then the following floor space will also be required:

a main handling area, 3 metres wide, along the axis of the warehouse; a gangway 2 metres wide, across the centre of the warehouse; and an inspection space 1 metre wide around the entire stacking area.

The internal dimensions of the warehouse will be:

- Width (W) = 1 m + 6 m + 3 m + 6 m + 1 m = 17metres
- Length (L) = 1 m + 15 m + 2 m + 15 m + 1 m = 34 metres

giving a total floor area of 578 m.

If the warehouse is to have a trussed roof, the walls should be at least one metre higher than the intended stacking height: in this example 5 m + 1 m = 6 metres.

The percentage utilisation of the building will then be: $\frac{1800 \times 100}{578 \times 6} = 52\%$

NOTES:

Similar calculations indicate that in small capacity warehouses (10 to 30 tonnes) only about 20% of the space is usable. Medium capacity warehouses (50 to 100 tonnes) have only about 30% usable space. Thus the larger a warehouse is, the more economical it will be in terms of cost of construction per tonne stored.

Figure 6.19. Inside view of a standard warehouse.

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Introduction

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As has been discussed at length in Chapter 1, there are many reasons for storing food grains and also numerous types of storage facility available. For any given situation there is usually a choice of storage methods. Chapter 6 has described traditional types of storage used in developing countries, and also warehouses for the storage of bagged grain. This chapter concentrates on structures available for the storage of grain in bulk, where this is deemed most appropriate and economical in commercial grain handling systems.

Centralised bulk storage facilities which receive grain from farmers and safely store it for maybe 12 months or until it can be exported or disposed of domestically, provide a combination of strategic, commercial and buffer storages. Their essential purpose is nevertheless that of long-term operational storage in that they provide a buffer between harvest receivals and the markets or consumers of grain.

The type of store most suitable for a particular situation often depends on the purpose for which it is to be built.

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Factors influencing the choice of bulk store

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Compared to most other foodstuffs, such as meats and vegetables, grains are relatively easy to store. If grain is kept insect-free and below its safe moisture content, it will keep for many years with minimal loss of quality or nutritional value. Low temperature is an important factor in minimising insect activity and in maintenance of nutritional quality in general. Storage at or below the safe moisture content is essential for prevention of deterioration caused by microorganisms and insects (see Chapters 2 and 8 respectively).

Where insects are present, temperatures are high, and most especially where moisture content is above safe levels, then storage of grain becomes both risky and difficult, and losses will be difficult to avoid. It is in these circumstances that the type of store and its design become critical to the safety of the stored grain. It is worth remembering that most often, the value of the grain (in dollars-per-tonne) is usually greater than the cost of the structure in which it is stored. Minor expenditure in improving the quality of the store can thus be quickly recovered if commodity losses are commensurably reduced.

Whilst the choice of storage design is wide, the essential requirements needed to store grain safely remain the same. These are that the storage structure must keep the grain free from water ingress, insects, rodents and birds. The store should also permit easy and economical disinfestation of grain in the event of insect infestation and, if grain is to be stored at moisture content above 'safe' levels, provision should be made for cooling the grain. These matters are discussed in more detail in the following sections.

Sue of Grain Storage

Mathematical, graphical or computer modelling can be helpful in determining the volume of storage that is required. In some cases, it is a relatively simple exercise to determine the requirements - for instance where harvested grain is to be received over a short period, dried over a longer period and dispatched over 12 months, it is a simple matter to calculate the buffer storage requirements for wet and dry grain. This type of situation can be illustrated by a simple graphical model as shown in Figure 7.1 (see Figure 7.1. Model for determining the Volume of storage required.). Here, a quantity "Q" tonnes of grain is assumed to be received into storage over a period "tr" days, and dried over a period "td" days. It is then dispatched over period "to". If we assume a uniform rate of drying and dispatch, then the maximum wet storage requirement is:

fw*Q where fw (the wet storage factor) = (1 - tr/td);

and the maximum dry storage requirement is:

fd*Q where fd (the dry storage factor) = (1 - td/to).

More complex models are required where the rates of receival and out-turn are less clearly defined; for instance at a shipping import terminal where the rate of receival will depend on ship arrival rates, berth availability etc. and where out-turn rates may depend on the inland transport system. In such situations computer models are very helpful in optimising various design parameters including the storage volume, number of berths, ship unloader capacity and out-turn capacity. An optimum-cost solution can thus be determined through sensitivity analysis, by varying the values of the input parameters.

Specialised software is available for such modelling exercises, however in simpler cases models can be

developed on spreadsheets to produce satisfactory results.

Specialised programming languages are available which are especially useful in simulation modelling 'systems', for instance, where it is desired to look at complete storage and handling systems in a region. Such languages are available for PC applications include SLAM II (produced by Pritsker Corporation of the USA), SIMAN (produced by Systems Modelling Corporation of the USA) and GPSS/H (produced by Wolverine Software Corporation). These modelling languages are not inexpensive, and require training to use them effectively.

Selection of Storage Type

Once a storage need is identified, the choice arises as to the type of store that is most suitable for a particular application. The following storage options may need to be considered: round or rectangular, tall or short, steel or concrete, flat floored or hoppered, permanent or temporary.

Some basic guide-lines, or principles, are offered:

(i) Round or Rectangular

In terms of structural cost per tonne of storage, round stores are generally more economical than rectangular ones. The reasons are simple:

Firstly: grain exerts a horizontal pressure on the structure which contains it. A round store will resist this pressure through the development of hoop tension forces which are very efficiently resisted (eg by steel

reinforcement). A rectangular structure must resist grain loads through the development of bending stresses which are less efficiently resisted than tensile loads since both tensile and compressive forces have to be resisted. In addition, in the case of a rectangular 'horizontal' store, the walls act as retaining walls and their foundations have to resist overturning moments caused by the grain loads. Foundations for cylindrical structures have mostly to resist the vertical loads imposed on them from the walls.

Secondly: the roof structure of a rectangular structure has to carry its loads in bending, compared to the roof of a cylindrical structure which can be designed as a shell (for instance a cone), which carries its loads in direct compression and tension.

Another important advantage of cylindrical structures is that they have less joints. In the case of silos where the bins are independent (i.e. not connected to each another), there is a joint between the wall and the floor, and a joint between the wall and the roof. It is thus usually a relatively simple matter to seal these joints to make the structure air-tight and suitable for fumigation. Ideally the roof should be rigidly attached to the wall, since this not only makes sealing easier, but also greatly increases the stiffness of the wall in resisting bending stresses. In such cases silicone type sealants are useful for sealing the roof-wall joint, however where a sliding joint is required bituminous based mastic sealants sandwiched between the joining surfaces have been successfully used.

Rectangular structures, by comparison, have more joints (for instance at the comers) and by the nature of their construction, sealing for fumigation is generally more difficult to achieve.

Horizontal stores have another inherent disadvantage, in that they require more complicated and longer conveying systems to place grain in them. Usually an internal conveyor is required with a tripper (or similar device) to spread the grain over the floor surface. A cylindrical store, on the other hand, requires only a central point for filling.

(ii) Tall or Short

In the case of flat bottom stores, structural efficiency is also increased by minimising the height of the structure. For a given volume of storage, the lower the height of the walls, the more grain pressure is applied directly to the floor surface and the less load there is on the walls. Furthermore, the minimum structural surface area (and hence cost) for a given volume of grain, is achieved if the wall height is relatively low. For instance in the case of a cylindrical 'tank' with a conical roof, the minimum surface area of walls and roof is achieved when the wall height is around half the radius of the bin. It is thus no coincidence that the lowest cost stores are generally in the shape of squat cylindrical 'tanks' where the walls are relatively low compared to the diameter.

To take an example: a rectangular warehouse or shed structure may typically have a wall height of say 8 metres, and a length about 21/2 times the width. Thus to store 12,000 tonnes of corn (or say 16000 cubic metres) with a repose angle of 30, it may be calculated that the length of the shed will be about 60 metres and the width 24 metres. By comparison, a tank store with the same volume and same wall height will have a diameter of about 41 metres. A comparison of the structural surface areas of the two alternatives gives the following results:

Table 7.1. Comparison of structural areas for 12,000 tonne stores.

Comparison of Structural Areas for 12,000 tonne Stores		
Area	**Warehouse**	**Tank**
Wall Surface	1510 m*	1000 m
Roof Surface	1660 m	1524 m

Floor Surface	1440 m	1320 m
Total Area:	4610 m	3844 m

*** Including 'gable' end walls.**

Since the structural components are represented by the surface areas, then the comparison can be used as a preliminary gauge of relative cost. Additionally as mentioned earlier, the walls and roof of the tank store will usually be lighter and less costly than those of the warehouse.

Tank storage is not, however, suited to all situations; for instance where high throughputs are required it is usually desirable to have a self-emptying bin using a sloping floor. In such cases, it is more economical to design higher walls of smaller diameter: to minimise the cost of hopper bottoms (which are usually suspended above ground level) and the risks of ground water infiltration, and to facilitate conveyor design and installation. In instances where land values are high, or where space is limited, it may be expedient to opt for tall bins, even with flat floors to maximise space utilisation.

The chief disadvantage of flat bottomed stores is associated with the difficulty of emptying them and in removing the 'dead' grain that is not discharged by gravity. There are various means of achieving this; for instance portable conveying equipment may be used, or pneumatic systems, or front-end loaders. Another commonly used alternative is the sweep conveyor (usually a screw or auger) which automatically rotates about the bin centre and draws the grain towards the discharge point. Sweep conveyors are usually buried under the grain when the bin is full, and operate only after gravity discharge is completed. Sometimes they are suspended above the grain surface and lowered with winches to perform their function. Either way, it should be born in mind that the investment in permanently installed sweep conveyors can be high, and is seldom warranted if they are to be operated only once or twice per year.

Nevertheless, where low throughputs are required, such as when a store is to be filled and emptied only two or three times a year, the lower capital investment in a large diameter flat store outweighs the additional capital and operational costs associated with emptying it. An analysis of capital and operational costs is usually necessary to evaluate minimum cost solutions where a store may be emptied more than (say) five times per year.

(iii) Construction Materials

The choice of construction material is usually between steel and concrete, though in some countries timber or masonry are still used as alternatives.

The choice between steel and concrete is dependent on a number of considerations, all of which ultimately come down to capital and operational costs. The fact that in most countries steel and concrete are both so widely used indicates that these costs are generally not dissimilar.

Where price considerations do not dictate the type of construction, the following observations may be helpful:

- **Steel silos are often quicker to erect than concrete ones (though this is not universally true).**
- **Steel silos provide excellent storage where grain is dry. Where grain moisture content is high, there may be a greater likelihood of moisture migration developing due to the heat conductivity of the steel causing temperature gradients to develop between the inside and outside of the grain mass. This in turn can result in moisture condensation on the surface of the grain.**
- **Welded steel silos will remain gas-tight throughout their lives since they are not subject to cracking or differential movements. They are however subject to corrosion and require maintenance to keep**

the paint coatings effective. Choice of coating system is an important consideration, as it will effect both capital and maintenance costs; paint systems should be selected to suit particular requirements and expert advice should be sought, particularly in potentially corrosive environments.

- Proprietary bins made from light gauge bolted steel panels are a low cost storage option (Figure 7.4). They can be difficult to seal adequately for fumigation due to the large number of bolts requiring sealing (8,000 to 10,000 in a 1000 tonne silo). With light gauge steel panels there is a likelihood of distortion of the bolt holes and relative movement between panels when the silo is under load. Choice of sealing washers under bolt heads and nuts is important, and impregnated felt washers are reputed to perform much better than unreinforced neoprene types which tend to distort under pressure. Silicone type sealants are effective as a sandwich seal between panels, and specially formulated high build acrylic brush applied sealant is useful for sealing joints between roof and wall, and between floor and wall. The acrylic is usually reinforced with fibreglass or similar fabric.

Some suppliers give warranties that their bins can achieve and retain their air-tightness. Where this is proven to be the case, this type of bin can be quite satisfactory for longterm storage. The extra cost of sealing such bins is in the order of US$ 5.00 per tonne.

- Another type of proprietary steel bin is the Lipp silo (Figure 7.5), formed from spirally wound galvanised steel strip or coil. The process involves continuous rolling of the coil to form the cylindrical silo wall, including folding of the adjoining edges to connect and seal them. Only thin steel (up to 4mm) can be used for the process, hence vertical stiffening of the walls is necessary for larger silos, above about 1200 tonnes. Bins any larger than this (1,350 tonnes, 12 metre diameter) require internal vertical stiffening to prevent buckling of the thin steel wall. They are painted white to reflect solar radiation, thus minimising surface temperatures. Once the foundations are built, the roof prepared

and the rolling system is in place, erection of Lipp silos is relatively rapid, taking a few days per bin (similar to slip-formed concrete silos). It does however require skilled operators to keep the walls cylindrical and vertical. Another consideration is the need to use specially formulated steel strip which is manufactured in only a few industrialised countries.

- **Steel bins are less robust than concrete bins and require careful engineering design. For instance there have been many instances of steel bin failures resulting from unforeseen grain loads, particularly during emptying; eccentric loadings resulting from discharging the grain from the side rather than the centre of the bin should always be avoided in steel bins. Complex engineering solutions are needed to evaluate the buckling strength of the bin walls and also the complex stress combinations in hopper bottom steel silos at the joint between wall and hopper.**
- **Generally, where very tall bins are required (above about 25 metres high), steel becomes uneconomical because of the extra steel - often in the form of vertical stiffeners - that is required to resist compression buckling of the walls. By comparison, concrete bins only require enough steel to resist hoop tension forces, the vertical compression loads being carried by the concrete.**
- **Concrete is usually the preferred construction material in coastal areas or where high corrosion risk is severe (see above). As also mentioned above, it is also usually preferred where bins have to be very tall (above 30 metres).**
- **Tall concrete bins are usually constructed using slip-formed techniques. This involves the use of specialised equipment for moving the forms, however the technology is well known and used throughout the world. Because it involves the continuous pouring of concrete over several days, high levels of supervision are required to ensure satisfactory results. There have been many instances of poor construction quality and even silo failures as a result of inadequate supervision of the work as it is done.**
- **Another common method of concrete silo construction uses 'jump' forms, where the walls are**

constructed in individual lifts with joints every 1.2 metres or so. Good formwork and an experienced contractor are required to achieve good results.

Construction is slower than with slip-formwork, but labour requirements are lower also, and set-up time is usually less. Because it is a non-continuous process, supervision is somewhat easier. Careful treatment of the horizontal construction joints between each lift is necessary to ensure water tightness and gas-tightness.

Short walled 'squat' concrete silos are more commonly constructed using either fixed form (in-situ) construction, or 'tilt-up' methods (Figure 7.8). This latter system involves casting of wall panels on the ground, and lifting them vertically into position. Post-tensioned cables are used to hold the panels together and to resist the grain loads imposed on them.

- With tall concrete silos, it is traditional in many countries to build bins that interconnect with one another, forming 'star-bins' between the main bins and thus providing additional storage. However there are several disadvantages in this form of construction which should be considered. Firstly, their construction is more difficult than that of individual unconnected bins and costs are therefore higher; also the interconnections create bending stresses in the bin walls which may cause cracking to occur. This can lead to difficulties in achieving gas-tightness for fumigation. Often it is no less costly (in unit cost per tonne of storage) to build separate disconnected bins, and in most cases this should be the preferred option (Figure 7.9).

  Roof construction is also simpler with independent bins, and gas-tightness of the wall-toroof joint is usually easier to achieve. Independent bins do, however, use up marginally more land area (because of the space required between the bins) and conveying distances are also slightly increased.

  Independent (disconnected) bins also permit the use of conical roofs which are structurally more efficient and lighter than flat slab roofs. Cast-in-situ concrete conical roofs are expensive to form, however costs can be saved using steel, either welded on the ground and lifted into place, or using a

light structural frame and placing individual roof sheets into position. An alternative is to precast concrete panels and to place them into position one by one to form the cone.

- **Contrary to general belief at one time, it is not difficult to achieve and maintain high levels of air-tightness for fumigation in concrete silos without recourse to sealing membranes, post-tensioning or other measures. It is however easier to achieve and maintain gas-tightness in independent bins than in interconnected ones. Care in design is needed to minimise risk of wall cracking (by limiting tensile stress in reinforcing steel) - i.e. by providing adequate reinforcement to the walls, preferably in a double rather than a single layer. Good construction supervision is also necessary throughout the construction period to ensure conformity with design and specification requirements.**
- **Concrete silos are not well suited where CO2 may be used for disinfestation of grain. CO2 reacts aggressively with calcium hydroxide in the cement matrix of hardened concrete, forming calcium carbonate and water. The process is called carbonation, and it occurs naturally (but very slowly) with CO2 in the atmosphere, and slightly faster with the CO2 that is generated by respiration of the grain inside the silo. When high concentrations of CO2 are used in concrete silos for disinfestation purposes, large amounts of gas are 'absorbed' by the concrete giving rise to loss of concentration, and also the risk of high negative pressures developing in the bin if it is well sealed. Carbonation is not detrimental to the concrete, but it chemically neutralises the alkalinity of the calcium hydroxide which provides corrosion protection to the reinforcing steel. The use of fly-ash as a cement replacement is not recommended as it is reported to increase the rate at which concrete carbonates.**
- **Another type of storage is the "dome" or hemi-spherical shaped concrete silo, constructed using pneumatic inflation either before or after placement of the concrete. Some structural problems have arisen with domes constructed by inflation of the concrete when it is still wet (i.e. where the concrete is placed prior to inflation) due, it is believed, to difficulties involved in achieving concrete compaction and in maintaining a truly spherical shape to the shell. Domes constructed by "shot-**

crate" application of concrete after inflation of an outer sealing membrane are reported to be more robust. Typically, unit capacities are around 2500 to 5000 tonnes.

- The lowest-cost form of storage is the 'bunker' store (Figure 7. 11. Cross section of an earth-wall bunker store as used in Queensland, Australia. Precast concrete panels are an alternative form of wall construction which is commonly used.) where grain is placed on a prepared (and well drained) surface, and covered with a plastic sheet. This technique was first developed in Australia, where it is extensively used to supplement permanent storage capacity. Several million tonnes of grain are stored each year in bunkers. Capital costs are very low, however operational costs are higher because of the manpower involved in filling, covering and emptying them. Storage volumes of 25000 to 50,000 tonnes in one bunker are not uncommon. Despite the apparent risk to which the grain is put in bunker storages, losses are generally very low provided the storages are well drained, and regularly monitored to check for damage to the plastic covers. In Australia, losses are generally much less than 0.1%. Bunker storages are ideally suited for fumigation with phosphine provided care is taken in sealing of joints in the covers. The system has been adopted by many countries outside Australia.

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Sealed stores

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When a new grain store is being planned, there should be no question as to whether or not it should be possible to seal it effectively to make it air-tight for fumigation. The benefits of sealed stores are such that the small costs involved during initial construction (negligible in many cases) should not warrant consideration. Despite claims to the contrary, there are no disadvantages to building sealable stores, and when circumstances arise where ventilation is required (e.g. to aerate the grain), ventilators can be provided to allow this to be done.

Low-cost sealing is most easily achieved at the design stage. Retro-sealing of stores which have not been designed to be sealed can be expensive, and in some cases (particularly with small stores) it can be uneconomical. Sealing technology has been developed extensively in Australia where the warm climatic conditions are highly conducive to insect pests and where the need arose to develop means of effectively and economically controlling them. In Queensland, Australia, all stores constructed since 1975 have been built to strict gastightness standards, and for many years all new stores have been built to such standards throughout the country. In Western Australia, some 60% of stores are sealed, most of which have been retro-sealed in the last 15 years.

Fumigation of grain is much cheaper and more effective than the use of chemical protestants, and residue problems are avoided. Furthermore, once fumigated, grain in a sealed store can be maintained free from insects because the sealing prevents access for reinfestation. 100% mortality can only be achieved if grain is fumigated in properly sealed stores, which are routinely tested to check their gas-tightness (see below).

Diurnal temperature variations cause pressure changes in the air inside the store, and it is usually uneconomical to design stores (in particular their roofs) to withstand the pressure differentials that can occur. Some means of ventilating sealed stores is thus necessary to avoid these pressure exceeding safe values. Pressure-relief valves should be pressure actuated; in other words they should remain sealed when

pressures are below the critical value. One option is to use an oil bath with a baffle extending below the liquid surface such that air-pressure inside the store will displace the oil and allow air to pass below the bafle. Non-evaporative oil should used for the purpose.

Another type of valve uses counter-weighted diaphragms which lift off gasket seals when the pressure reaches a preset value such as are used in the oil industry for protecting oil tanks from damage as a result of internal pressure changes. See Figure 7.12 (see Figure 7.12. Oil-bath and Diaphragm-type pressure relief valves.) (opposite).

Steel bins are particularly prone to diurnal pressure variations due to the thermal conductivity of the steel. Internal air temperature changes can be minimised by painting the steel surfaces white since this will significantly reduce day-time steel temperatures by reflecting much of the sun's radiation. It should be noted that galvanised surfaces do not reflect as much radiation as white surfaces, and these should be painted white also.

Condensation, Moisture Migration and Moisture Diffusion

The question of condensation risk often arises in any discussion about sealed stores, especially in the case of steel structures. Yet there is little evidence to support the theory that sealed stores actually cause condensation. Theoretically, there should be less risk of condensation in sealed stores than in unsealed ones provided the grain stored in them is at or below its 'safe' storage moisture content.

In a properly sealed store at constant temperature, the grain and air mixture are in moisture-equilibrium with each other. Different grains have different moisture equilibria with air, and for each grain type, the

moisture equilibrium level changes slightly with temperature. Typically, however, grain at a 'safe' moisture level of 12 to 13% is in equilibrium with air with Relative Humidity of about 65%.

Condensation will occur only where the air temperature drops below its Dew Point. In the case of a grain storage, it is only the air in the 'head-space' above the grain surface that is likely to experience any rapid decline in temperature (e.g. at night time), since the grain itself is an excellent heat insulator, and temperatures within the grain mass will change only very slowly. From a psychrometric chart (Figure 5. 3) it can be seen that air at 65 % RH and 25C will need to cool to 18C before reaching its dew point. Cooling rates can be quite rapid with steel surfaces, however the air inside will lose its heat mainly through convection which will be much slower. In the process, the RH of the cooled air will be reduced by grains at the surface absorbing water vapour. It should be noted that only very small quantities of water are involved, and that the change in grain moisture content will be very small. Even if condensation on the underside of the roof was to occur, the amount of water that would be deposited would be very small. For instance, a 40 metre diameter tank silo with 1 metre of head-space above the grain has a head-space air volume of around 1500 cubic metres. If the head-space air is initially at 25C and 65% RH, and it cools to 10C without moisture absorption by the grain, then (from the psychrometric chart) the initial air moisture is 13 grammes per kilo-gramme of dry air, and the final moisture is about 8 gm/kg. From this it can be calculated that the amount of moisture condensing would be around 9 kg, or enough to raise the moisture content of the top centimetre of grain by 0.08%. Where bins are only partially filled with grain (i.e. where there is a large head-space volume) there is potential for an increased amount of condensation. However the total amounts of water remain low provided the store is sealed and not open to entry of moist air from outside.

Experience in Australia suggests that problems with condensation do not occur in sealed stores when the grain is kept at or below its safe moisture level. Problems will occur if grain moisture levels are high, or if

insect infestations occur, since in both circumstances biological activity will cause a localised increase in temperature and moisture content. This creates thermal instability in the grain mass, resulting in a convection movement of air and moisture which in turn enlarges the volume of affected grain. This chain reaction can ultimately result in massive spoilage with wetting and crusting of the grain surface if not controlled. Crusting is likely to occur whether the store is sealed or not, the problem emanating from within the grain mass itself, and is a result of poor storage management. Sealable storage provides a management tool which can be used to reduce the risk of such occurrences.

Moisture diffusion is not the same as moisture migration. It will occur in a grain mass in which temperature differentials exist for extended periods of time, such as when warm grain is kept in storage during cold winter conditions. This has sometimes been reported to cause condensation problems in sealed stores. It may be noted that diffusion is a physical process of moisture and heat redistribution, which is quite separate from moisture migration resulting from insect or fungal 'hot spots' which are heat generating. Such situations are, however, better handled by aerating the grain to equalize temperatures, than by selecting ventilated (or unsealed) structures for grain storage. It may be noted that without aeration, average temperatures in a grain bulk will follow average outside temperatures with a delay of 2 or 3 months, depending on the size of the bulk.

Methods of Sealing

The easiest stores to seal are fully-welded steel silos, since the structure is effectively sealed by virtue of its welded construction. Concrete silos can also be sealed with ease provided joints are properly detailed, and care is taken to prevent cracking of the walls (as discussed above). In either case (with both steel and concrete silos), attention is needed to the design of openings in the structures: grain inlets and discharge

valves, man access doors, etc. These must be fitted with suitable gaskets to ensure sealing when closed. Sealable discharge valves require careful detailing, since they also have to withstand grain pressures. Various methods are commonly used which overcome this problem (Figure 7.13. Two alternative arrangements (schematic) for sealing silo discharge valves. A, a valve plate which can be lifted to seal against the silo base; and B. a flexible seal attached to the silo base which can be tightened down against the valve plate.).

As discussed earlier, bolted light-gauge steel bins, and other similar structures such as steel sheds and warehouses, are less easy to seal unless special care is taken during design and construction to ensure that all bolts are fitted with suitable sealing washers, and joints between adjoining plates are carefully sealed with appropriate sealants. Silicone sealants are well suited to sealing surfaces which are to be fixed together, such as overlapping sheets of iron. Silicones should be 'neutral cure' type which will not cause corrosion of the steel surfaces. Joints between roof and wall require special detailing to minimise the gap between them to allow easy sealing.

Another method of sealing of joints, particularly when retro-sealing structures, involves the use of high-build "co-polymer" acrylic coatings. These are easier to apply than silicone sealants, and can be either brush or spray applied. High quality coatings can bridge small gaps, and will remain flexible enough to accommodate movements over a long period of time. This is particularly useful for sealing existing joints which cannot be opened easily for the application of silicone type sealants. Acrylic coatings require minimum surface preparation and can be applied over concrete to seal cracks, and also to steel surfaces to seal over joints.

When gaps are wider than about 2mm, acrylics perform better if a flexible fabric 'bandage' is used as a bridging medium to support the coating. This is especially the case if relative movements across the joint

are likely.

Joints with gaps wider than about 10mm can be sealed with closed cell polyurethane foam, which can be spray-applied over adjoining surfaces to act as a bridging medium. In the case of very wide gaps, solid infill such as light gauge steel can be used in combination with other sealants. Polyurethane application involves spraying of two liquid chemical components which, when mixed together in the spray gun, expand on contact with the air to form a rigid foam.

Testing for Gas-Tightness

Testing of stores for gas-tightness should be carried out when they are commissioned. It should also be carried out routinely each time a fumigation is to be undertaken. The standard gas-tightness test was evolved by the CSIRO Stored Grain Research Laboratory, Australia, in the early 1970's and has proved an easy and effective means of determining the suitability of stores for effective fumigation.

The test involves applying a positive or negative pressure differential between the inside and outside of the sealed structure, for instance by means of a small fan or air compressor. Once the test pressure is reached, the air supply is cut off (and sealed) and the drop pressure recorded over a period of time. The acceptance criterion for an empty store is that the time taken for the pressure to drop to half its initial value (its half-life decay time) should be not less than 15 minutes. For a full store the time should be not less than 8 minutes. Test pressures are normally in the range of 0.75 to 1.5 kPa, depending on the strength of the structure being tested. Tests should be carried out at times of relatively constant air temperature so that pressure decay periods are not affected by temperature generated pressure variations.

It may be noted that the pressure decay standard is independent of storage volume. The standard is thus much more tolerant of air-leaks in large stores than in small ones. It can thus be deduced that small stores are more difficult to seal than large ones, since much more attention has to be given to sealing of small leakage paths. Nevertheless, farm-bins of 50 and 100 tonne capacity are often sealed in Australia, and a growing market exists there for sealable bins sold by small-bin manufacturers.

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Aeration

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Ambient Aeration

Aeration is a process of forcing air through grain to reduce its temperature. It is a very useful storage management tool which can preserve grain from deterioration, especially where the moisture content of the grain is above its safe level. Aeration can be used as effectively in sealed stores as in unsealed ones - sealed stores merely requiring the provision of an air-exhaust ventilator which can be sealed whenever fumigation is to be carried out.

In terms of storage design, the requirements for ambient aeration are simply (a) to provide some form of perforated ducting on the floor through which air can be blown into the grain, and (b) venting above the grain for air exhaust. (With downwards aeration the floor ducting is used for exhausting the air and the roof opening is the air inlet.) Floor ducting can be in the form of corrugated circular or semi-circular ducts on top of the floor surface, or troughed ducts flush with the floor surface. The latter are more costly, but allow for easier removal of grain from horizontal floors.

Good design of aeration systems is essential for efficient cooling. For instance, ducts must be of adequate size for the required air-flow, and should be located to ensure good distribution of cooling air throughout the grain mass. In general, duct sizes should be such as to limit air velocities to no more than 10 m/s, and duct surface area should be sufficient to limit air velocity at the duct/grain interface to around 0.2 m/s. Detailed discussion of duct design is beyond the scope of this bulletin. However, besides the many papers on the subject, there are now several computer software packages which can be used for their design.

Reducing grain temperatures by aeration offers numerous benefits. It reduces the rate of insect population growth; it reduces the rate of microbial (or mould) development; it preserves germination viability and it prolongs the effectiveness of insecticide chemicals where these are used. If temperatures can be reduced low enough (to around 10C wet bulb), insect population growth rates can be stopped altogether. In all cases, it is the wetbulb temperature which governs the benefits that can be achieved from aeration cooling.

It is apparent that ambient aeration requires periods (e.g. at night time) of low wet bulb temperature to effect cooling of the grain. Such conditions are not always available in tropical climates, particularly during the wet season. The major requirement during such times is more often on drying rather than cooling, however where aeration cooling is required or warranted (for instance after drying, or to delay mould development prior to drying), some air cooling and/or dehumidification may be needed to achieve the requisite conditions (see below).

To be effective, aeration requires the use of a well defined strategy and a good control system for operation of the fans. Where these are not effective, aeration can result in high costs for little or no gain, and can even be counter-productive. The key to successful aeration, is to design the cooling rate to minimise grain spoilage. For instance in the case of high moisture grain, it may be beneficial to begin with high rates of aeration to achieve a modest temperature reduction so as to delay the onset of fungal activity. Subsequently a reduced rate of aeration can be used to achieve further temperature reductions at a slower rate. Selection of appropriate ambient air to achieve optimum temperature loss is the basis of aeration strategy.

When air is forced through a grain mass, it carries with it first a 'temperature front', and then a 'moisture front'. The temperature front moves quite rapidly, while the moisture front moves very slowly. Above the temperature front, the grain remains at its initial temperature and moisture level; below it the grain is at the wet-bulb temperature of the aeration air. Below the moisture front, the grain is at the same RH as the aeration air. With aeration, the aim is to ensure that the temperature front is a cooling front, and that heating fronts are largely avoided. Ideally, aeration air should also be selected to avoid the creation of wetting fronts, however at normal rates of aeration the speed of the moisture front is so slow that wetting problems seldom cause more than very localised damage.

The speed of the temperature front is governed largely by the rate of air-flow, and the temperature of the aeration air. Surprisingly, it is largely independent of the initial grain temperature. To design an aeration system, it is necessary to know (approximately) the climatic conditions so as to define the condition of the ambient air that is likely to be available for grain cooling. Also the initial temperature and moisture levels of the grain need to be known, so as to determine the maximum time that can be allowed for the cooling front to pass through the grain before deterioration begins. Given these factors it is possible to calculate fan and duct sizes, and to predict the performance of the system in operation. As already stated, several

software packages are now available which can be used to perform the calculations and produce an optimum design for fans, ducts, etc.

Numerous control systems are available for controlling fan operation, some being relatively simple, and others more complex. Most are based on micro-processing technology, and they differ principally in the degree of sophistication in the monitoring systems that they use. One of the simplest (yet effective) systems is the 'set-point' controller which monitors only dry-bulb ambient air temperature. It is designed to provide a predetermined amount of aeration (in terms of the number of hours per week that the fans will operate) by automatically adjusting the minimum 'set-point' air temperature at which the fans will start. By continuously monitoring air temperatures and fan operating hours, the controller calculates the optimum periods for aeration to achieve maximum temperature reductions, whilst ensuring a predetermined number of fan hours per day. The number of fan-hours of aeration can be adjusted manually; by reducing the fan-hours, the controller is able to select colder air to achieve lower grain temperatures, however the time taken to cool the grain will be increased. The strategy for grain stored at high temperature is thus to begin with 'rapid' aeration during which the controller select the coldest air whilst achieving fan operation for (say) 50% of the time until the cooling front has passed through and the entire grain mass has been initially cooled. This may take a week, depending in the air-flow rate. The controller is then adjusted so that the fans to operate only during the coldest 15% of the time. This will cause a further reduction in temperature (of maybe only 2 or 3 degrees), however this cooling front may take a month to pass through the grain.

More sophisticated (and more expensive) controllers may measure not only dry and wetbulb air temperature, but grain temperatures as well. Such systems can ensure that aeration will only occur when ambient air is sufficiently cool to maintain a cooling front - i.e. by avoiding all air that is warmer than the grain. Such a strategy will provide no aeration at all at times when air temperatures remain above grain

temperature. This may not be a problem if the grain is dry and insect-free, but it could result in major problems if localised heating goes undetected.

Refrigerated Aeration

Aeration with refrigerated air achieves much lower temperatures when ambient conditions are warm. It is an expensive method of disinfestation compared to fumigation, but can be justified for storage of grains such as malting barley and seed grains in hot conditions, where maintenance of germination viability is important. Technically, the requirements are the same as for ambient aeration, except that no fan control is required since the system will operate 100% of the time until the temperature front has passed through the grain mass. An evaporative cooling system is used to reduce air temperature and to remove moisture. It is useful to place the fan between the cooling unit and the store, so that heat from the fan can be used to raise the air temperature by a few degrees, thus reducing its relative humidity and minimising risk of grain wetting.

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

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Costs of bulk storage

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As a rough rule of thumb, the costs of modern bulk grain storage and handling facilities can be broken down roughly as follows:

Storage Component:	40 to 60%
Structures and Supports	10 to 20%
Mechanical Equipment	20 to 40%
Electrical and Controls	10 to 20%

Obviously, there are many instances where storage costs are much less than 40% - for instance in high throughput facilities where the 'storage' component is no more than a shortterm buffer to allow optimisation of the use of the handling equipment.

But in true 'storage' situations, where the purpose of the facility is to hold grain for an extended period of time, it is generally the case that the storage structures account for the largest component of the total cost. Thus it is normal practice to develop a design for a grain handling facility around the storage component; in other words to estimate the storage volume required, evaluate the type of store best suited to the requirements, and then to design the conveying and other systems to suit.

The cost of a store depends to such an extent on 'unit size' (i.e. the size of each individual bin or storage unit) and on locality (i.e. cost and availability of labour and materials), that the optimum solution for one

given set of circumstances may be quite different to another. However as a rule of thumb, the following points may be helpful (based on 1992 costs):

- **Bunker storage is the lowest cost storage available. It is also the quickest to build, and thus provides an ideal solution for emergency storage purposes. The construction cost can be as low as US$2.00 per tonne, depending on topography, drainage requirements etc. Operating costs can be high, and are to a large extent dependent upon the local cost of labour. Plastic covers may cost as much as US$2.00 per tonne or as little as US$0.50 per tonne, depending on material used. Heavy duty PVC covers can be expected to last three or more seasons (depending on the rate of Ultra Violet degradation), while lighter weight polyethylene covers are best replaced each season.**
- **The larger the size of a storage unit, the lower is its cost per tonne of capacity; current prices for large (greater than 5000 tonne) tank stores in developed countries are in the range of $US25 to $US35 per tonne, excluding handling equipment. Smaller tanks of 1000 or 2000 tonnes capacity may cost $US40 per tonne.**
- **In terms of cost per tonne, flat bottomed tank storage is generally cheaper than sheds or warehouses, even for stores of 20,000 to 30,000 tonnes capacity. There are few instances where unit volumes larger than this are justified, bearing in mind the difficulties of segregating grain in warehouse type stores.**
- **Tall hopper-bottom silos are cost justified in high throughput situations, but their cost (per tonne) is likely to be at least twice that of tank storage. Costs of $75 to $100 per tonne (or more in some instances) can be expected.**
- **The extra costs associated with building sealed storage facilities are negligible if they are properly designed.**

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Integrated pest management (IPM) in the control of storage insects

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The characteristic problems of stored-grains pest control in the tropics, with particular reference to developing countries, are concisely described by Taylor, Golob and Hodges (1992). They indicate the crucial importance of effective pest control for a broad range of storage entrepreneurs, including resource-poor farmers, commercial operators, and national marketing organisations; and a wide variety of storage situations in which simple, traditional on-farm systems and large scale bag-storage systems predominate. Bulk storage occurs quite commonly for small bulks, at farm level; but is less common than bag-storage in large scale operations except at large grain mills and at some central marketing depots.

Pest control measures, in general, have to be integrated into an operational system, be it large or small in scale, if they are to be effectively applied. This is a basic principle, not a novel concept, but it connects well with the modern idea of Integrated Pest Management (IPM). The use, in that term, of the word 'management' is appropriate, especially with regard to the need for the integration of pest control measures into management systems, but it should be remembered that the two words, 'management' and 'control', are almost synonymous. The fundamentally important emphasis should be placed upon the word 'integrated' .

Integrated pest control can be defined as the acceptable use of practicable measures to minimise, cost-effectively. the losses caused by pests in a particular management system. For the measures to be cost-effective they must be appropriate to and acceptable into that system. They may be simple or complex but they must suit the system objectives and its technical capabilities. Furthermore, in this context, cost-effectiveness requires that all costs and benefits, including sociological and environmental effects, should have been taken into account.

The term integrated pest management is used to imply that a flexible and technically informed approach is also required. In defining this term it may be considered necessary (McFarlane, 1989) to specify the

inclusion of scientific and cost-effective pest monitoring procedures which permit judicious adjustments to the timing, choice and intensity of control actions. It may also be advisable to point out that specific pest control measures, as distinct from general crop or commodity husbandry practices, should generally be omitted unless the circumstances warrant and permit their cost-effective inclusion.

Insect pest management for stored grains, like preharvest pest management, can thus be seen, historically, as a traditional approach in which good husbandry is the primary requirement. Unfortunately, it must also be acknowledged that the advent of readily available, relatively inexpensive synthetic insecticides has led to considerable over-dependence upon these hazardous tools with, in some cases, a consequent neglect of basic good husbandry. The current emphasis upon integrated pest management is, in effect, a reassertion of the need to put traditional good husbandry in place as the fundamental basis of pest control. In grain storage, as with other durable agricultural products, it is good commodity management and good store management which are the major prerequisites (Tables 8.1 and 8.2).

The various options for more intensive insect pest control, which are also listed in Tables 8. l and 8.2, include several which are themselves based upon traditional concepts of pest management. Thermal disinfestation, cooling and hermetic storage are examples. These latter two methods are also examples of the opportunities, provided by the process of storage, to manage the generally enclosed storage environment in such a way that insect pests are prevented from multiplying or, as in efficient hermetic storage, effectively eliminated. Preharvest problems of insect pest control are rarely, if ever, so easily managed!

Control of the storage environment is thus an essential element in grain storage pest management. It involves, primarily, the controls on in-store climate and infestation-pressure which can be achieved by technically sound store design and construction. Equally important, however, is the climatic control

attainable by scientific management of the commodity to ensure that the stored grain is itself both dry and cool when loaded or, in ventilated stores and bins with aeration equipment, that the storage procedure achieves drying and cooling sufficiently rapidly. In a fully loaded store it is the stored grain itself which largely determines and stabilises the temperature and humidity conditions in the store.

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

Control of grain quality before storage, to minimise the intake of heavily infested and badly damaged or uncleaned grain, is feasible and is commonly practiced to a considerable extent. Even at the small farm level it is possible to segregate the crop at harvest, especially with maize on the cob and unthreshed sorghum and millet, selecting relatively undamaged material with good storage potential and setting aside the more evidently infested or otherwise damaged material which, if there is no other option, can at least be used first. By such means, the rate of deterioration due to insect infestation can be considerably retarded in the main stock of stored grain. There is little doubt that some subsistence farmers use this form of commodity management fairly effectively. Certainly, one can sometimes observe onfarm grain stocks, that have received no special insecticidal treatment, with relatively little insect damage after several months storage at an ambient temperature that would permit the rapid increase of any well-established initial insect population.

Scientific approaches to grain storage pest management, having regard to grain storage as a part of the

food production and distribution management system, have sometimes referred to the biological ecosystem concept as a means of comprehending grain storage processes and problems. In a recent contribution Dunkel (1992) has applied ecosystem principles in a broad analysis directed towards an improved understanding of physical and biological interactions including socio-economic factors. The purpose was to generate improved understanding of the stored grain ecosystem and to identify objectives for future postharvest research. This treatment of the subject should serve to enhance the growing awareness of storage as a system within a system and to stimulate systematic and objective analysis of grain storage problems. Whether or not one prefers to use the term 'ecosystem' is less important and this somewhat academic term should not be allowed to obscure the main issues.

Table 8.1. Prerequisites and options for on-farm storage pest management

Essential	**Optional**
Basic IPM	**Additional measures**
Site and store management (protection from birds, rodents and weather plus basic hygiene)	**Maintenance of conditions favourable to natural control:** **- by cooling (where feasible) by insect parasites, pathogens, etc. and/or** **Thermal disinfestation by solar heat and/or Treatment with traditional additives (if sufficiently available and effective)**
	or

Commodity management (cleaning, drying, etc.)	**Treatment with synthetic insecticides (if suitable formulations sufficiently available and effective)** **or** **Hermetic storage (pits or metal drums, etc.)**

Table 8.2. Prerequisites and options for storage pest management at main depots

Essential	**Optional**	
Basic IPM	**Disinfestation**	**Prevention of reinfestation**
Site and store management (protection from birds, rodents and weather plus basic hygiene)	Insecticide admixture * Fumigation! or Thermal *	Provided by the treatment Residual insecticide sprays?! Physical protection! (Sheeted stacks or packaging) or
Commodity management (cleaning, drying, etc.) - with bulk storage if appropriate	Irradiation * Hermetic! Controlled atmosphere! Grain cooling!	Insecticidal space treatments! Provided by the system Provided by the system

		Provided by the system

Notes: * May entail double handling for in-bag storage. Efficacy doubtful. Extra management skills and/or other inputs required.

The integration of various control techniques, within the framework of integrated pest management, has become a focus for research in stored products work (Evans, 1987a). The importance of a multidisciplinary approach to stored grain research has also been stressed (White, 1992). This is very valid but it is useful to recall that a great deal of the research done in the past has been of this nature. It was pointed out (McFarlane, 1981), at a stored products pest management symposium held in 1978, that the need for an interdisciplinary approach is generally well-known. Entomology, mycology, chemistry, engineering and food science are commonly involved, but effective integration of technical solutions is often lacking; possibly because some of the more pragmatic disciplines, notably economics, sociology and business management, are not always sufficiently involved. It is the interface between the research team and the storage managers, whether these be individual farmers or a large storage organisation, which may sometimes be the most crucial barrier to progress.

A clear perception of the need for solutions which can be integrated into the management system, because they meet the business objectives and can be accommodated within existing management capabilities, is probably the most important requirement (Hindmarsh and McFarlane, 1983). In this context it is of some interest, although not very surprising, that a correlation has been found amongst farmers in India between 'grain hoarding capacity' (which relates to the farmers' existing business objectives and capabilities) and the adoption of improved storage practices (Thakre and Bansode, 1990).

Modern theories of pest management have also generated the concept of economic control thresholds (ECTs). An ECT is most simply defined as the level of pest damage which justifies, in cost/benefit terms,

the expenditure of resources upon control actions (Hebblethwaite, 1985). It is always a variable threshold because the costs and benefits of any action will depend upon the situation and its circumstances. An ECT is situationspecific. This is especially true, and not only for postharvest pest control, when one considers the great differences in opportunities and constraints between the small farm level in developing countries and more sophisticated levels of operation. Nevertheless, it is possible to generalise to some extent (Figure 8.1. Conceptual control thresholds for insects on stored grains). For insect control in grain storage the ECT is likely to be at or very close to zero:

a. **where consumer demands place a high value on freedom from insect damage and/or freedom from any sign of insect infestation;**
b. **where there is a definite intention to store grain for a protracted period, in which substantial insect damage can be predicted, and where the eventual market is not insensitive to loss of quality.**

In both cases the assumptions are made that at least one potentially cost-effective package of control measures is available and that the package provides for sustained control: including efficient prevention or control of reinfestation. In most sophisticated situations, where consumer quality standards are likely to be high, these will be valid assumptions. Otherwise the ECT could not be zero and the required quality standards would have to be met by reconditioning the product. The losses, including reconditioning costs, would then have to be borne by the system or the consumer. A real economic loss would have occurred, masked by marketing tactics. Such events do, undoubtedly, take place.

Where grain is being stored for domestic use, or for eventual sale in an uncritical market, the ECT may be well above zero. This can be true even when all parameters of economic damage are considered because, in fact, the true economic significance of a low percentage of insect damaged grain may be virtually nil. The actual loss in real food value is likely to be negligible and the market value of the associated weight

loss, if saved, may not offset the full costs of pest control actions.

The need to minimise the cost of insect pest control is a major factor militating against the extensive use of some of the more 'environmentally friendly' measures which might otherwise be preferred to the continued use of suitable fumigants and contact insecticides. However, it must also be acknowledged that chemical pest control measures, in grain storage, are often not only the cheapest but also the most reliably efficacious of the possible options. Where this remains true, and for as long as such treatments are accepted as generally safe, one important requirement for IPM in grain storage will be to ensure that chemical measures are recommended only where they can be safely and efficiently used and only when they are economically justifiable.

The economic justification of control measures, including where necessary the use of chemical pesticides, should take account of all costs and benefits. Many of these may be assessable only in subjective terms that are greatly dependent upon local attitudes and sensibilities. However, measurable losses of quantity and certain quality parameters can be objectively determined. A manual of methods for the evaluation of postharvest losses (Harris and Lindblad, 1978) is available and provides useful information, subject to a need for modification of some methods in particular circumstances. A critical review of the methodology (Boxall, 1986) gives further guidance based upon experience gained, since 1978, from field work in many developing countries. Choices among methods, several of which have become subjects of considerable controversy, should always be made with due regard to the actual circumstances and the prevailing objective. There is no single 'best method' for all circumstances and, for practical purposes, operational facility and repeatability are generally more important that fine precision. From the storekeeper's viewpoint a demonstrable loss reduction from, say, 5% to 4%, however statistically significant, may be of little or no practical importance; whereas a reduction from 10% to 5% (or from 2% to 1% in a sophisticated storage system) may be of considerable interest: provided, always, that the demonstrated

reduction can be achieved in routine practice.

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Insect pests of stored grains in hot climates

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The insect species of most importance in the tropics as pests of stored foodgrains, including pulses (legume grains), are listed in Table 8.3. Recognition of these common major pests, at least to the genus level, is not difficult for a trained inspector and there are many useful recognition charts and some excellent keys to specific identification. One of the most recent is contained in a Training Manual "Insects and Arachnids of Tropical Stored Products: their Biology and Identification" produced by the Natural Resources Institute (Haines, C P [ed], 1991). This publication also contains summarised biodata for important species. Another, by Weidner and Rack (1984), may be more useful in francophone countries.

There are many other publications which illustrate the common insect pests of stored products and describe their biology. The familiar details are not all repeated here. Instead, the points which seem of particular importance with regard to pest status are discussed more broadly.

Table 8.3. Important insect pests of tropical stored grains or grain products

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

Notes:

***Now established in Africa as well as in the Americas. **Common only on very dry grain; especially in Sahelian North Africa. ***O. mercator (Fauvel) may also occur but is more commonly a pest of oilseeds.**

The grain weevils (Curculionidae) are well-known as major primary pests of stored cereal grains. They

are able to establish themselves on whole, undamaged grains of maize, sorghum, rice and wheat so long as the grains are not exceptionally dry. However, Sitophilus zeamais is the dominant species on maize while Sitophilus oryzae is dominant on wheat. Neither species is a significant pest of millets and other grains that are too small to permit the full development, within a single grain, of the weevil larva.

The bostrichid beetle Prostephanus truncatus (the Larger Grain Borer) is a highly destructive primary pest of maize, especially maize stored on the cob. This insect is now established in several East and West African countries following recent accidental introductions from its previously more limited indigenous range in meso-America (Dick, 1988; Golob, 1988; McFarlane, 1988a). The Lesser Grain Borer (Rhyzopertha dominica) is more cosmopolitan and is well-known as a destructive pest of most stored cereal grains including millet. It is not generally common on maize.

The bruchid beetles listed in Table 8.3 are the only significant pests of stored pulses. Acanthoscelides obtectus and the less cosmopolitan Zabrotes subfasciatus are generally restricted to dry beans (Phaseolus vulgaris) while Callosobruchus spp are generally restricted to the other legume grains, notably cowpeas and mungbeans (Vigna spp). The anobiid Lasioderma serricorne is sometimes reported as a significant pest of stored beans and other pulses but it is not a primary pest of foodgrains. It is, however, a considerable pest of cereal-based animal feeds, wholemeal flour and high-protein milling offals.

Apart from the one exception noted above (L. serricorne) all of these beetles are primary pests in the sense that they can initiate major damage to the grains and most of them are also able to commence their attack in the field before harvest. The other beetles listed in Table 8.3 are generally regarded as secondary pests which can be of major importance on grains previously damaged either mechanically or by other insects. The dermestid Trogoderma granarium is exceptional in that it can cause major primary damage but rarely occurs as a primary pest except in arid climates, or on very dry grain, where other

primary pests are inhibited by the dryness.

Of the moths (Lepidoptera) listed in Table 8.3 only the gelechiid Sitotroga cerealella is able to cause substantial primary damage to the grain kernel. Like the grain weevils it can also infest the grains before harvest and like the Lesser Grain Borer it is a considerable pest of millets as well as all the larger cereal grains.

The other moths listed are warehouse moths, and the rice moth Corcyra cephalonica is included here although it is less commonly abundant on other cereal grains. The larvae of all three species can do substantial damage as secondary pests. They can also attack the whole grain at the site of the embryo, which is typically excised completely, and may thus be of special importance as pests in seed grain stores.

Many other insects may occur quite commonly and sometimes abundantly on stored cereal grains especially when they are underdried or have been heavily infested by the major primary and secondary pests. Some of these are listed in Table 8.4. This list, although quite extensive, is not exhaustive. Most of the species included are capable of doing some damage to the grain and while several are unable to thrive in the absence of mould growth, or are most commonly predators and scavengers rather than grain feeders, their presence would be unacceptable to many consumers. Evident signs of their previous activity, in the form of insect fragments and waste matter, will be equally unacceptable where high quality commands a premium price.

Table 8.4. Insect species (additional to those in Table 8.3) found on underdried stored grain or grain residues

COLEOPTERA:	ANTHRIBIDAE	Araecerus fasciculatus Degeer
	BOSTRICHIDAE	Dinoderus spp.

	BRUCHIDAE CLERIDAE CRYPTOPHAGIDAE DERMESTIDAE LATHRIDIIDAE MYCETOPHAGIDAE NITIDULIDAE OSTOMIDAE PTINIDAE SILVANIDAE TENEBRIONIDAE	Bruchidius spp., Specularius spp. Necrobia rufipes Degeer Thaneroclerus buqueti Lefevre Henoticus californicus (Mann) Cryptophagus spp Attagenus spp., Dermestes spp. Corticaria spp., Lathridius spp. Typhaea stercorea (L) Carpophilus spp. Tenebroides mauritanicus (L) Ptinus spp.*, Trigonogenius spp., Gibbium spp. Cathartus quadricollis (Guerin) Alphitobius spp., Gnatocerus spp. Palorus spp.
LEPIDOPIERA:	OECOPHORIDAE	Endrosis sarcitrella (L)
PSOCOPTERA:	LIPOSCELIDAE	Liposcelis spp.

Note: Common only in cool upland tropics.

The psocopteran (psocid) species listed in Table 8.4, which include the familiar 'dust lice', sometimes mistaken for mites (Acarina), have received more attention in recent years than previously; both in the tropics and in temperate countries. In the latter, they have attracted attention as occasional pests of various commodities including skimmed milk powder. In the humid tropics they sometimes occur as troublesome pests of cereal grains, notably milled rice, on which they are sometimes very abundant (Rees,

1990). It has been shown that a psocid population can feed and multiply on damaged or imperfect cereal grains (Shires, 1982). When milled rice is exposed to very dense populations the feeding damage, on some individual kernels, can be massive (McFarlane, 1982). Whether or not such damage occurs sufficiently extensively to constitute an economically significant weight loss in storage practice has yet to be demonstrated. However, it has been shown (V. Pike, personal communication) that measurable weight losses can occur, especially on under-milled rice, and that the protein and lipid content of the infested rice may be reduced. The nuisance-value of these small insects, when they occur as dense, swarming populations in warehouses, is also considerable. Furthermore, surface scarification due to psocid feeding may improve the apparent whiteness of infested milled rice and thus obscure the visible evidence of mould growth and possible contamination by mycotoxins.

Pest status

The status of any particular insect pest may vary between different commodities, different varieties of the same commodity, different climatic regions and agro-industrial systems and between different socio-economic groups. It is affected by the form in which the commodity is stored (Figure 8.2. Pest status as affected by handling and processing.), by the environmental conditions and by consumer attitudes. As with the psocid problem, referred to previously, it may also be affected by the sensitivities of store supervisors and their work-force.

Key		

S.zm	Sitophilus zeamais	- on maize, sorghum and rice
S.o	Sitophilus oryzae	- on wheat, sorghum and rice
S.c	Sitotroga cerealella	- on all cereals
P.t	Prostephanus truncatus	- on maize
R.d	Rhyzopertha dominica	- on all cereals
T.c etc	Tribolium castaneum & other secondary beetles	- ditto
E.c etc	Ephestia cautella & other warehouse moths	- ditto
L.s	Lasioderma serricorne	- on all grains
A.o	Acanthoscelides obtectus	- on beans
C.spp	Callosobruchus spp.	- on cowpeas, etc.
*	Very low status (possibly negligible)	
**	Low status	
***	Low - moderate status	
****	Moderate - high status	
*****	High status	

Pest status may also vary between biotypes of the same insect species due to differences in the capacity to cause grain damage (McFarlane, 1990) or to adaptations to other foodstuffs. As an extreme example of this, although grain weevils are usually insignificant as pests of stored pulses there are biotypes of S. oryzae that multiply successfully on stored split peas (Holloway, 1986) and on mung beans (C P Haines, personal communication: including field records). Certain strains of S. oryzAe have been noted as having greater flight proclivity than others (Kiritani, 1959). This species, unlike the maize weevil S. zeamais,

does not usually fly very readily, although it has wings.

The influence of maize varietal characteristics upon the preharvest infestation of maize cobs by S. zeamais has been much investigated (Floyd and Powell, 1958; Giles and Ashman, 1971; Schulten, 1976). It is clear that the cob sheath, in those cultivars which produce sheathing leaves completely enclosing the entire cob, provides considerable protection against the weevil. Storage of cobs in the sheath, which does not significantly impair the grain drying rate in ventilated cribs, therefore reduces the status of the grain weevil as a pest and will be beneficial where weevils are the main threat (Dick, 1988). Even without the sheath, grains on the cob are considerably less susceptible to weevil attack than the shelled grains. The reasons for this have been clarified recently; by Kossou, Bosque-Perez and Mareck (1992). Unfortunately, maize on the cob, especially without the sheath, is more heavily attacked by the grain moth S. cerealella. The Larger Grain Borer Prostephanus truncatus is also favoured by storage on the cob, with or without the sheath. The impact of this pest in those African countries where it has recently established itself has been dramatic for this reason as well as on account of the more rapid and destructive grain damage caused by the adult borers (Golob, 1988).

The status of this new pest in maize-based farming systems in Africa, traditionally dependent upon cob storage as a modest pest management stratagem, has been such that pragmatic thresholds for control action are commonly exceeded (McFarlane, 1988a). In consequence, demonstrably cost-effective treatments of shelled maize grain with admixed powder formulations of suitable synthetic insecticides have been readily adopted in several regions where they were, formerly, less often used. As a further consequence, it may be that the overall insect control level has been considerably enhanced, since the recommended formulations are generally 'cocktails' of two active ingredients that can give effective control of a broad spectrum of storage insect pests (Golob, 1988).

The storage of sorghum and rough rice (paddy) in the panicle, millet on the head and cowpeas in the pod also serves as a modest form of insect pest management. However, the storage of unthreshed grains, although it may retard the build-up of infestation by some pests, does not prevent it entirely and different insects are affected in different ways. Thus, on sorghum, infestation by grain weevils is usually reduced but the grain moth S. cerealella is likely to be more successful (Giles, 1965; Wongo and Pedersen, 1990). On unthreshed rice and millet, for similar reasons, the grain moth will have increased pest status.

The low status of grain weevils as pests of millets and other small grains, previously mentioned, is due primarily to the limited grain size since the complete larval development, in these species, has to take place within one kernel. The lesser grain borer (R. dominica) and the grain moth (S. cerealella) are not so handicapped because their larvae are able to migrate, if necessary, from one kernel to another. However, the grain moth is a low status pest on large grain bulks and tightly-built large bag-stacks, where the beetles are serious pests, because the moth is unable to move freely amongst close-packed grains to lay its eggs and the first instar larvae are unable to travel more than a few centimetres in search of food.

Most storage insects, especially the important pests, are able to survive and multiply rapidly on well-dried grain. However, grain dried to below 12% mc inhibits the development of most species to some extent and on exceptionally dry grain (<8% mc) the grain weevils, for example, are insignificant pests. The grain borers remain of considerable importance at these low moisture levels and the "khapra" beetle (T. granarium) becomes increasingly important.

This insect assumes major pest status and dominance over almost all other storage insects at the very low moisture contents (down to about 4%) which equate to the extremely low humidities (< 20% rh) that characterise the most arid climates and, also, the insect ecosystem created by stored malting barley which is usually dried to this very low level and is not uncommonly imported into the tropics.

Factors affecting development and control

Grain moisture content considerably affects pest status but it is not a factor which can be cost-effectively manipulated, in most situations, to achieve sufficient control of insect pests. Cost-effective drying, in common practice, can achieve control of moulds and will lessen the problems of insect infestation; in particular it will greatly reduce the spectrum of pest species. However, it will not prevent significant damage by one or more of the major insect pests.

Insect development and population growth rates are more dramatically affected by temperature and here the developmental limits are more clearly defined and generally applicable. Upper limits for development and survival vary to some extent between species, with the grain borers again more resistant than the grain weevils, but temperatures above 45C are eventually fatal to all storage insects. At 50C most species will die quite quickly, within a matter of hours, and complete disinfestation of wheat grain can be achieved rapidly, economically and without damage to the grain by very short exposures to air heated to 60C (Evans, 1987b).

Rapid insect development occurs within a fairly narrow range of 5-10 degrees around the optimal temperature which, for most storage insects, is in the region of 30C. At temperatures nearer to 20C development proceeds more slowly and population growth may be considerably reduced. At 17C or less it is relatively negligible and pest status is consequently greatly reduced. However, even at 15C some species are able to continue feeding, to some extent, so that grain damage may very slowly increase. Insect populations will certainly not be eliminated at these temperatures and, while grain may often be held safely in cool storage, any eventual transfer to warmer conditions will bring about a resurgence of the suppressed infestation. Even in cold storage (at 6-9 C) some, at least, of the important insect pests of

stored grain can survive longer than one year (Wohlgemuth, 1989).

Insects require oxygen for respiration. Living grains, when sufficiently dry (12-13% me), are dormant and respire very little. Grain properties, including viability, are virtually unaffected in cool conditions by protracted hermetic storage. Insects, however, will use up the oxygen and eventually die. The traditional concept of sealed (hermetic) storage as a means of controlling insect infestation depends upon this. Most storage insects will die when the oxygen in the storage atmosphere is reduced, by the insects' respiration, to 2% (Hyde et al., 1973). With light infestation the process may take 6-8 weeks but, if airtight conditions are maintained, the infestation will be controlled and probably eliminated before serious damage is done. There is new evidence (Donahaye, 1990) that insects may adapt to low oxygen tensions and evolve strains with considerable resistance to sub-optimal levels even down to about 1%. However, it seems very improbable that any storage insect would multiply rapidly in such conditions.

Physical disturbance of grain, by turning it from one elevator bin to another, can reduce live grain weevil infestation to a considerable extent and thus retard its further development (Joffe, 1963). A more complete kill of all insect life stages can be achieved, by mechanical high-speed impact, in the entoleters included in the processing line of many grain mills. In small-scale storage it may be less easy to achieve the degree of disturbance necessary for effective control of grain weevil and other cereal grain insect pests, although very small quantities of grain held in small pots or gourds could be shaken sufficiently violently for this purpose. Bruchid pests of stored pulses may be particularly susceptible to control by physical disturbance. In the bean bruchid A. obtectus this may be because the hatched first instar larvae require an approximately 24 hr period to penetrate the bean testa (Quentin et al., 1991). These workers have shown that twice-daily 'tumbling' of small lots of stored beans, in partly-filled cylindrical containers, reduced bean bruchid populations by 97%. Daily sieving on a fair-sized coarse mesh can achieve similar results (M N Silim; private communication). However, the practicability of these proposed techniques, for

routine use by farmers or traders in developing countries, is unproven.

Insect behaviour patterns may affect pest status and pest control. Examples have been given of the ways in which adult oviposition behaviour and larval feeding behaviour can affect pest status in the grain moth and pest control in bruchids. The development of infestations (pest population development) may also be affected by, for example, the diapause habit which characterizes several storage insects including, most notably, the khapra beetle T. granarium. Diapause may postpone population development, usually in unfavourable conditions, and it may also impair the effectiveness of control measures; including fumigation and the use of contact insecticides as surface sprays for 'clean-up' treatments in empty storages. Locomotory avoidance behaviour, especially in the flour beetle T. castaneum (Wildey, 1987), is also of considerable interest.

Storage management, which may be described as the science of cost-effective storage organisation (McFarlane, 1988b), greatly influences pest development and control. It encompasses decisions upon the location of stores, storage periods and the quality control objectives for stored commodities. All of these have substantial implications for pest management and are components of the complex interactive network of factors affecting loss reductions in grain storage (Figure 8.3. Factor interactions and key issues for pest management and loss reduction in grain storage.).

Figure 8.3 draws attention also to socio-economic factors affecting, in particular, the acceptability of control measures. Modern techniques, especially those involving the application of synthetic insecticides to stored grain, are especially prone to consumer sensitivity. However, many traditional techniques face comparable problems. The use of wood ash and other supposedly non-toxic 'natural' grain protectants may not be acceptable in all circumstances, nor even to all those people at the small farm level in developing countries who are often supposed to prefer such treatments.

The insect resistance problem

The development by pests of acquired resistance or increased tolerance to pesticides is now a well-known pest management problem. It is coming to be recognised as not so much a remarkable phenomenon as an almost inevitable natural consequence of pesticide use. There is little doubt that much of the existing problem, which in recent decades has come to affect many species of storage insects and a wide range of insecticides (Champ and Dyte, 1976), stems from careless use. Resistance to phosphine fumigants in particular (Taylor, 1991) is almost certainly due in part to the not infrequent use of grossly inefficient application techniques.

There is general agreement that the rate of resistance development, in any particular pest species and to any particular pesticide, is to some extent susceptible to control (i.e. management). Possibilities for the containment of resistance include sustained improvements in application techniques, where acceptable pesticide dosage rates remain effective, and the adoption of alternative pesticides or other control measures where the degree of resistance to a particular pesticide prohibits its use. Continued monitoring of resistance, in field populations, is also necessary.

Concepts of reducing resistance by genetic control (Wool, 1975) have progressed to some extent (Wool et al., 1992) and are not implausible. However, their practicality and cost effectiveness in stored-grains pest control remain undemonstrated. Moreover, it has been shown (McFarlane, 1990) that some resistant strains of several storage insects have a reduced capacity to cause grain damage, through an impaired population growth rate. There is no reason to suppose that all resistant biotypes will be less damaging

than their susceptible counterparts but the monitoring of this capacity, in field populations, is feasible and seems worthwhile. Conversely, it would seem illogical to foster a reversion to susceptibility in cases where the resistant biotype has a substantially reduced capacity to cause damage and, therefore, a considerably reduced pest status.

The possibility that insects may develop resistance to other control measures has been noted already with regard to reports of increased insect tolerance to low oxygen tensions in controlled atmosphere storage (Donahaye, 1990). As in the development of pesticide resistance, considerable genetic flexibility is to be expected. However, one may also expect that insect adaptability to massive constraints on fundamental biotic requirements, such as aerobic conditions, will be more limited than their ability to exploit the more natural genetic potential for metabolising extraneous toxicants.

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Chemical control techniques

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General considerations

The chemical compounds, including both fumigants and contact insecticides, which are approved by FAD/WHO for use on food grains to control storage insects, are regularly reviewed. Their safety in use,

for pest control operators and food-grain users, is carefully considered before approval is given and that approval may be withdrawn if new circumstances indicate the need for the exclusion of a particular compound. In general, the contact insecticides that are approved for use are compounds of relatively low mammalian toxicity, which are considered to be non-hazardous when applied at prescribed dilution rates for the purposes indicated. They are also relatively safer to handle than many of the pesticides quite commonly approved and widely used for preharvest pest control. Nevertheless, transportation and handling of the insecticide concentrates are hazardous. These hazards and the required precautions will be discussed further at the end of this section. At the outset, however, Tables 8.5 (see Table 8.5. Acute mammalian toxicities (LD50 - mg/kg body weight) for contact insecticides currently of use in stored-Brain insect control.) and 8.6 (see Table 8.6. Maximum residue limits (MRL) and acceptable daily intake levels (ADI) (mg/kg or ppm) recommended by FAD/WHO as at April 1992.) may be consulted for relevant data on mammalian toxicity, for a broad range of contact insecticides which are or have been used in the control of storage insects, and for the limits recommended by FAD/WHO for chemical residues, from contact insecticides and fumigants, in grain and grain products. It should be noted, in passing, that there is no acceptable residue for the insecticide DDT, which remains available in many developing countries but is no longer recommended for use in stored-grain pest control. Lindane, which is still of some use, is given a very low residue limit (0.5 ppm). This serves to preclude or discourage application to grains for export to countries which object to its use. It should also be noted that the limits for fumigant residues broadly represent the maximum levels that should be expected if fumigation treatments are properly done. This applies also to residues of inorganic bromide and these have recently been declared of no toxicological concern by the U.S.A's Environmental Protection Agency and by the British Government. The very low limit for phosphine in Table 8.6 reflects the generally negligible permanent residue which remains after the use of this fumigant.

A recent development affecting the distribution and use of pesticides has been the publication, by FAO, of

a Code of Conduct (Anon., 1990). The purpose is to indicate responsibilities and establish voluntary standards of conduct for all public and private bodies engaged in or affecting pesticide distribution or pesticide use. It is particularly directed to countries where national regulatory legislation is lacking or inadequate. It draws attention to a comprehensive series of guidelines, also published by FAO, on regulatory practices, packaging and storage of pesticides, labelling of containers, disposal of waste pesticides and their containers, and other pertinent matters including especially the Prior Informed Consent (PIC) Procedure. This aims to protect the right of countries importing pesticides to be made fully aware of bans or restrictions placed on particular pesticides, elsewhere, so that informed decisions may be made on whether or not further importations of such pesticides should be permitted. Insecticides covered by the PIC procedure include, for example, DDT and lindane which have been mentioned already as compounds which remain in use in several developing countries although banned or severely restricted elsewhere.

Current usages for stored-grains pesticides, including fumigants and contact insecticides, constraints on their use and the ways in which chemical pest control may be integrated into storage systems are subjects which have received much attention. The following account may be usefully augmented by reference to various publications including, for example, Champ and Highley (Eds.) 1985.

The use of fumigants

Fumigants are toxic gases used to disinfest a commodity in an enclosure which, ideally, is completely gaslight. Fumigation enclosures should certainly be sufficiently gaslight for the gas to penetrate and remain in the commodity for long enough to kill all stages of the insects present in or amongst the grains. A gas or vapour that does not have the ability to penetrate the grain is not, strictly speaking, a true

fumigant.

The purpose of a fumigation is thus to obtain a more-or-less immediate disinfestation of the commodity and the space enclosing it. Fumigation is the only chemical treatment that can achieve this effect and this relative immediacy of disinfestation, together with its completeness if done properly, are the main advantages of this particular chemical control technique. Its main disadvantages are that the treatment confers no residual protection against reinfestation, once the commodity is again exposed, and the fact that the most effective fumigants are all highly toxic to humans and other non-target organisms. The precautions required to ensure the safe use of fumigants are, necessarily, much more stringent than those required to ensure the safe use of most other insecticides.

The list of fumigants in Table 8.6 excludes those that are no longer widely approved for use on stored grain due to restrictions placed upon their use in some countries. Examples are carbon tetrachloride and ethylene dibromide, both of which are low-volatility fumigants with recently identified chronic user hazards. Another low-volatility halogenated hydrocarbon, ethylene dichloride, is not so clearly implicated but is less commonly available than it was formerly. Methyl bromide and phosphine are now the only fumigants commonly in use on a world-wide scale. The advantages and disadvantages of these two fumigants are summarised in Table 8.7. In addition, it should be noted that both phosphine and methyl bromide are currently regarded as gases with potential negative impact on the atmospheric environment. Constraints on their use are likely to increase and requirements for careful, responsible use, with more regular monitoring of application rates, are likely to be more strictly enforced.

Table 8.7. Phosphine and methyl bromide as fumigants: advantages (highlighted) and disadvantages.

Phosphine	Methyl bromide

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

*** Not recommended for use at temperatures below 12C.**
Source: Adapted from Pest Control for Food Security, FAO Plant Production and Protection Paper 63 (Prepared for FAO by ODNRI), FAO, Rome (1985).

The desirable properties of a grain fumigant, notably efficient penetration of the commodity, toxicity to target insects and lack of harmful residues, make it unlikely that new chemical compounds will become available as fumigants (Taylor, 1991). Carbon dioxide can be used as a conventional fumigant but low

toxicity to insects and the consequent high degree of gastightness necessary for effective insect control makes it unlikely that this gas will find widespread use except in controlled atmosphere (CA) storage systems.

Detailed information on the properties and use of phosphine and methyl bromide as grain fumigants, including application procedures for fumigations in various types of fumigation chamber or under gas-proof sheets, is included in a separate FAO publication (Bond, 1984) and is not reproduced here. General guidance on dosage rates, however, is given in Tables 8.8a and 8.8b. It should be noted that, for phosphine, there are considerable differences in tolerance amongst the various insect pests of stored grain. The data in Table 8.8a (see Table 8.8a. Average concentrations of phosphine (mg/l) required to give 100 per cent mortality of all developmental stages of insects under experimental conditions.) are intended to illustrate this rather than to indicate practical dosages. A general dosage recommendation is given beneath the table. For methyl bromide, differences in the amount of gas sorbed by particular commodities are generally more important and these are taken into account by the schedules presented in Table 8.8b (see Table 8.8b. Dosage schedules for fumigation with methyl bromide where the enclosed volume is filled, e.g. stacks under gas-tight sheets.).

Notes: The dosage rate per tonne can be read directly from the table according to the commodity.

Recommended dosages are also given as g/m3 for situations where the volume, but not the weight, of the commodity is known. The volume dosages have been obtained by dividing the dosage per tonne by the stowage factor. These dosages are alternatives and should not be added together.

Where Trogoderma spp. are present, dosage should be increased by 50 percent.

If a 48hr exposure period is reduced to 24 hours the dosage rate should be increased by 50 per cent. If a

24hr exposure period is increased to 48 hours the dosage rate should be reduced by not more than 30 per cent.

Where stacks of less than 30m3 (approximately 20 tonnes) are treated under sheets, dosages should be calculated as if the volume were 30m3 (20 tonnes).

Adapted from: Pest Control for Food Security, FAO Plant Production and Protection Paper 63 (Prepared for FAO by ODNRI), FAO, Rome (1985)

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

The further prolongation of recommended exposure periods for phosphine, beyond the three day minimum that was formerly recommended for hot climates, followed from extensive investigations into the susceptibility of the developmental stages of storage beetles (Hole, et al. 1976). The pupal stage of grain weevils was found to be remarkably tolerant but other life stages were shown to be sufficiently susceptible to permit effective use of phosphine if the minimum exposure period were extended to 4 days, at favourable temperatures, to allow the tolerant pupae to pass into the more susceptible adult stage.

The growing frequency of resistance to phosphine in storage insects constitutes a problem, previously discussed, but does not generally invalidate the use of this fumigant which can still be expected to provide effective control of the major pest species when treatments are carried out using proven techniques (Taylor, 1991). Problems may arise where control measures against psocids are warranted. Considerable

tolerance to phosphine, in all the life stages but especially the egg, has been demonstrated in the common species Liposcelis entomophilus (V. Pike, personal communication). The same investigator has shown that the currently available alternative fumigant, methyl bromide, should prove effective at normal dosage rates whereas effective phosphine treatment would require an extension of the exposure period beyond the normally practicable limits for sheeted-stack fumigation. Tolerance to phosphine in the egg stage has also been observed in other insects (Hole et al., 1976; Bell, 1976) but this does not generally persist throughout egg development as it appears to do in L. entomophilus. It is this persistent tolerance, throughout a 6-9 day developmental period (at 27C), which makes phosphine unreliable for psocid control. It may also explain the rapid and spectacular resurgence of psocid infestation, following phosphine fumigation and the elimination of susceptible predators and competitor species, in those grain storage situations where this phenomenon has been observed.

Practical constraints on the use of fumigants to treat stored grain include consideration of the chemical residues which they may leave in the treated grain and the effects which such residues, or the treatment itself, may have on grain quality. For seed grain this includes germinability and seedling viability. In this regard phosphine has considerable advantages and is certainly to be preferred over methyl bromide for seed treatment. It is also less commonly associated with problems due to persistent sorbed chemical residues. Problems can arise from the visible residues of the metal hydroxide which remain after the decomposition of tablet or pellet formulations. Moreover, these usually contain some undecomposed phosphide, which can also be found in spent satchels and other application packets. However, the hydroxide material itself is not harmful and the risk posed by undecomposed phosphine can be sufficiently minimised if recommended procedures are followed.

The available advisory literature on fumigation procedures relates mainly to relatively large-scale applications in warehouses and other storage complexes. Possible small-scale applications in tropical

developing countries, at farm level or by urban traders, should not be disregarded. Such operations were, in the past, largely limited to the occasional use of low-volatility halogenated hydrocarbons: notably various mixtures of ethylene dichloride with carbon tetrachloride. Such formulations may still be available in some countries but their use is now generally discouraged because of recently identified long-term user-hazards. Methyl bromide and most other high-volatility fumigants are generally precluded by the much greater acute toxicity hazards and by the recognised need for special equipment and training for users. The advent of phosphine, however, increased the likelihood that fumigation treatments would be attempted by untrained people. The relative ease of handling the solid formulations of this fumigant, especially the familiar tablets and pellets, greatly facilitates their retail distribution, sometimes without the manufacturer's protective packaging, in any country where effective curbs on such distribution are not in place. Extension workers as well as opportunistic salesmen are sometimes at fault in this regard and, in consequence, phosphine treatments of small farm-level stocks of grain, or of larger quantities in traders' stores, may be carried out ineffectively and may in some instances be a serious hazard to the user or other people. Inefficient use of phosphine, as has been mentioned already, will also exacerbate the insect resistance problem. Proposed efforts to monitor phosphine use and to promote effective techniques should be extended to include small-scale applications and should give full attention to associated hazards. Where necessary, tighter controls on the sale and use of phosphine should be introduced and applied.

Developments in fumigant application techniques

(i) Store fumigation

The concept of fumigating the free space and entire contents of a store, rather than individual stacks of bagged grain, is not new and has been practiced regularly for many years, particularly in South Asia. This

method of disinfestation has the potential advantage of controlling insects on the walls, floors and inner roofing surfaces, as well as in the grain, thus greatly reducing the immediate re-infestation pressure on the store contents.

Unfortunately, most whole store fumigation in the past has been carried out in buildings that were not designed specifically for this method of disinfestation. As a consequence, most were not capable of retaining fumigant gas sufficiently well to provide complete control of insects. There seems little doubt that whole store fumigation has encouraged the development of insects that are resistant to phosphine.

Recent investigational programmes have demonstrated that purpose-built storage buildings (Bisbrown, 1992) can serve effectively as fumigation chambers. In Sahelian West Africa, for example Senegal (Hayward, 1981), such stores already exist. However, there is little evidence that they are regularly used for that purpose.

Where existing storage buildings can be sealed to render them reasonably gas-tight, investigations have shown that effective fumigation can be achieved using a method of phased dosing with aluminium phosphide. The method involves application of fumigant in two portions, the second of these 24 or 48 hours after the initial application. Using this technique it is possible to prolong the period during which insects are exposed to a lethal concentration of fumigant, even in buildings in which some leakage of gas is taking place (Friendship et al., 1986).

(ii) Sheeted stack fumigation

In most developing countries, the commonest method of fumigating stored commodities is with bag stacks under sheets. The technology involved is relatively basic and good standard recommendations are available, including detailed advice on choosing suitable sheets (Friendship, 1989). Nevertheless, many

fumigations of this type are carried out unsatisfactorily. Common reasons for treatment failure are the use of torn or perforated fumigation sheets, which allow fumigant to escape, or poor sealing of sheets at ground level which also allows excessive leakage. The most common method of sealing sheets at ground level is by means of tubular sandbags ('sandsnakes') which hold down the sheet in contact with the floor. Frequently, insufficent of these are provided to permit satisfactory sealing, or the sandsnakes are too small or too lightweight to effect a gas-tight seal. Proper sealing of sheets requires sandsnakes to overlap continuously around a stack, with at least two sandsnakes over the folded sheet corners. Latest experimentation suggests that for effective sealing of heavy-duty (and less flexible) sheets, such as those of laminated PVC, larger and heavier sandsnakes are necessary than those commonly used. The width of tubing used for the larger sandsnakes should be of the order of 150 to 200 mm. These, when filled, should provide a contact width on the floor of at least 100 mm. A disadvantage of this type of sandsnake is the increased weight, which is an important consideration for pest control teams with frequent operations or much travelling to do. It is therefore advisable to ensure that the heavier type of sandsnake is not too long, and is fabricated from strong material such as lightweight canvas. Where possible, sandsnakes should be provided for each individual store or store complex to avoid the need for further transportation.

(iii) Circulatory systems for phosphine

A recently introduced and patented technique known as 'Phyto-Explo Fumigation' enables bulk grain to be effectively treated in deep structures using phosphine. A shaft is driven into the grain, using compressed air, and is connected to a piping system which allows air circulation within the grain by means of a small pump. Fumigant is evolved from a phosphide formulation introduced into the headspace above the grain and gas is drawn down into the grain by the circulatory action of the pumping system. This technique permits effective distribution of fumigant in deep silos and in ships holds, rendering disinfestation possible without transferring the grain. The same technique can be used with methyl

bromide enabling rapid treatment of silos not provided with a permanent circulatory system.

The use of contact insecticides

Currently acceptable compounds, and recommended rates for their application as dust formulations admixed with cereals or as liquid surface treatments, are given in Table 8.9. Compounds used for space treatments, and their recommended application rates, are given in Table 8.10. These two tables (and Tables 8.5 - 8.8) are reproduced from FAO Plant Production and Protection Paper 63 (Anon., 1985), a manual of pest control for food security reserve grain stocks prepared for FAO by the former Storage Department of TDRI (now NRI). This contains detailed information on application procedures and equipment for fumigants and contact insecticides.

Most reputable insecticide manufacturers also provide useful literature on application rates for their own products together with appropriate safety precautions which should be followed. Some also indicate suitable application equipment and there are many other publications, with or without commercial bias, which give comprehensive guidance on the various spray-pumps, mistblowers and fog generators that are available. The choice of a particular piece of equipment is generally less important than the care given to its use and maintenance. The best advice to give here is that the choice should be made, on the basis of information obtainable from accessible sources, with particular regard to cost, availability of spare parts, the user's own assessment of suitability for the purpose and the apparent robustness of the equipment.

The focus of attention in this bulletin is upon the differences between the various types of insect control treatments, i.e. the application techniques, with regard to pest control objectives and the constraints which limit effectiveness in particular circumstances.

Table 8.9. Recommended insecticide application rates.

Insecticide	Dust admixture with cereals (ppm)	Surface treatments (g/m)	
		Walls	Bags
Malathion	8-12	1-2	1-2
Pirimiphos methyl	4-10	0.5	0.5
Fenitrothion	4-12	0.5	0.5-1
Chlorpyrifos methyl	4-10	0.5-1	0.5-1
Dichlorvos	2-20*	0.5	
Methacrifos	5-15	0.2	0.4*
Lindane	0.5		
Pyrethrin/piperonyl butoxide (1:5)	3	0.1	
Bioresmethrin (resmethrin)	2		
Phenothrin	5		
Permethrin	0.05-0.1	0.05-0.1	
Carbaryl	5-10	1-2	
Bendiocarb	0.1-0.2	-	
Dioxacarb	0.4-0.8	-	
Propoxur	-	0.5	-

Notes: * Short persistence. '-' The insecticide is not normally used in that type of treatment.

Source: Pest Control for Food Security Plant Production and Protection Paper 63 (Prepared for FAO by ODNRI) FAO, Rome (1985).

(i) Grain admixture treatments

Admixture treatments depend upon reasonably uniform application of a suitable contact insecticide, or in some cases a mixture of insecticides, at an acceptable dosage level. Table 8.9 gives application rates in parts per million (ppm) of the active ingredient for a range of commonly used insecticides applied as dusts (dusting powders) on grain. Such formulations are generally recommended for small-scale treatments because dusting powders are fairly easily supplied, ready for use, in suitable small packs and are more easily applied. Liquid formulations can also be used, if suitable application equipment is available, and these are generally preferred for large-scale treatments. This is especially true in commercial grain storage, mainly because the admixture of dusts with grain alters the bulk density and may affect grading standards but also because spray applications are more easily automated and incorporated into grain conveying systems.

In either case the application rates specified in Table 8.9 apply and it is most important to understand that these rates are for the active ingredient (a.i.). It may help to think of these as a.i. dosage rates to distinguish them from the formulation application rates. These latter are more or less standard, at 50g or 100g of dusting powder per 100kg of grain or 1-2 litres of the dilute spray-mix per tonne of grain. For liquid treatments the most convenient carrier is water and the application rate is designed to allow effective treatment with minimum added water. A simple calculation shows that for grain treated at 1 litre/tonne with a water-based spray the moisture is increased by approximately 0.1%. The calculation of the required concentration of active ingredient in the spray-mix or dusting powder, to give the

recommended dosage rate in ppm, weight-for-weight on the grain, is also quite straightforward. The simplest possible example is that an a.i. dosage of 10ppm on grain will require a 2% dusting powder applied at 50g/100kg grain or a 1% powder applied at 100g/100kg. Likewise, it will require an approximate 1% spray-mix for an application rate of 1 litre/ tonne.

The advantages of insecticide admixture treatments are that they are generally inexpensive and a single application of an effective insecticide, correctly formulated, will give control of existing insect infestation (including, eventually, any insect stages within the kernels) and will protect the grain against reinfestation for a substantial period. The duration of protection varies considerably between different insecticides and, more importantly, between different climatic conditions. In the tropics, relatively high grain temperatures may reduce performance to some extent, although the preferred insecticides will generally give good results for several months. High moisture content (above the recommended 'safe storage' level) in the treated grain will more seriously impair the performance of some insecticides: notably malathion and fenitrothion. However, it is usually possible, by good storage management, to delay the treatment of grain until it is sufficiently dry and this should be the objective (Daglish and Bengston, 1991).

Disadvantages of admixture treatments include the effect of admixed powders upon the bulk density of the grain, but in many situations this is unimportant, or the risk of overwetting the grain if water-based sprays are used carelessly or in unreliably automated spray-rigs. However, the practical problems of ensuring the availability of stable insecticide formulations, especially with ready-to-use dusting powders, have proved to be the major constraint on successful widespread use of the technique. Malathion in particular is very prone to instability if formulated as a dilute dusting powder (usually at 2% w/w) on an unsuitable carrier. Many of the more recently introduced insecticides, including for example pirimiphos-methyl ("Actellic") and the synthetic pyrethroids, appear less prone to this problem. However, effective quality control on dilute dusting powders, which are mostly formulated locally to avoid heavy transport

costs, is essential to the success of insecticide admixture treatments recommended for use at the small farm level in developing countries. Formulations should be monitored for stability and to ensure that the nominal concentrations are initially correct. Distribution channels should also be controlled to ensure that retail packets are withdrawn before sale if they have been in stock for longer than the predicted shelf-life.

(ii) Insecticide deposits on bulk grain surfaces and bagstacks

Spraying the surface of a bulk of uninfested grain, in a bin or in flat bulk storage, can give quite good protection against reinfestation for a limited period, depending on the persistence of the insecticide used. Application rates would be similar to those indicated for other surface treatments in Table 8.9. For sustained protection the treatment would have to be repeated rather more frequently than is usually recommended. The decay of insecticidal effectiveness on exposed surfaces is generally faster than in a bulk treated by admixture and re-spraying at intervals of more than 1-2 weeks is likely to allow a limited build-up of infestation which, once established in grain below the surface, will be largely unaffected by retreatment. In practice, control of warehouse moths is often quite well achieved but control of beetle pests is generally less effective. Quite good control of the grain moth, 5. cerealella, is also likely since this insect is unable to penetrate far below the surface of a grain bulk.

An alternative treatment, for the same purposes, would be the use of a dusting powder applied to the surface and raked-in to a depth of 10-20cm. The application rate should be as indicated in Table 8.9, based on the estimated grain weight in the treated surface layer. Insecticidal sprays and dusting powders applied as surface treatments to protect fumigated bagstacks against reinfestation are also of limited effectiveness. Early work showed that layer-by-layer spray treatments, applied during the building of a bagstack and immediately prior to fumigation, could be reasonably effective. For example, malathion,

applied at about 1g/m2 in a water dispersible powder formulation, gave complete protection against T. castaneum, in tropical conditions, for 1-2 weeks and a useful degree of control for 4-6 weeks (McFarlane, 1961). Respraying of exposed surfaces, at monthly intervals, was suggested for longer storage periods. However, in practice, the initial layer-by-layer treatment is rarely if ever used and bagstack spray treatments are generally limited to the exposed surfaces with re-application at monthly intervals or even less frequently. A broad concensus of opinion, based on observations in practical storage situations, regards these treatments as generally ineffective in tropical climates. Where they are used, even on a regular basis, the need for periodic refumigation to combat resurgent infestation is not avoided. There is considerable evidence that this resurgence is due to reinfestation at the stack surfaces although faulty initial fumigation may sometimes be partly to blame.

(iii) Insecticide deposits on the fabric of grain stores

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

Recent trials in grain storage warehouses in Java (Hodges et al., 1992) found no substantially significant differences in the resurgence of pest populations, following the fumigation of all bagstacks and an initial spray treatment of the warehouse fabric using fenitrothion at 1g/m2, between warehouses with routine, monthly respraying of walls, or walls and floors, and those with no respraying treatment.

There can be little doubt that properly applied surface treatments of walls and floors, using a recommended insecticide at the correct application rate (Table 8.9), will kill many, if not all, of the insects exposed to the insecticidal spray or to the residual deposit immediately after the treatment. However, although a persistent insecticidal effect can be found on some surfaces, for many days and even for many

weeks, it is inevitably a declining effect. Actual efficacy, in terms of insect control, is unlikely to be very great. As noted by Hodges et al. (1992) many of the insects which enter a store in the tropics do so in flight and the proportion of these that will settle upon a sprayed surface for long enough to be killed by the diminishing insecticide deposit can hardly be very great.

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

(iv) Space treatments

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

Space treatments, to be effective, require reasonably good sealing of the enclosure which should certainly be made windtight. Complete gastightness is not essential.

Most of the insecticidal formulations that have been employed for space treatments leave a small residual deposit upon exposed surfaces and may have a slight persistent insecticidal effect. However, this is generally negligible unless the treatments are applied repetitively and frequently. Space treatments achieve most effect through their direct impact on insects in flight or trapped on exposed surfaces during the treatment. In general, and probably for this reason, they appear to be most effective against

warehouse moths and some other insects (such as the beetle L. serricorne) that spend little or no time concealed within a commodity bulk or bagstack. For maximum effect, even against these more susceptible species, space treatments should be applied regularly and frequently: preferably daily at dusk when insects are generally most active in flight.

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

Application rates for space treatments are given in Table 8.10 (see Table 8.10. Application rates for space treatments.). The mention given to lindane and pirimiphos methyl 'smoke' treatments relates to the use of the solid particle aerosols commonly referred to as smoke generators. Lindane 'smokes', in particular, have been shown to have a considerable residual effect, when applied frequently or at the higher dose indicated in Table 8.10, but the use of this insecticide in circumstances where its residues may accumulate in foodstuffs is not acceptable.

Safety precautions

Wherever toxic chemicals are used in pest control the maintenance of safety should have highest priority. This relates to those handling or applying the chemicals and also to those other persons or animals that may be affected, directly or indirectly, by the chemical treatments. FAO guidelines, previously mentioned, on many relevant asects of safety in use are available from that source.

Detailed information on safety procedures in the use of chemical pesticides is contained in other FAO publications; notably Bond (1984) on the use of fumigants and Anon. (1985) on both contact insecticides and fumigants. All those involved, in any way, in the promotion, planning or implementation of chemical control measures should be familiar with the recommended procedures and should ensure that all appropriate precautions are observed in the situations and circumstances for which they have responsibility.

In addition, the specific precautions recommended by pesticide manufacturers for the use of their products, which are or should be clearly drawn to the attention of the user on all product labels, should be observed by the user. Local sales agents should be required to ensure that hazardous materials are not retailed to users who may be unable to read or understand the accompanying information on application rates and safety precautions. The only exception that should be made to this is where another competent agency takes full responsibility for providing the necessary verbal instruction and practical training to potential users.

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Alternative and supplementary control measures

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The currently available options for grain storage and the pest control methods usually associated with

each storage technique are reviewed in Table 8.11. In Table 8.12 (see Table 8.12. Pest control techniques: current options.) the pest control methods themselves, including some of the biological techniques referred to only briefly in the previous Table, are reviewed more comprehensively with regard to their principal advantages and disadvantages.

These Tables, together with those presented at the outset of this chapter (Tables 8.1 and 8.2) should make it fairly clear that most insect control techniques are inherently related to certain forms of storage and, moreover, that none of them is perfectly complete and without disadvantages. Chemical control techniques, although discussed separately in this chapter, should also be seen to depend upon good basic storage practice and to be supplementary to the control achieved by other techniques.

Physical measures

The effects of various physical factors upon insect development and control have been discussed already. The particular measures that are important as supplements to other insect control procedures are cleaning and drying. Those which may provide alternatives to other forms of control are cooled grain storage, hermetic storage, thermal disinfestation and, in some circumstances, mechanical disturbance.

The cleaning and drying of grain for storage are essential measures and the techniques are described elsewhere in this bulletin. Practical difficulties in achieving the desired freedom from excess moisture and foreign matter are frequently encountered. There can be no doubt that failures to overcome such difficulties do occur and that these lead to increased insect infestation. The rate of insect development may be somewhat accelerated and, more importantly, the spectrum of infestation will be greatly increased (Table 8.4). Practical recommendations take best account of this when they acknowledge the difficulties

that may occur but emphasise the need for cleaning and drying to be done as thoroughly as possible, especially when grain is to be stored for a long period. The longer the expected storage period, the greater the need for efficient cleaning and drying.

Techniques for the storage of damp grain, in hermetic conditions, under controlled atmospheres or with mould-suppressant treatments, have been developed but these are regarded as unsuited to the storage of grain for use as human food (Christensen, 1982). However, the practical value of ventilated cribs for the storage of maize on the cob and other grains on the head or in the pod, when insufficiently dry for sealed storage, should not be overlooked. Advice on optimum design for maize cribs, with particular reference to the humid tropics where the restriction of crib width to facilitate drying is important, is given in FAO Agricultural Services Bulletin No.40 (Anon., 1984).

The development of other temporary storage procedures, especially for underdried rough rice, has received much attention in countries where the introduction of new cultivars has led to massive production increases and, sometimes, to the regular harvesting of grain in wet weather. Limited applications of mould-suppressant chemicals, such as propionic acid, have been found effective and may be acceptable for short holding periods (5-7 days) prior to proper drying (Kamari and Yon, 1980). The use of admixed desiccants, such as common salt (sodium chloride) or wood ash, may also be of limited usefulness.

Aeration and cooling, by natural aeration in small, ventilated stores (e.g. maize cribs), or by forced aeration in larger stores, can significantly retard the development of insect infestation. Where it is possible to reduce the temperature of a grain mass to 17C or less the infestation will be effectively suppressed although not eliminated. Suppression could be achieved, by selective aeration, in many parts of the tropics where early morning temperatures are of this order. More attention should perhaps be given to this (Gough and McFarlane, 1984; Calderon et al., 1989). The particular importance of maintaining

relatively cool storage conditions for seed grain stored in tropical climates is well known (Christensen, 1982). The trade-off between design costs, for improved thermally-insulated storage structures, and the cost of drying the grain to very low moisture-content, to counteract the effect of high temperature, has been analysed by O'Dowd et al. (1988).

The principles of hermetic storage are outlined elsewhere in this chapter. Small-scale applications in the tropics are not uncommonly reported and attempts have been made to encourage the use of this technique in many parts of the tropics. However, it can only be cost-effective, in practice, where the storage management objectives will accomodate the principle and where suitable containers are available at a reasonable price. It is best regarded as a technique for selective application to particular commodities or to particular stocks clearly identified as reserves for protracted storage. Large-scale applications are likely to be handicapped by the cost of maintaining airtightness in large structures and by the common commercial requirement that grain stocks should be renewed at regular intervals (Hyde et al., 1973). However, considerable interest in the technique remains (Calderon et al., 1989).

Thermal disinfestation techniques include simple exposure to the heat of the sun, a traditional procedure that can achieve disinfestation in thin layers of exposed grain but which may often, in practice, do no more than drive off any adult insects or free-moving larvae. At the other extreme is the sophisticated technique, based on fluid-bed grain drying systems, described by Dermott and Evans (1978). Between these extremes lie opportunities for using solar drying equipment for grain disinfestation (McFarlane, 1989) and the occasional use of conventional hot-air grain dryers for this purpose in the reconditioning of infested grain. All of these techniques need careful management to ensure an effective kill of all stages of the insects in the grain without causing physical (thermal-stress cracking) or physiological (germinability loss) damage to the grain. This can be achieved in the simplest and most sophisticated systems, it is least likely to be achieved by the use of conventional hot-air dryers. Thermal disinfestation (like fumigation)

provides no ongoing protection against reinfestation and, moreover, if heated grain is put into storage without sufficient cooling any subsequent infestation may develop very rapidly.

Mechanical disinfestation techniques also show a range of refinement from the simple turning of grain through bulk-handling systems (Joffe, 1963) to the use of sophisticated percussion machines (entoleters) in flour mills. As with thermal disinfestation, the treatment provides no ongoing protection and may cause physical damage to the grain which, if it is returned to storage, may therefore be made susceptible to infestation by a greater range of insect species.

Traditional grain protectants

The occasional use of abrasive mineral dusts, natural desiccants like wood ash and various plant materials with repellent or insecticidal properties is well known and documented (Golob and Webley, 1980). Recent interest in such materials, intensified by a common concern to reduce, if possible, the general dependence upon synthetic pesticides by promoting the use of alternative materials, has produced a flood of information on experiments that have tested many plant materials. Regrettably, much of the published information is of limited value because practical aspects, including availability and acceptability for use as food grain protectants, are generally overlooked. However, a new bibliographic database on this research has been produced (Rees, Dales and Golob, 1992) which sorts more than 1000 references to work, mostly published since 1980, according to the materials used and the insect species against which they have been tested. The authors point out that the majority of papers in the database describe laboratory experiments or small-scale trials at research stations and that the conclusions drawn by the authors therefore have little significance for practical application. They indicate the need for further work that focusses attention on practicalities. This should, incidentally, reduce the currently over-extended list of candidate materials

to more realistic proportions.

It is fair and useful to note here that there have been a few exceptional papers on work in this area. Some recent work in Colombia (Baler and Webster, 1992), for example, included practical on-farm trials which assessed a vegetable oil, kitchen ash and black pepper as protectants for stored beans and included realistic evaluations of economic effectiveness and acceptability. The latter aspect included effects on germination, palatability and cooking time, which were found to be insignificant. All three treatments gave effective protection against A. obtectus for several months, taking 4% grain damage as the economic damage level.

Other workers have identified various commonly available cooking oils, notably palm oil but also groundnut oil and coconut oil, as being particularly effective (and used in some countries) for the protection of pulses against bruchid beetles. The oil obtainable from the seeds of the widely-grown neem tree (Azadirachta inidca) has also been found effective but comprehensive evaluations of its economic acceptability are less easily identifiable. Makanjuola (1989) gives a good account of laboratory investigations and field trials in Nigeria that tested other materials from the neem tree, including water-based leaf extracts, for the protection of cowpeas and maize. The results showed good protection of cowpeas (against C. maculates) for five months but only moderate protection of maize (against 5. zeamais) and found that seed extracts were more effective than leaf extracts.

Modern biological methods

Irradiation techniques and controlled atmosphere storage are included here, although they may also be regarded respectively as physical and chemical techniques, because their use depends upon radical

interference with biological systems or processes.

Watters (1972) and Banks (1976) give useful reviews of the possible applications of various irradiation techniques. There has been much subsequent research, especially to determine suitable dosage rates and operational procedures, with regard to safety as well as efficacy, but the use of irradiation as a direct control measure remains limited by basic problems of capital cost, running costs and other aspects of practical feasibility. The method shares with fumigation and thermal disinfestation the obvious disadvantage that it confers no protection against reinfestation. Insect resistant packaging of grain or grain products, immediately prior to irradiation, would seem the most logical adjunct in countries where socio-economic circumstances favour the adoption of this sophisticated and relatively expensive control technique. The indirect applications of irradiation, to achieve the suppression of pest populations through the release of sterilised males of the pest species, appear unlikely to prove economically attractive for the widespread control of grain storage insects.

Controlled atmosphere (CA) storage has become an important addition to the available options for stored-grain pest control. Extensive information on CA storage is now available and recent symposia on this research area have presented several comprehensive compilations, the most recent by Champ, Highley and Banks (Ed.) 1989. The present position and future prospects are usefully reviewed by Banks, Annis and Rigby (1990).

Conventional biological control techniques for possible application in stored-grain pest control, including control by the use of predators, parasites, insect diseases and sterile males, the use of pheromones for pest monitoring, mating disruption or enhanced mass trapping, and the use of resistant crop varieties, are summarised in McFarlane (1989), based on papers by Dobie (1984), Haines (1984) and Hodges (1984). There are published reports of the successful practical application of a number of these techniques,

notably in the USA (McGaughey, 1978; Arbogast and Mullen, 1990; Brower and Mullen, 1990; Brower and Press, 1990), but the area of most interest for application in tropical countries is the use of crop varieties with resistance to storage insects as well as preharvest pests. The conceptual impact of some of these biological control techniques is indicated in Figure 8.4. It should be noted that control by the use of a resistant variety will generally retard the increase of infestation and grain damage, thereby prolonging the period in which damage remains relatively low, while control by predators or parasites can be expected to suppress the pest population and the consequent grain damage but is unlikely to restrict insect numbers or grain damage to a low level.

Current possibilities for integrated pest management

(i) Farm level improvements

As suggested by Dobie (1984) and many other authors the development and use of improved grain cultivars, with resistance to storage insects as well as to preharvest pests, could provide the key element in IPM for stored grains. This would be of particular importance for loss reduction at farm level because, if the improved cultivars were both agronomically suitable and acceptable in all other respects to farm-level users, the adoption of this IPM strategy by farmers should be quite straightforward and would require no change in their traditional approach to grain storage. It would permit the renewed realisation of traditional concepts of safe storage, for a substantial period, by good husbandry alone (Figure 8.4. Pest population growth (solid line) and increase of grain damage (solid/broken line) as affected by different pest management regimes., diagram A). It must be understood that this would not, in most circumstances, reduce on-farm storage losses to less than the customary level generally accepted by farmers storing their own preferred varieties. However, it would reverse the trend towards increased losses which has been

observed in those areas where farmers have been encouraged to plant high-yielding varieties which, typically, are more susceptible to damage by storage insects. Moreover, there should be a net gain provided that improved resistance to storage insects can be coupled successfully with high yield characteristics.

Tactical opportunities for supplementary improvements in grain storage by small-holder farmers are indicated and discussed by Golob (1984) with particular reference to maize grain but considerable relevance to most other grains. They include realistic modifications to traditional storage structures to enhance their performance or to adapt performance to seasonal climatic change. The relative efficacies of various grain protectants, including some of the common traditional materials, are also considered. It is clear that several of these do have some value as a means of further extending the safe storage period but it remains true that reliable formulations of suitable contact insecticides, where these are available to the farmer at a reasonable price, are likely to prove more cost-effective so long as they are properly applied and judiciously recommended. Recommendations for widespread use, without regard to the particular storage objectives of individual farmers, are unlikely to be generally adopted.

A need for improved grain stores, modelled on larger-scale bulk storage bins suited to more sophisticated management, is a popular idea that should be treated with considerable caution. There are examples of such developments that have proved successful but a great many more have failed because the real needs and management capabilities of small-scale farmers have not been perceived.

(ii) Improvements in large-scale storage

The main technical options for insect control in large-scale storage, which generally occurs in developing countries at the main depot level or in large grain mills, are summarised in Table 8.2 and have been discussed elsewhere in this chapter. Table 8.2 indicates those techniques which require additional

measures for sustained control and those which provide, in the technique itself, this essential element. Measures intended to prevent re-infestation that are of doubtful effectiveness, for reasons already discussed, are pointed out as are those techniques which are likely to require substantial management inputs to ensure success. Bulk storage, which can reduce pest problems or facilitate pest control, should also be considered but should not be regarded as a panacea. The advantages and disadvantages of bulk storage, with particular reference to its use in the humid tropics, are discussed in Champ and Highley (Eds.) 1988.

The choice amongst the technical options to develop cost-effective packages of measures for well-integrated pest control cannot be made without reference to particular situations. As has been previously stressed, it is the storage management objectives, together with the technical and financial constraints, that must be identified and analysed in each case. However, it is of interest that recent decades have seen a marked swing towards the use of physical barriers against re-infestation in combination with improved conventional fumigation or the introduction of controlled atmosphere storage techniques. Notable developments in this direction have been for milled rice storage in China (and in S.E.Asia; Annis et al., 1984), but this approach has considerable technical merit and is potentially of more general application.

The attainment of fully integrated pest management in large-scale storage will depend largely upon the development and adoption of improved pest-monitoring procedures, with increased capability for measuring pest population levels as a parameter of grain damage and quality loss, so as to ensure as far as possible the most cost-effective timing of pest control actions. Here again, in developing countries, recent advances in this direction have been particularly concerned with milled rice storage (Haines et al., 1990).

Increased attention to the monitoring of re-infestation pressure is noted by Desmarchelier (1977) as a requirement for the more cost-effective use of admixed insecticidal protectants. It is recommended here

also that judicious use of grain cooling techniques to achieve a net enhancement of insecticidal efficacy in such treatments. Even for those insecticides which show a positive correlation between temperature and toxicity to insects the increase in chemical persistence, at lower temperature, outweighed the reduction in toxicity.

These several lines of research exemplify the possible refinements of established insect control procedures that are required for improved storage pest management. Such approaches are likely to prove more beneficial than attempts to devise complex packages of control measures, including as many as possible of the various available options, with the mistaken idea that IPM necessarily calls for such complexity. As was stated at the outset, the essence of IPM is the integration of cost-effective measures with management objectives and capabilities. With regard to this purpose, current efforts to develop computer packages ("Expert Systems") to guide management decisions are of interest. Systems with potential relevance to grain storage in the tropics include one, announced by the Australian Centre for International Agricultural Research (ACIAR), which will provide advice to optimise the use of grain protectants, and another, from NRI, which addresses more generally the application of pest control in grain storage.

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The economic importance of rodent pests

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There are three major reasons why rats and mice are considered pests:

a. They consume and damage human foods in the field and in stores. In addition they spoil it in stores by urine and droppings reducing the sales value.
b. Through their gnawing and burrowing habit they destroy many articles (packaging, clothes and furniture) and structures (floors, buildings, bridges, etc.). By gnawing through electrical cables they can cause fires.
c. They are responsible for transmitting diseases dangerous to man.

After harvest the crop attains its highest value, taking into account all the costs of producing it, processing, (packaging), storage and distribution prior to consumption. The actual value of the losses caused by rats vary by crop, variety, year, geographical location, pest species involved, length and method

of storage and climate (Gratz 1990). The exact post-harvest losses are difficult to assess. A review can be found in Jackson (1977) and Meehan (1984). Some examples based on surveys are given below which indicate the huge financial losses that have been found and can generally be expected.

Surveys conducted in small warehouses in the Philippines indicated losses of 40 to 210 kg of grain in each (Rubio 1971, Agnon 1981 as cited in Benigno and Sanchez 1984); at the time this was equivalent to about US $ 80 for each unit. Interviewing farmers in Bangladesh on rodent damage inside houses provided an estimated loss equivalent to US $ 29.50 for a six month period (Bruggers 1983). This figure is supported by Mian et al (1984) who found that, on average, households were each infested by about 8 mice and 2 rats. At 10.5 million households the annual losses are estimated at US $ 620 million for the entire country in houses only. Higher estimates were found by Krishnamurthy et al (1967) in a similar study in India. In large grain stores the situation may be even worse. For example, Frantz (1977) estimated that each godown in Calcutta had, on average, a population of about 200 Bandicoot rats. At an estimated 50 gm one rat can destroy in one night appreciable losses will accumulate.

To these food losses, costs for cleaning produce, the losses due to damaged packaging (Meehan 1984) as well as structural damage have to be added. It is impossible to put an exact estimate on these losses, but it is obvious that the damage caused by rodents is enormous.

Diseases transmitted by rats to man pose a serious public health problem in tropical countries. Apart from causing human suffering, they are responsible for financial losses incurred through work-days lost and additional medical bills.

While this topic is not directly related to post-harvest problems, it bears relevance to postharvest rodent control. As rodent pests in stores and households are controlled the rate of disease transmission will be reduced. Gratz (1988), Fiedler (1988) and Meehan (1984) have reviewed this aspect in detail.

Just as it is difficult to put exact figures on losses caused by rodent pests, it is not easy to estimate the exact benefits of rodent control. However it is apparent that rodent control is mostly if not always cost effective.

In the U.S.A. the annual loss to rodents is estimated at US $ 900 million (Clinton 1969 as quoted in Meehan 1984), while the annual cost of control is estimated at US $ 100 million (Brooks 1973 as quoted in Meehan 1984). According to Sumangil (1990) losses of rice in the Philippines were reduced from US $ 36 million to US $ 3.5 million with the advent of organised rat control programmes.

In Bangladesh two national strategic multi-media rodent control campaigns were organised and analysed in detail. Net profits were calculated at US $ 800,000 for each campaign, based on a single crop and season (Adhikarya and Posamentier 1987). Calculated benefits would be a multiple of this figure, if all crops could have been surveyed and the reduction in structural damage and human suffering could be quantified. Further field studies in the same country have shown clearly that losses can be reduced by 40-60% at farm level also (Posamentier 1989).

Dubock (1984) and Richards (1988) describe some examples of rodent control in urban and rural situations, including warehouses, in various Asian and Central American countries. The cost-benefit ratios ranged from 1:2 to 1:30. Hernandez and Drummond (1984) found that in Cuban warehouses the loss of 1% of the amount available to human consumption could be readily preventable by standard control techniques.

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Rodent species of post-harvest importance

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There are more than 4000 species of mammals, of which about 1700 are rodents (Anderson and Knox Jones 1967). Of the rodents the Family MURIDAE contains the most species, and of the genera the genus Rattus. However not all the 1700 rodent species are pests. About 150 species have been defined as a pest at some locality to some crop at some time or another, but only 20 could be termed important (Fall 1980). Very few species indeed are regularly described as pests in the literature. In connection with post-harvest losses, the number of species occurring in and around human habitation, drops to below ten.

Of these, three species are found throughout the world: the house mouse (Mus musculus), the house or roof rat (Rattus rattus) and the brown rat (R. norvegicus). The multimmate rat (Praomys natalensis) and the spiny mouse (Acomys cahirinus) are found in Africa; while the Pacific rat (R. exulans), the bandicoot rat (Bandicota bengalensis) and occasionally the striped squirrel (Funambulus pennant)) (Posamentier 1989) occur in Asia. Other species may enter buildings occasionally, but are of local importance only.

The brown rat, Rattus norvegicus (also known as grey, house, sewer, Norway, or wharf rat)

This species is cosmopolitan, but thought to have originated in Asia. It has spread gradually around the entire world during the last two centuries through international trade and human settlement (Meehan 1984). Its range is limited to coastal areas especially ports. In many Asian countries it is displaced by B. bengalensis (Deoras and Pradhan 1975), and it is probable that populations of R. norvegicus in these areas are replenished only by new arrivals from outside.

Many colour variations occur. In general it is brown-gray dorsally and light-gray ventrally, the tail is bi-coloured, and the feet are white. The head+body length is 180-250 mm and a fully grown adult may weigh up to 400 grams, although heavier individuals have been recorded (Niethammer 1981). The tail is shorter than the head+body length. The ears are thick, opaque, and short with fine hairs, while the snout (front of face) is characteristically blunt.

It is the most important species in Europe, because it lives in close proximity to man and has often been responsible for passing diseases on to man. Living in close social groups, it may be rated as the major post-harvest rodent pest in Europe.

The ship rat, Rattus rattus (also known as black, roof, fruit, rice field, or Alexandrine rat)

Also cosmopolitan and spread through international trade, this species originated in South East Asia (Meehan 1984). However, unlike R. norvegicus, the ship rat commonly lives well inland and has penetrated deep into continents.

There are many subspecies and forms of R. rattus and, because of this, it is difficult to give a definitive description of it. In the same country the coloration may range from almost black to red brown dorsally and dark grey to white ventrally. The head+body length is 150220 mm and the fully grown adult weight is 150-250 grams (Niethammer 1981). The tail is longer than the head+body length. The ears are thin, translucent, relatively large and hairless, while the snout is comparatively pointed.

Although it has become fairly rare in Central and Northern Europe and Asia, R. rattus has become a field pest in many countries and, because of its good climbing ability, infests fruit orchards besides entering buildings. This species was responsible for carrying the fleas which spread the plague in the Middle Ages. For more detailed information on the biology of one of the subspecies, R. rattus mindanensis, see Sumangil

(1990).

The Pacific rat, Rattus exulans (also known as the Polynesian rat)

This is a relatively small species. It is coloured gray-brown dorsally and light grey ventrally. The head+body length is 110-130 mm, and a fully grown adult may weigh up to 45 grams. The tail is longer than the head+body length (Niethammer 1981).

It is common throughout the Pacific islands ranging westward to western Bangladesh (Poch 1980), and is found in agricultural fields and in villages. Due to its excellent climbing ability it is a common pest of coconut trees.

The house mouse, Mus musculus

This species is also cosmopolitan, having apparently originated in the steppes of Central Asia on the Iranian-Russian border (Schwartz and Schwartz 1943). It is now the most widespread mammal in the world (Meehan 1984).

There are many subspecies and colour variations are extreme: the fur dorsally is usually brown to brownish grey (although black and other colours occur), and grey ventrally. The head+body length is 70-110 mm, and a fully grown adult weighs 15-30 am. The tail is about as long as the head+body length. The ears are quite large in relation to the rest of the body, while the feet are comparatively small and the snout pointed.

The house mouse is a good climber and lives in social groups. It can be a serious pest in agricultural fields and buildings, but has also been recorded in native or natural vegetation.

The Egyptian spiny mouse, Acomys cahirinus

This species ranges from Mauritania to Pakistan and is usually found in semi-desert, rocky country, dry woodland, thorn scrub and savannah (Greaves 1989). However it has become commensal in some places, replacing M. musculus, causing damage to stored grain and domestic premises.

The commensal form is nearly black with a grey belly. The head+body length is 60120 mm, and the tail much shorter than this. Hairs on the back are stiff, and are the distinguishing feature of this species. While litter size may be small (2-5), a female may have up to 12 litters in one year.

Apparently this species has an unusual resistance to anticoagulant rodenticides. This means that control has to rely on strict sanitation practices and the use of acute rodenticides such as zinc phosphide.

The multunammate rat, Praomys (Mastomys) natalensis

This species is economically the most important rodent pest in Africa, and a true indigenous commensal (Fiedler 1988). In many areas it may be replaced by the much larger R. rattus.

The fur is soft, brownish on the back and greyish underneath. The head+body length is up to 150 mm, and the fully grown adult weight is 50-100 g. The tail, which is uniformly dark, is about the same length as the head+body.

Most distinctively, the female has up to 24 nipples on her belly (other rat species rarely have more than 10) and the reproductive potential is high, particularly since this species lives in large social groups. Consequently, very large population explosions occur from time to time, causing huge losses.

The lesser bandicoot rat, Bandicota bengalensis

This is a common species in Asia, which ranges from Pakistan eastwards and, according to some reports, has reached Indonesia. Otherwise it does not seem to have left the mainland continent of Asia. It seems to be replacing R. rattus and R. norvegicus in India (Prakash 1975) and probably other Asian mainland countries also.

The fur is dark or (rarely) pale brown dorsally, occasionally blackish, and light to dark grey ventrally. The head+body length is around 250 mm, and the uniformly dark tail is shorter than the head+body length.

In addition to consuming or spoiling much stored produce, the lesser bandicoot rat is a very active burrower and is responsible for much structural damage to the storage buildings as well. It is also a very good swimmer able to live in deep water rice fields, where it can cause much damage to the crop. In Bangladesh and Myanmar (India) it is the most important rodent pest in both urban and rural areas. It is certainly also important in other Asian countries.

B. bengalensis is very aggressive even against individuals of the same species (Posamentier 1989); consequently, the large burrow systems made by these rats are normally occupied by only one adult each.

This species is very susceptible to most rodenticides (Brooks et al 1980, Poch et al 1979), although findings by Greaves (1985) indicate that some individuals seem very tolerant to some rodenticides. However in practical field trials in Bangladesh no problems were encountered with zinc phosphide or coumatetralyl (Posamentier 1989).

Notes on the Biology, Behaviour, and Habits of Rodent Pests relevant to their control.

(i) Reproduction

Although most rodents live for only about one year they are prolific breeders, multiplying rapidly under most favourable conditions. A female rat may have up to to five litters in her lifetime, R. norvegicus and R. rattus averaging 7 or 8 young in each litter. The multimammate rat can have up to 20 young in a litter, the average being about 11. A female bandicoot rat may share a burrow with a weaned litter, have a litter suckling and be pregnant all at the same time. The house mouse can have a new litter every four weeks (Meehan 1984).

(ii) Senses

Rodents have well developed senses of smell and touch, but poorly developed eyesight. They have excellent light sensitivity but poor acuity and are colour blind (Meehan 1984). This allows poison baits to be coloured, for safety reasons, without modifying their acceptability by the target species (assuming that the colouring agent does not have an adverse taste or odour).

They possess a good sense of hearing including frequencies in the ultrasonic range up to 100 Khz. This has led to the development of ultrasonic deterrent devices, of variable effectiveness.

(iii) Physical capabilities

The following facts need to be remembered when it is intended to rat-proof a building.

R. rattus R. exulans, and the house mice are very good climbers, R. norvegicus less so and the bandicoot

rats almost not at all. However all are able to use very small openings for their size or move up cracks and pipes to gain access to buildings. They are also good swimmers and readily take to the water. They are also good jumpers: R. norvegicus can jump vertically 77 cm and horizontally more than 120 cm, house mice can jump to a height of 24 cm (Meehan 1984).

The burrowing activity of rodents (especially the bandicoot rats, R. norvegicus and the multimammate rat) is a particular nuisance to store owners in tropical countries. Floors subside, easing the entry of other individuals, providing hiding places, causing a loss of stored produce and even leading to a partial collapse of buildings.

Rodents make burrows to breed in, for storing large amounts of food, and for protection against predation and extreme climatic conditions. In the case of bandicoot rats these burrow systems may be 100 cm deep and very extensive. Additional small 'escape burrows' are made by some species to minimise travelling to food and water.

R. rattus and house mice do not always make burrows but construct well hidden nests on the ground, in trees, or the upper parts of buildings.

Rodents derive their name from their gnawing behaviour (Latin: rodere = gnaw). Their incisor teeth grow continuously and need to be used, otherwise they will grow back into the cheek disabling proper feeding. The ability to gnaw through even soft metals is not only a nuisance but can also be hazardous, as mentioned in the opening paragraph of this Chapter.

(iv) Eating Habits

Rodent pest species are omnivorous, an additional reason why they are successful pests. In spite of this

there may be some preferences in the field if a choice is available. Overall, rats and mice in the wild will take a balanced diet.

The quantity of food taken may also vary. Under laboratory conditions, rodents have been observed to consume about 10% of their body weight per day (shitty 1954, Meehan 1984, Spillet, 1968, Brooks et al 1981, Posamentier and Alam 1981). Enclosure studies indicate that under near field conditions the amount consumed or destroyed is about five times the amount eaten in the laboratory (Haque et al 1980), although the proportion actually consumed is uncertain. What is certain, however, is that the actual losses caused are a multiple of their dietary requirements.

Many workers have studied food preferences in attempts to find the 'perfect' bait. The results of these studies are very variable depending on genetics, learning ('food imprinting'), weather and other complicating factors. A review of the subject can be found in Meehan (1984) and Posamentier (1989). In terms of bait acceptance the most important variable is to lay the bait at a time when little food is available. In buildings this means making food as inaccessible as possible, which will be discussed later.

Most rats return to a fixed place of feeding. House mice on the other hand are haphazard, inquisitive feeders (Crowcroft 1966).

(v) Activity

Most activity takes place during the hours of darkness, which is also when they do most of their feeding. There are two peaks of activity, the major peak occurring just after sunset and a minor peak just before sunrise. This has been observed for M. musculus (Dewsbury 1980), R. rattus (Barrett et al 1975), R. norvegicus (Calhoun 1962) and B. bengalensis (Parrack 1966). When hungry, or under crowded conditions, they may also be active during daylight hours.

(vi) New Object Reaction and Bait Shyness

It is probably their ability to rapidly adapt their behaviour to new or changing situations, above all else, that has caused some rodent species to become major pests. This is most apparent in their reaction to 'new objects' placed in their environment by man.

R. norvegicus is naturally very suspicious and tends to avoid any object that is new to it. It may take several days before an individual will enter a trap or take bait. Even then, if the new object appears to be food, only a small amount is taken. If the food contains an acute poison causing symptoms after a short while, rats may not touch the bait again. This is commonly called bait shyness.

R. rattus behaves similarly but not to the same extent, while M. musculus tends to explore rather than avoid new objects.

The New Object Reaction wears off in time, but has to be taken into account when a rodent control programme is planned.

(vii) Movement

Many rodent pests are characteristically mobile and able to disperse rapidly. This allows them to move quickly into and take advantage of new areas with favourable conditions (Fiedler 1988, Meehan 1984). However once individuals have established a territory or home range, they will not move very far, as long as conditions remain favourable.

It is often believed that rodent pests invade areas from several kilometres away. This is not exactly true. If large numbers of rodents suddenly appear in an area, it is probably because environmental conditions

have become favourable for them, and indigenous populations are able to increase at several places in the area at about the same time. This then gives the impression that the animals are on the move. It should be realised that for such a small ground living animal like a rat it is far too risky to move long distances because of predation and exhaustion.

Nevertheless it is known that bandicoot rats, and others, will move from surrounding fields into villages at harvest time, that is when fields suddenly no longer provide enough food (Posamentier 1989). In built up areas containing food stores B. bengalensis moves within an area 30 to 146 meters in diameter (Spillet 1968, Chakraborty 1975, Frantz 1984), depending on the location of the warehouses, when they are emptied, structural conditions and the availability of water.

Under experimental conditions and in certain environments R. norvegicus will move about three kilometres in one night (Meehan 1984). It is therefore not surprising that disinfested areas are quickly invaded by new animals from neighbouring areas or buildings. Increasing the area in which a rodent control programme is to be carried out will therefore help to reduce the rate of reinvasion.

(viii) Habitat

Rodents prefer buildings with good cover in surrounding areas; where vegetation reaches right up to the walls of the building, which ideally (for them) should have soft floors, broken brickwork and the like, and be untidy (Figure 9.1). Under such conditions control, particularly with rodenticides, is virtually impossible.

Competition

Animals compete for food and shelter. Such competition may be either inter- or intraspecific; that is between different species or among members of the same species.

For example it has been shown that B. bengalensis, M. musculus and R. rattus compete with one another for space; the bandicoot being the dominant species, and the house mouse the least competitive. In the context of control this means that if B. bengalensis is successfully eliminated from a store, R. rattus may move in. If R. rattus is then removed, M. musculus will move in. This situation needs to be considered when devising a control strategy, because the control techniques for these different species vary.

Several species live in loose or tight social groups (i.e. R. rattus and R. norvegicus) with a fairly fixed hierarchy. More dominant animals will have first access to food and shelter. In a control programme this means that the more dominant animals are removed first, because they are first to feed on the poisoned bait. The parts of the population lower in the hierarchy will be controlled with the second or subsequent bait applications. The technique of 'pulsed baiting' is based on this behaviour and is discussed later in this Chapter.

Indicators of the presence of Rodents

There are several ways by which rodents may signal their presence. The most easily noticed are damage and burrows. In stores footprints may be noted in dusty places and, of course, rodents will leave their droppings scattered about. Often the species can be identified by the size and shape of droppings.

Less obvious are the 'smears' found in places regularly visited by rats. They are caused by rats brushing their bodies against objects or when they slide around rafters and corners. Smears are indicators of heavy

usage and infestation, and good places for laying down tracking powders'.

However these signs are normally apparent only after a substantial population has become well established, when the point in time for economical control has already passed. The acute observer should try to find the more subtle signs of rats just passing through to investigate the store. This can be done by searching for foot prints in fine sand or tracking powder placed at strategic points. Areas around and outside the store should also be checked frequently for the presence of rodents.

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Control of rodent pests

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Principles of Control

Before the various techniques, methods or strategies of controlling or managing rodents are described the general principles involved need to be discussed. An understanding of these principles by all those involved will assist in devising specific control strategies for a given situation. It will also help when explaining the need for certain activities to the staff actually executing the control work.

In tropical countries rodents pose a continuous problem because of the climatic conditions, uninterrupted

food supply and relatively open structures. Therefore the control of rodent pests should be approached as a management problem much more so than a simple and single poisoning action. For a control strategy to be effective staff responsible need to be trained and informed, their activities must be co-ordinated, responsibilities confirmed, inputs and equipment readily available and the entire action must be planned.

Control strategies should aim at preventing losses and thus require a pro-active rather than the more normal reactive approach (Colvin 1990) (Figure 9.2. The philosophy behind any management strategy should be the prevention of problems.). Once a large population of rodents has established itself in a store considerable losses, that cannot be retrieved, have already occurred and subsequent control action is expensive. It should stressed that information from different sources should be incorporated into a control or management strategy and not just the techniques.

There are many more techniques and methods of controlling rats than are described here. Those given here have been selected as being the most practical for use in tropical countries. Meehan (1984) provides a comprehensive description of techniques and a complete list of available rodenticides.

(i) Monitoring

An important element of any rodent programme is monitoring. Usually it means surveillance for the presence of rodents. However it should also mean looking for features in the environment which would encourage rodents to migrate into it. Monitoring should be organised formally and regularly; that is, specific staff should be made responsible for it and report regularly, maybe once a week to a superior on the situation. The report should include the following aspects:

- **dates monitored;**
- **number, types and positions of signs of rats;**

- **condition of the building (broken pipes, walls etc., state of produce, tidiness or cleanliness);**
- **conditions immediately outside the building with respect to potential infestation points;**
- **qualitative reports by others;**
- **dates of baiting;**
- **number of bait stations used and positions;**
- **amount of bait and labour used;**
- **recommendations for improvement, such as repairs to structures, or further action required.**

Control of a rodent infestation is rarely completely successful; but if it is, it is usually only for a very short period. Therefore there is a need for continuous monitoring even after a successful control campaign regardless of the techniques and bait used.

For more ideas on monitoring techniques see Kaulkeinen (1984).

(ii) Co-operation

If an area is made rat-free due to good management and/or effective control measures, rats from near-by areas will migrate into it. It is therefore more efficient if control campaigns are conducted in several adjacent areas simultaneously. In the case of a village all households should be motivated and organised to control rats at the same time. While control in one household will still benefit the owner, benefits increase as the number of participating neighbours increases.

In the case of stores, large and small, surrounding areas including other stores should also be disinfested. This means that all the store keepers or managers involved should coordinate and synchronise their rodent control activities for maximum effect.

Preventive Measures

The maxim: 'Prevention is better than Cure' is just as true for rodents as it is for other pests and diseases. Therefore the prime objective of any rodent control campaign should be to create environmental conditions which will discourage or prevent the pests from reentering an area after its rodent population has been removed by one means or another.

(i) Sanitation

Rodents require food and shelter. Therefore it is most important to reduce the availability of these two key factors, which should be central in devising any kind of strategy. In the case of buildings the most effective method of rodent prevention is the improvement of hygiene or sanitation in and around them. Primarily this means sweeping the store and keeping both it and the surrounding area neat and tidy, i.e. free from any objects such as empty containers, idle equipment or discarded building materials, which could provide cover or nesting places for rodents. It also means removing food scraps left over from feeding pets or domestic stock (i.e. poultry farms) at the end of the day's work.

Observations have shown over and again that these simple actions, even in the tropics, are the most effective preventative measures that can be taken.

In a tidy store any infestation will be noticed at a very early stage, making other control measures far more effective. With reduced access to food and no places to hide, rats will not become established, that is live and breed, inside a building. Regular disturbance is something rats and mice avoid.

Control procedures should take the life history and behaviour of species present into account (Colvin 1990). Rats avoid clear spaces. Therefore by keeping a strip of two or more metres around a building clear of vegetation will reduce the chance of rats entering the building.

This should be augmented by keeping a strip of about one metre on the inside from the wall totally clear and swept. Branches overhanging the building should be lopped off to prevent climbing species to enter from above.

The above suggestions are enough to eliminate serious problems with rats and mice in buildings, even in stores where large quantities of food items are stored. Rats feel uneasy if their 'paths' and 'markings' are removed or cleaned daily by sweeping. They will not feel secure enough to remain in a building and damage packaging in their search for food. If they do, the damage is minimal and immediately noticeable.

(ii) Proofing

Since it is not practical to remove all food from stores and households, it is necessary to restrict access by rats. This is accomplished by proofing buildings or keeping food in -rat proof containers.

When rodent-proofing a building only materials which they cannot gnaw through should be used. Also, it should be remembered that some rodent species are good climbers and jumpers, and most can squeeze through surprisingly small holes and cracks (young mice need no more than a 0.5 cm wide crack to gain access).

Hard metal strips should be fitted to the bottom edges of all wooden doors and their frames, and vulnerable windows should be protected with tight wire netting screens in hard metal frames. Steel rat guards fitted to drainpipes and other attachments to the building should be at least one metre above

ground level. Door hinges and similar fittings should be so placed or protected that rats cannot use them for climbing.

Floors and walls should be kept in good repair. New holes dug by rats should be filled in immediately, with cement reinforced with pieces of crumpled chicken wire. If cement is not immediately available a temporary seal can be effected with tightly packed earth between the wire mesh. The important point is that repairs should be carried out as soon as the damage is noticed, which should be within a few hours of it being done if the building is inspected daily.

Although rats are active mainly after dark, they will move about during day as well when there is no human activity. Therefore doors of stores should stay tightly shut during the day as well, when the store is not in use.

If the building itself cannot be made rat proof, then foods and other valuables should be kept in earthenware containers or metal drums with good lids.

Jenson (1965) provides further detailed information on rodent proofing.

(iii) Natural Prevention (Predation)

Normally predation will not keep rats and mice at economic population levels. One exception is the keeping of cats. Cats do not directly control rats and mice by feeding on them. It is their presence, which keeps most rats and mice away. A survey conducted in a Myanmar village has clearly shown that households with cats had no rats while those without cats in the same village were visited by rats.

Examples where predation may have an effect on field rodents and its limitations are described by

Prakash (1990) and Wood (1984).

While work done in Australia on controlling house mice with a nematode has shown promise (Singleton and Redhead 1990), there is no practical parasitic control method for rats and mice available at present.

Mechanical Control

Mechanical rodent control as a rule is not very practical. It is cumbersome, labour intensive, and often not very efficient. Mechanical techniques are more appropriate in households, and can be used if the owner has no access to poisons or is averse to their application

The method most commonly used in buildings is trapping. Often local traps are available and in some cultures people are very good at using them. They should be placed where rats move regularly. If placed along a wall, the trap should be perpendicular to it and the treadle with the bait should face the wall.

Sticky or glue traps are another way of catching rats and mice (Prakash 1990, Meehan 1984). They are boards made of wood, hard- or cardboard covered with very sticky material. There are different types of glue available and they should be checked for suitability (stickiness, and usability in humid or dusty conditions) before large quantities are ordered. The boards are placed in the same way as traps, and normally there is no need for bait to attract rats. These traps should be checked daily, but are not regarded as very 'humane'.

Flushing rodents out of their burrows, with smoke or by flooding them with water, can be very effective and suitable in some situations. Ultrasonic devices are mentioned regularly, particularly by manufacturers

of these devices, as a good repellent of rats and mice in buildings. However there is no scientific evidence of their effectiveness. It appears that rats become habituated to the sound or stay in 'sound shadows'. The subject is discussed by Meehan (1984).

Chemical Control

In large stores, particularly if situated in the city, it may be necessary to complement hygienic practices with chemical control. Because acute poisons invariably cause bait shyness, especially if applied over longer periods, it is strongly recommended that only anticoagulant rodenticides are used in buildings. Therefore acute rodenticides will not be discussed here.

It should be remembered that rats living in and around buildings are particularly suspicious of new objects, such as bait, bait stations and traps. Therefore it may take some time before these are accepted by rats. For this reason it is important that once these objects are placed they are not touched or removed again. If the bait or trap has not been touched after, say, a week rats are probably not nearby and it should be moved to another location. However chemical control is only useful in connection with strict hygienic practices.

As a rule operators should be supplied only with ready-to-use rodenticide baits. Firstly, mixing can be dangerous to the operator. Secondly, a wrong concentration can lead to bait shyness if too high, or to sub-lethal dosing if too low. Normally ready-to-use baits do not increase costs substantially.

ALL rodenticides can also harm other animals including man. Therefore great caution should be observed at all times when they are used.

(i) Anticoagulant Rodenticides

Anticoagulant rodenticides interfere with the blood clotting mechanism of the body - the animal gradually dies because of loss of blood through external and internal wounds, that is haemorrhage. Very small internal wounds (breaking of small capillaries) are constantly caused by normal movements. The rat feels almost nothing, it simply feels more and more tired and eventually dies. Therefore bait shyness with anticoagulants is unusual even with higher concentrations of active ingredient.

Resistance to some anticoagulants has been observed in industrialised countries, where they have been used very extensively over long periods. So far, resistance has been of no serious consequence in tropical countries, particularly in view of the fact that new compounds (e.g. difenacoum, brodifacoum, bromadiolone) are now available in most countries. The antidote to anticoagulant rodenticides is Vitamin K.

Multiple Dose Anticoagulant Rodenticides

Multiple dose anticagulant rodenticides, such as coumachlor or coumatetralyl, need to be available at all times because rats have to feed on the bait several times over a period of up to seven days (depending on the species) before death is caused.

The poison bait should be placed inside bait-stations. To save resources each bait station should contain 50 to 100 gm of bait at all times. Bait availability should be checked each morning and bait taken by rats or which has become mouldy should be replaced. The quantity of bait used depends on the level of infestation and should be adapted to local conditions; and the number of bait stations necessary depends on the size of the building. As a rule of thumb a station should be placed every five to ten meters along the wall. Additional bait stations should be located in positions where rats are likely to enter a building, along

obvious rat runways, or in places where rats may hide. The distance between bait-stations depends on the species involved: house mice, for example, normally have a smaller feeding range than rats. However an operator will quickly learn how and where to place bait-stations, if the situation is regularly monitored and the operator is not changed.

If no more bait is taken and it appears that no more rats are present, baiting can be discontinued. However surveillance should continue and baiting must be re-started at the first signs of rats.

Single Dose Anticoagulant Rodenticides

Single dose anticoagulant rodenticides, such as brodifacoum, flocoumafen or bromadiolone act in the same way as described above but rats normally have to feed on the poisoned bait once only (1.5-2 0 g for rats in the case of the most potent compounds such as brodifacoum). In some situations and for some species it appears that more than a single feed is necessary (see Meehan 1984). Overall though these anticoagulants are by far the most poisonous to rats and very useful to practical rodent control.

If loose bait is available the use of bait-stations is recommended. These prevent spillage and spoilage. If blocks are used they can be laid down at regular intervals and in places frequented by rats, but should not be accessible to other animals or children.

(iii) Pulsed Baiting

The technique of pulsed baiting was introduced with the new single-dose anticoagulants, such as bromadiolone and brodifacoum (Dubock 1979, 1984). This contrasts with saturation baiting, in which bait is available to rats continuously over long periods until the population has declined to near zero. Pulse baiting is not necessarily more effective, but it is certainly cheaper, because the amount of labour and the

quantity of bait required is much lower than in saturation baiting.

As mentioned earlier, death is delayed by three or more days after ingestion (depending on the species of rat and the type of rodenticide). This means that rats will continue to feed on bait even though they have received a lethal dose, which would be a waste of bait. In addition in some species (e.g. R. norvegicus), animals of lower hierarchal ranking cannot feed until 'higher' animals are removed from the population.

This behavioural characteristic is exploited by baiting in pulses. Poisoned bait is laid for 13 days (depending on the rodenticide) and discontinued for about a week, allowing the first batch of animals to die and thus be removed from the population. The next baiting pulse will remove another batch of rats. Normally three baiting pulses are sufficient to remove almost the entire population. The intensity of baiting periods (pulses) depends on the rat population in and around the building and the rate of immigration from neighbouring areas. In spite of the above the intervals between and number of pulses has to be decided each time based on the results of monitoring.

The positive experience with the use of pulsed baiting in different countries and crops is summarised in Dubock (1984).

(iv) Perimeter Baiting

The idea of perimeter baiting is to place bait in a circle around and outside the immediate area of interest and hopefully prevent rats from immigrating. However it is very difficult to give exact guidelines on the diameter of the circle, the distance between baiting points and the quantity of bait to use. The idea has its merits and an operator should experiment with this technique; for example, by placing baiting points between the store and places through which rodents might reasonably be expected to immigrate.

(v) Fumigation

Individual rodents may be killed incidentally during the fumigation of grains and buildings for the control of insects (see Chapter 8). This section deals specifically with fumigation for rodent control.

The control of rodents by fumigation can be very effective, but it may be expensive and dangerous. It should be remembered though that the gas must have access to burrows, if these are present in the building. That is the burrows should be open and the fumigant used must be heavier than air.

If the species concerned makes burrows which are easy to spot (e.g. R. norvegicus, B. bengalensis or P. natalensis), they can be fumigated directly. The simplest method is to use a powder which releases hydrogen cyanide, or aluminium (magnesium) phosphide tablets which release phosphine when placed into the burrows. The gases are generated when the powder or tablets come into contact with moisture in the soil. Alternatively, methyl bromide gas may be pumped into the burrow system.

As soon as the fumigant has been applied all burrows must be closed, by filling the entrance holes with earth. However, fumigants cannot be used in loose or sandy soils as too much gas escapes, and the treatment may not be effective. Occasionally, rats have been known to block tunnels and prevent complete distribution of the gas, so that some individuals survive.

It is important therefore, always to check for reopened burrows or other signs of survival a few days after the prescribed fumigation period.

Fumigation gases used for rodent control are also dangerous to man and other animals. Therefore, strict safety precautions must be observed Meehan 1984). Only trained and properly qualified operators should be employed to use fumigants. They should be seen to be observing the following basic principles of

fumigation:

1. **two operators must always be present at a fumigation;**
2. **suitable respirators must be worn;**
3. **operators should stand upwind when gassing;**
4. **fumigants should not be used in strong winds or when it is raining;**
5. **fumigants must not be used near buildings inhabited by man or animals as open burrows may be inside; and**
6. **operators should know about first aid and have appropriate first aid equipment with them.**

Contact dusts

Contact dusts are dusts containing rodenticide which are placed on runways and other places frequented by the house mouse, for example near burrow entrances. Such dusts, while serving also as tracking powders (see earlier), are favoured in the control of house mice which, because of their erratic feeding behaviour, are not easily controlled by baiting. The dust is picked up on the fur and feet and, since mice groom themselves often and regularly, it is automatically ingested.

However care must be taken when using such dusts, as they may easily contaminate stored products like grains and may be undetectable.

Safety

Rodenticides, whether chronic (i.e. anticoagulants) or acute, are poisons and should be treated as such and at all times. Some may be more toxic to humans or non-target animals than others, some non-targets may be less affected by certain rodenticides than others.

Nevertheless, it is important that safety procedures are rigidly enforced wherever they are used. Meehan (1984) discusses the toxicity of various rodenticides in some detail.

Standard safety precautions when handling poisons include:

- **wearing protective clothing during operations;**
- **not eating, drinking or smoking during operations;**
- **not breathing in dust during operations (wear dust mask);**
- **keeping baits out of reach of others, especially children and domestic animals;**
- **thoroughly washing the skin, clothing and equipment after operations.**

Unwanted poisoning

Much has been written about the potential danger to non-targets of feeding on bait (primary poisoning) or animals feeding on poisoned rats (secondary poisoning). For a short overview the reader is referred to Kaukeinen (1984), Godfrey (1984), Hoppe and Krambias (1984) and Hegdal et al (1984).

It is difficult to assess the exact effect under practical conditions. Unwanted poisoning reported by large scale operations or through accidents, usually involve domestic animals. To date no significant effects on non-rodent wildlife have been associated with the use of conventional anticoagulants (Kaukeinen 1982).

The danger of unwanted poisoning can be virtually eliminated in buildings if some simple rules are adhered to:

- **bait should be laid so that no other animals, including man, can have no access to it; in buildings this should be fairly simple;**
- **the amount of bait laid out should be adapted to the anticipated population of rats, that is as little as necessary and placed in small quantities per station;**
- **application should be late in the afternoon, just before rats become active and as birds retire; in stores this is not so important;**
- **bait should be removed entirely after a control programme is terminated;**
- **dead rats, if found, should be buried or burnt; and**
- **rodenticides should be under lock and key, and empty containers should be disposed of properly.**

Stray dogs and cats (and crows and vultures in some countries) may be at risk through feeding on dying or dead rats (secondary poisoning). Normally these animals, because of their size, would need to feed on several rats before they would be affected and more to receive a lethal dose. The chance is very low with most anticoagulants and even with zinc phosphide, because most of the poison is broken down in the stomach. Nevertheless, operators should be aware of these potential dangers at all times.

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Designing control programmes

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There is no step by step advice or specific strategy one could propose to cover all situations. The strategy needs to be developed by a knowledgeable person familiar with the situation concerned. Even then, it will be necessary to test different procedures. The discussion below will attempt to provide some general ideas, which would assist in developing such a strategy and will stress some points to clear misconceptions.

Even today people still talk about rat free towns or stores. This may be possible in theory or in some special situations. However it is expensive and impractical (Drummond 1969) and certainly unrealistic in the tropics (Wood and Chan 1974).

When designing a strategy one should also decide on and differentiate between the temporary clearing of a heavily rat infested store and the long term prevention of rat infestations. The latter should be aimed at; because it is cheaper, more rewarding and more professional in the long run. This points to all the measures called for under hygiene and sanitation. Modern rodenticides are good but, at least in buildings, hygienic practices are better.

In this respect the key factors are organisation and regular finance (Sane) et al 1984). This means that planning, execution and monitoring of all activities are of paramount importance (Meehan 1984, Drummond 1981). They include the following points:

- **collection of all relevant information leading to a control strategy and plan of action relevant to the situation at hand;**

- **communication on and co-ordination of the programme with other interested parties; and**
- **appreciation of the problem by all involved.**

The information obtained from surveys and other sources will flow into the situation analysis and control strategy, that is: who should be involved, where are the points of infestation, which repairs are necessary, what costs can be expected, and what are the potential losses. It is considered justifiable to spend an amount equivalent to the value of about 10% of the potential losses on rodent control.

The level of co-ordination and co-operation required depends on the situation. In a village it may mean motivating and informing all households. A store situated in an isolated rural location would require the involvement of the owners of the fields surrounding the store. If the store is situated in a city or port, other storekeepers or the council may need to be involved. As mentioned earlier, the larger the area involved in a rodent control programme, the more effective it will be.

Figure 9.3. A well performed situation analysis is the first step in developing an effective and suitable management strategy.

One person on the premises should have a fair knowledge of rodents and their control. Although training may not be essential, it helps in improving efficiency. Most people, particularly in tropical countries, have learned to live with rodents. Therefore, it is necessary to create a general awareness of the problems and the benefits (Dorrance 1984), and preferably involve as many people as possible in the control programme. The importance of making a specific person responsible for rodent control (Becker 1981) is often overlooked. It is necessary to be able to report to a responsible person, since this will ensure continuity of activities. Often after an intensive control campaign, and the reduction of the rat population, interest wanes and with it all associated activities until the next heavy infestation occurs (cf. Hoque and Saxena 1988).

Making a person responsible for rodent control may be the first and most worthwhile step a warehouse manager can make towards reducing his rat problems efficiently.

The following more specific guidelines may serve as a starting point in the design of a plan of action.

Management

Efficient rodent control can only be executed when the necessary framework for it is set. The points below would be the responsibility of the manager of a warehouse or warehouses or the chief extensionist for a village.

1. **Installing a person responsible (rodent control officer) for rodent control including a job description;**
2. **setting up a monitoring and reporting system;**
3. **providing a labour force or designating people to assist the rodent control officer in his duties;**
4. **making all necessary materials and equipment available when needed;**
5. **organise and execute short information or training courses for staff or households;**
6. **creating a budget for rodent control;**
7. **co-ordinating and/or co-operating with other relevant groups and people; and**
8. **supporting the rodent control officer in the execution of his duties.**

Monitoring

It is important to emphasise that monitoring must be performed regularly and promptly reported on. As far as possible it should include coatings of potential losses (from damage surveys), costs of control and potential benefits. Reports must include recommendations for future actions, and a plan for action based on the results of monitoring. It is suggested that reports are submitted at least once a month. This will aid management in providing budgets and motivate all people involved.

Technical Aspects

The procedures and techniques listed below are considered to be most effective, and should appear in the plan of action. They need to be adapted to local requirements, and could therefore include techniques not mentioned in the list. The person responsible for each action, and the time/date when it has to be executed, must be named in the plan of action.

1. Sanitation must remain in the forefront of any rodent control, inside and outside the building, including:

- **removal of vegetation and rubbish outside close to the building;**
- **tidying the store inside removing items that do not belong there and keeping strips near walls clear;**
- **regular cleaning by sweeping and removing all food scraps (i.e. from feeding pets or animal food in poultry sheds) in the late afternoon;**
- **checking incoming and outgoing produce for infestation;**
- **occasionally clearing the entire store of all produce and cleaning it out thoroughly.**

2. Proofing the building: including regular, even if simple, repairs and other improvements.

3. Chemical control should be seen as an adjunct to sanitation and be in line with the following recommendations:

- **use of new generation single dose anticoagulants;**
- **operators and workmen should handle only ready to use bait formulations;**
- **pulsed baiting is suggested as the first technique to be tried; perimeter baiting should be considered;**
- **application techniques should be practiced constantly and improved as monitoring results dictate; and**
- **all safety measures should be observed.**

The effectiveness of rodent control arrangements depends upon the people responsible for their implementation being aware of the problems involved, their motivation and their interest in achieving success. The tools required are: (a) regular monitoring, (b) well trained operators and (c) access to labour and materials when they are needed. It is fair to claim that in rodent control the problem are mostly concerned with people and not the rats. Hence the reduced stress on control techniques in this Chapter.

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