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Protection of farm-stored grains, oilseeds and pulses from insects, mites and moulds

Publication 1851/E (Revised)

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Recommendations for pesticide use in this publication are intended as guidelines only. Any application of a pesticide must be in accordance with directions printed on the product label of that pesticide as prescribed under the *Pest Control Products Act*. **Always read the label.** A pesticide should also be recommended by provincial authorities. Because recommendations for use may vary from province to province, your provincial agricultural representatives should be consulted for specific advice.

Covering Page Illustration
(*Top*) Steel bins used for farm grain storage in Western Canada; (*bottom left to right) Aspergillus* mould on wheat, mould mites and rusty grain beetles.

This document is available via the Internet at the Cereal Research Centre's web page at http://www.agr.gc.ca/science/winnipeg/

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Protection des céréales, des oléagineux et des légumineuses à grain entreposés à la ferme contre les insectes, les acariens et les moisissures

Preface

This publication describes pests of farm-stored grains, oilseeds and pulses and outlines methods for their prevention, detection and control. Prolonged storage of such crops occurs mainly on the farm, so pests are most likely to cause damage in farm bins. To avoid or control damage caused by pests, the producer needs to understand the problem and use current control practices. The safe storage methods that we promote here are based on sound management practices and a general knowledge of insects, mites and moulds. We emphasize the use of cool temperatures through aeration to protect stored crops.

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Contents

Good storage practices

- Prevent losses from insects, mites and moulds by storing grain, oilseed and pulse crops properly; preventing infestations is easier, safer and less expensive than controlling them.

- Prepare the bin before storing the new crop: sweep or vacuum the floor and walls; burn or bury sweepings that contain spoiled or infested grain; seal cracks to keep out rain, snow and flying insects; and spray the walls and floors with a recommended contact insecticide.

- Install an aeration system to reduce grain temperatures and to reduce moisture migration.

- Dry tough or damp crops soon after harvest because they are more likely to become mouldy or infested with insects and mites than dry (straight-grade) crops; then cool after drying.

- Examine stored crops every 2 weeks for signs of heating or infestation; check either temperatures or carbon dioxide levels; and check insect activity by using traps, or probe and sift grain samples.

- Heated or mouldy crops should be dried. If the heated grain cannot be dried immediately, the rate of deterioration can be reduced by cooling the grain by aeration or moving and mixing the spoiling grain with cooler grain.

- Insect infestations can be controlled or eliminated by cooling the grain by aeration or mixing it with colder grain.

- Check the headspace of granaries during January to March and remove any snow before it melts.

- Observe safety precautions when applying insecticides; only persons licenced for fumigation application should apply fumigants.

Introduction

Protecting stored grain and oilseed crops from spoilage is an essential part of their production; failure to do so may result in their being downgraded. Heated or insect- and mite-infested crops in storage quickly lose weight and quality and may cost individual farmers thousands of dollars in lost income. Storing grains and oilseeds cool and dry in clean, uninfested bins that are weatherproof and well-aerated prevents such losses, maintains quality, and assures saleability.

The small, light-avoiding insect and mite pests of stored crops can penetrate deep into bulk-stored crops. In empty bins, they hide in cracks and crevices where they survive in residues until a newly harvested crop arrives. Most do not attack field crops and are not brought into storage with the grain, although rice weevils and lesser grain borers infest cereals in the field in warm climates. Stored-product pests also feed on dried animal and vegetable matter and on moulds; some survive on food that contains as little as 8% moisture. Cold-hardy insects can survive the winter in stored crops. During summer, some insects fly and can be carried by the wind from infested grain residues and animal feeds to granaries and even into houses.

In Canada, many of the insect and mite pests of stored grain and oilseed crops are cold hardy; these pests manage to survive the winter by finding protected habitats among the seeds or by adaptation to cold, or by changing to a nonfeeding, hardy life stage, as in some mites. Insects rarely reproduce at temperatures below about 17°C and mites below 3°C, but, when stored crops heat up, insects, especially the rusty grain beetle and red flour beetle, multiply rapidly and do much damage. The moisture content of grain also affects the extent to which insects and mites infest stored crops and cause them to heat and spoil. The insects, mites and moulds that cause grains and oilseeds to heat and lose condition are inactive at low temperatures (below about 0°C for moulds). Crops stored in small bins cool more rapidly and evenly during winter than in larger bins that are not aerated. Dry (straight-grade) grain or oilseed crops are less prone to spoilage than tough or damp crops. Tough grains and oilseeds are particularly prone to mite infestation. Canola is often infested by mites and moulds. Canola should be below 8% moisture content for prolonged storage.

Harvested grain or oilseed crops contain small amounts of storage moulds (storage fungi) that develop during storage and cause spoilage. Moulds develop rapidly in crops that are stored either tough or damp during warm weather (Table 1). Under warm, moist harvest and storage conditions, some fungi may produce poisonous mycotoxins.

Stored grain or oilseed problems are best understood when bulk grain is considered as an ecosystem in which living organisms (e.g., grains, insects, mites and moulds) and their nonliving environment (e.g., temperature, moisture and oxygen) interact with one another. Grain quality usually declines slowly, but when certain conditions occur in undisturbed bulks, spoilage is faster; complete loss of the crop quality may follow.

Protecting stored products

Types of storage

Well-constructed, weather-proofed bins are essential to prevent infestations and to preserve crop quality during long-term storage. Bins on high, well-drained land protect the crop from heavy rainfall and spring floods. Steel bins, when empty, provide fewer places for insects to breed than empty wooden granaries, but residual insects can be present in dust and chaff under perforated floors.

Erect steel bins on steel-reinforced concrete slabs to prevent cracks and moisture transfer through the floor. Use a caulking compound to fill both cracks in the floor and open joints between the floor and wall. Shape the concrete pads slightly convex to shed water. Fill bins no higher than the top ring, leaving ample head room above the surface of the grain for inspection and sampling. Install aeration systems that cool the stored crop and reduce moisture migration to minimize the risk of spoilage and insect or mite infestations during storage.

When yields are above average, crops are often stored in machinery sheds or barns. Take extra care to prevent spoilage when using these types of storage. Fill cracks in concrete floors with a caulking compound.

For temporary crop storage, plywood sheets can be used to construct circular cribs. Locate cribs on high, dry land and cone the ground under the grain so that rain and melted snow water can drain away. Clear away grass or straw so that mice are not given shelter around the crib. Cone the grain as high as possible at the centre to shed rain and snow and to avoid a space between the top edge of the crib and the grain surface. Avoid walking on the grain as depressions will collect water. If a plastic sheet is placed over the coned grain, tie down the sheet with fish netting or place several old tires on top of the sheet to prevent it from flapping and tearing in the wind. Corner-vented sheets are designed to permit the escape of moisture but may allow in more snow than unvented sheets.

Prevention of spoilage

Most spoilage begins near the top centre of the bulk where moisture contents can increase due to moisture migration and snow blowing into the bin (Fig. 1). The quality of grains and oilseeds can be maintained economically by forcing air through bulk-stored crops. Air is blown in or drawn out by means of a fan (Fig. 2) attached to a bin equipped with either perforated ducts or a perforated floor. When air is blown in, the last part of the bulk to cool will be the top layer. Check from the top to determine whether the whole bulk is cooled or whether spoilage has begun. If the air is drawn out by reversing the airflow, the last part to cool is the bottom layer. In this case, spoilage may occur at the bottom of the bin where it is much more difficult to control or monitor.

Producers have three options for moving air through bins as a means of preventing spoilage:

- aeration to cool crop.
- aeration to dry crop.
- aeration with heat to dry crop.

Aeration

Purpose The purpose of an aeration system is to preserve dry stored grain by cooling the grain and preventing moisture migration. A properly designed and operated aeration system requires only small, inexpensive fans but the airflow rate is too low to dry the stored crop. Aeration helps to conserve the quality of malting barley without pesticide residues, fungal odours, or germination damage.

Airflow rate In aeration systems the usual airflow rates per cubic metre of grain or oilseed are about 1 to 2 L/s.

Fan size Usually, relatively small fans are required for cooling purposes. A cylindrical bin, 6.4 m in diameter and with a 6.8-m eave height, filled with 215m^3 (6000 bu) of wheat may require a fan of only 250 to 600 W (exact size depends on the actual performance of the specific make and size of fan).

When the main purposes of the ventilation system are to cool the crop and prevent moisture migration, the nonuniform airflow patterns developed by ducts placed on or in the floor are usually acceptable. A completely perforated floor produces a uniform air flow throughout the bulk, and reduces the chance of unventilated spoilage pockets developing. Even with a completely perforated floor, less air flows through the centre of the bin (Fig. 3). Install trap doors in perforated floors and ducts to facilitate removal of crop residue build-up that can harbour pests.

Grain harvested on sunny days can go into storage at a temperature 8°C above the ambient temperature. Stored grain temperatures can also be high if the grain was inadequately cooled after passing through a heated-air drier. When upward aeration is started to cool this hot grain moisture will condense on the cold bin roof and drip onto the grain surface. Such condensation will decrease as the roof warms up. Adequate exhaust opening in the roof will reduce this problem and continuous, uniform airflow will remove the added moisture on the top grain surface.

Fan operation Forced movement of cool, outside air through grains or oilseeds causes a cooling front to move through the bulk from the air entrance to the air exit. Aeration per cubic metre of grain or oilseed at an airflow rate of 1 L/s requires about 240 h or about 10 days of continuous operation to pass a

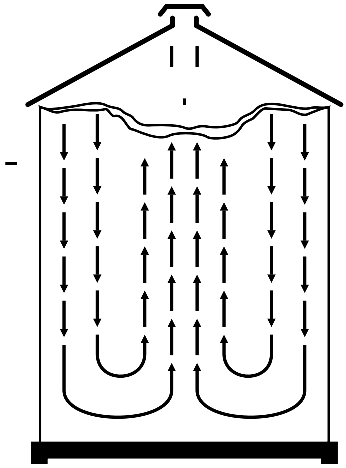

Fig. 1 Moisture migration in an unventilated bin during autumn and winter.

Fig. 2 Aeration unit.

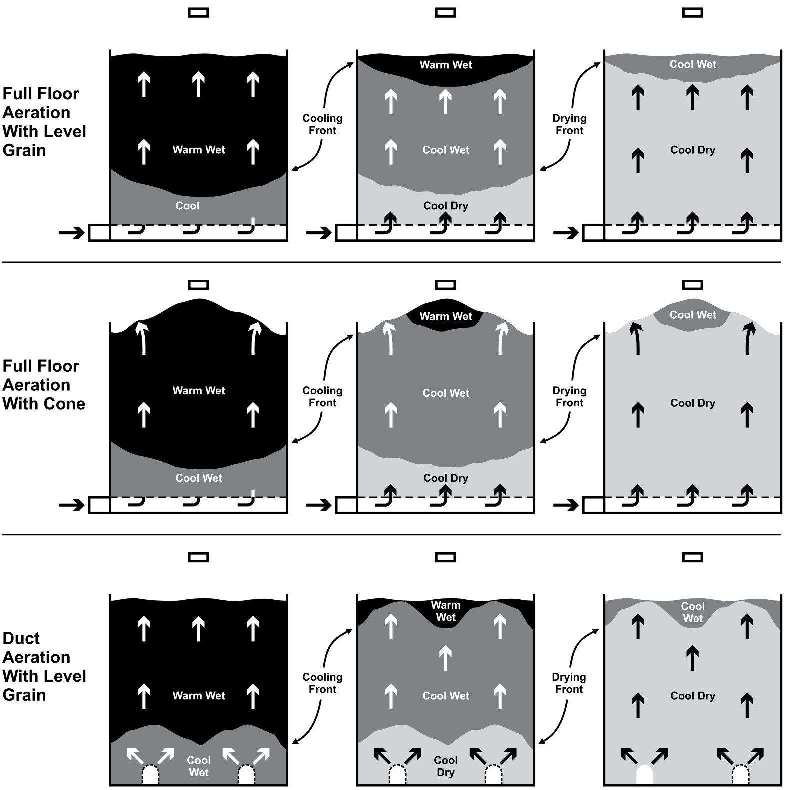

Fig 3. The movement of cooling and drying fronts through crops ventilated with air during autumn.

cooling front completely through the bulk. Do not turn off the fan until the seeds on top have the same temperature as the outside air. During initial cooling after harvest the moisture content of the cooled crop may be reduced by about 0.5 to 1.0%.

Normally the best management strategy is to run the fan continuously after harvest until the temperature of the stored crop has been cooled down below 20°C. When the outside air temperature has further dropped to about 5°C below the crop temperature, operate the fan again continuously until the new cooling front has passed through the bulk. In winter, repeat aeration until the outside ambient temperature and grain have reached a minimum.

In-bin drying with outside air

Drying process Moisture can be removed from stored crops by passing outside air through the bulk. In Western Canada, except for the winter months, outside air can be used with heat added only by the fan and motor. Grain in a ventilated bin begins to dry where the air enters the bulk, usually at the bottom of the bin. A drying front develops and moves slowly upward through the bulk. Below the drying front the grain is at the temperature of the incoming air and at a moisture content in equilibrium with the incoming air. For example, incoming air at 70% relative humidity will result in a moisture content of about 14 to 15% for wheat or 8 to 9% for canola. The grain above the drying front will remain at a moisture content within about 1% of its initial storage condition. To be effective, the drying front must be moved completely through the bulk before spoilage occurs. The rate of movement of the drying front is mainly affected by the airflow rate per unit mass of grain or oilseed.

To dry all the stored crop in the least possible time requires a uniform air pattern throughout the bulk. The airflow pattern in a bin equipped with a completely perforated floor and leveled grain surface is uniform unless a centre core of densely packed grain and dockage develops under the filling spout. Poor transitions from the fans to the plenum under the floor reduce the airflow through the bulk near the fan entrances.

Airflow selection To obtain the lowest equipment and operating costs, the lowest acceptable airflow should be selected. Minimum airflows for in-bin drying are chosen so that the crop dries just before it undergoes unacceptable spoilage in the worst drying years. Farmers should contact their local provincial biosystems or agricultural engineers for airflow and equipment recommendations.

Bin selection For a given diameter, taller bins require larger fans and hence more energy. The reduced cost of drying shallower grain or oilseed bulks must be balanced against the increased costs of steel and concrete as bin diameter is increased to store the same quantity of grain.

Fan operation Run the fan continuously in the fall until either the crop temperature has been brought down to -10°C or the grain is dry. In the spring, if drying was not completed the previous fall and no spoilage has occurred, then continue drying when the air temperature begins to rise above 0°C. Even under humid or rainy conditions operate the fan continuously. Moist air will rewet the bottom slightly, but the main drying front will continue moving through the bulk. As long as the fan is continued in operation for a few days after the humid period, the rewetting will distribute through the bulk and will probably not cause spoilage. Rewetting can be an economic benefit if the grain at the bottom has overdried below the maximum allowed selling moisture content. Although it improves the storage quality, any drying below this regulatory value reduces the saleable mass, and thus, the monetary value of the bulk. Rewetting, however, causes the grains or oilseeds to expand and may cause structural failure of the bin walls.

In-bin drying with heated air

Increasing the air temperature by adding heat reduces the relative humidity of air entering the bulk. For example, increasing the temperature of 20°C air at 70% relative humidity to 25° C reduces the relative humidity to 50%. Wheat exposed to 70% relative humidity air will dry to 14 to 15% moisture content whereas at 50% relative humidity the wheat will dry to 10 to 11%. Although this grain will store much better than the 14-15% wheat, its saleable mass will have been reduced by about 4 to 5%, causing a similar reduction in its economic value under present marketing regulations. Thus, heat added by electric or propane heaters, furnaces and solar collectors may be uneconomical. Usually the extra heat is an economic benefit only when the relative humidity of the outside air remains high for many days, such as in parts of eastern Canada. During warm weather, adding heat requires a larger fan and more-rapid drying because the crop spoils more rapidly. Later in the fall a smaller, less-expensive fan may be used in combination with a heater.

Prevention of infestations

Insects

To prevent and control infestations we need to know where and when insects occur. Surveys have shown that most empty granaries are infested with low numbers of insects and mites. Animal feeds, trucks and farm machinery are other sources of insect infestations. Some insects can fly as well as walk, which increases their ability to infest stored crops. Take the following measures before the crop is harvested to prevent infestation and spoilage during storage.

- Keep dockage to a minimum by controlling weeds in the growing crop; insects do not multiply extensively in stored crops that contain low amounts of dockage.
- Clean granaries, preferably with a vacuum cleaner; burn or bury the sweepings.
- Repair and weatherproof granaries before filling.
- Do no allow waste grain or feed to accumulate either inside or outside storage structures.
- Eliminate grass and weeds around granaries.
- Do not store crops in bins next to animal feeds that are likely to be infested.
- Spray the walls and floor of empty granaries with an approved insecticide about 1 week before crop storage.
- Examine grains and oilseeds that have been binned tough every 2 weeks: (1) push your hand into the surface at various points to feel for warmth or crusts;

and (2) insert a metal rod into the bulk to test for heating at various depths; after at least 15 min, preferably 60 min, withdraw the metal rod and test for warmth on the wrist or palm of the hand.
- Store new grains or oilseeds only in clean, empty bins. Bins that contain old grain might be infested.
- Try to sell high moisture grains first (as feed).
- Remember that cool, dry grains or oilseeds seldom spoil.

Mites

Mite infestations can be prevented and/or controlled by the following procedures:

- Keep the moisture content of cereal grain below 12% and that of canola below 8%.
- Transfer the grain or oilseed to an empty bin to break up moist pockets, or chill cereal grain at 15 to 16% moisture content with forced air during winter.

Storage fungi (Moulds)

To prevent storage mould activity, give particular attention to the moisture and temperature of the bulk at binning, especially in unaerated bins. Monitor bulk temperatures at 1- or 2-week intervals. Dry high-moisture and cool high-temperature grains or oilseeds by aeration (see "Prevention of spoilage"). Use spreaders to disperse dockage (small, broken and shriveled kernels; weed seeds; chaff; and straw) throughout the bulk. Remember that the increased bulk density in the bin reduces the rate of forced airflow through the bulk. Remove windblown snow before it melts and provides a focus for mould development. To control heating or spoilage in progress, move the bulk to cool it and break up high-moisture pockets. Alternatively, aerate or dry the bulk. Have someone with you when climbing into or onto granaries. Wear a dust mask to prevent inhalation of mould spores either when breaking up a mouldy crust within a bin or when handling spoiled grains or oilseeds.

Detecting problems

Inspect grain and oilseed stocks regularly to detect the first signs of infestation or spoilage. Sample bulks every 2 weeks to check for insects and heating. To detect insects, warm the sampled grain or oilseed in a screened funnel for several hours (Fig. 4). Insects and mites move away from the gradually drying grain and heat and fall into a collecting bottle.

Another way to check for insects in cereals is to screen surface samples using a No. 10 sieve (2.0-mm aperture). For the smaller canola seeds use a No. 20 sieve (0.85-mm aperture). Use a sampling probe to obtain deep samples. Warm the siftings for a few minutes and then examine them for insect movement. Check grains and oilseeds for heating by feeling the bulk's surface or a metal rod after it has been inserted for 1 h within the bulk.

To check for mites, sift grain or oilseed samples through a No. 20 or 30 mesh sieve (0.595-mm aperture). Warm the dust and screening to room temperature and examine them through a magnifying glass. Large numbers of mites in siftings look like clumps of moving dust. Smaller numbers that look like specks of dust are hard to see.

Insect-detection devices used to trap insects consist of probes — plastic tubes perforated with small holes that exclude grain kernels but allow insects to drop into, but not to escape from the trap (Fig. 5). Traps are generally not used in oilseeds where insects are usually not a problem. When cleaning samples in a dockage tester, free-living insects may be detected in the aspirator pan.

As a monitoring device, traps can detect infestations early so that produc-

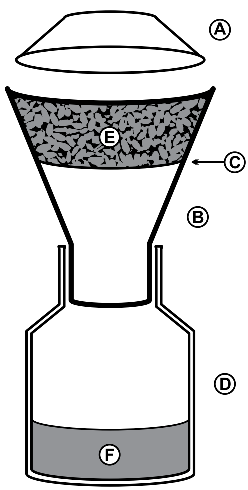

Fig. 4 Apparatus for extracting insects and mites from grains and oilseeds: *A*, light bulb; *B*, metal funnel; *C*, metal screen soldered to funnel wall; *D*, glass jar; *E*, 200 g of grain; and *F*, 50 ml of 70% alcohol, or water.

Table 1 Percentage moisture content of tough or damp cereal grains, oilseeds, and pulses

Crop	Moisture content (wet weight)	
	Tough (%)	Damp (%)
Wheat	14.6-17.0	>17.0
Amber durum	14.6-17.0	>17.0
Buckwheat	16.1-18.0	>18.0
Oats	13.6-17.0	>17.0
Barley	14.9-17.0	>17.0
Flaxseed	10.1-13.5	>13.5
Canola (Rapeseed)	10.1-12.5	>12.5
Mustard seed	9.6-12.5	>12.5
Rye	14.1-17.0	>17.0
Peas	16.1-18.0	>18.0
Corn	15.6-17.5	17.6-21.0
Soybeans	14.1-16.0	16.1-18.0
Sunflower	9.6-13.5	13.6-17.0

Source: Canadian Grain Commission 2001.

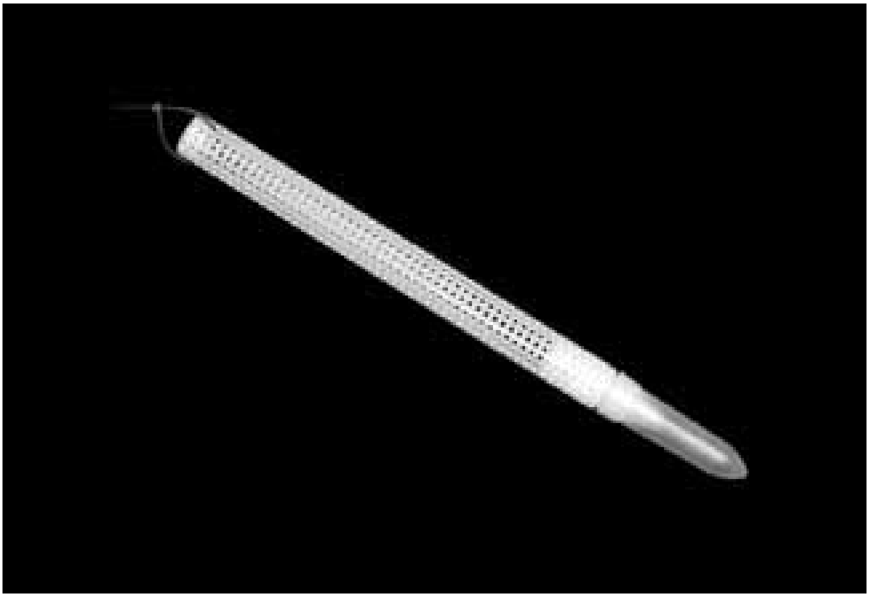

Fig. 5 Plastic trap for detecting stored-product insects.

ers or elevator managers can act before the grain has deteriorated to the point at which serious losses occur. Traps can be used in granaries, elevators, rail cars and ships to monitor grain at all stages of storage and transport. Push traps into the centre of a grain mass where insects generally accumulate because of warmth and higher moisture. Leave them for about 1 week (adult insects of some cold-hardy species continue to be captured down to 10°C) and remove by pulling on an attached rope. Take care to identify captured insects because grain-feeding pests require chemical control measures, whereas fungus-feeding insects indicate the grain is going out of condition and, therefore, should be moved into another bin or dried.

Spoilage and infestations

Development of storage fungi and insects is favoured by moisture and moderate-to-high temperatures. Continuing growth of these organisms in grains and oilseeds results in spoilage, heating and insect infestations.

Even when grains and oilseeds have been stored dry, moist spots may develop by moisture migration within the bulk or by rain or snow getting in through roof vents and other openings.

Grain along the inner perimeter and roof of the bin cools as the outside-air temperature decreases during fall and winter. Grain in the centre of large, unaerated bins (6-m diameter and larger) remains near the harvest temperature into mid-to-late winter. This temperature difference within the bulk causes air to move up through the warm bulk at the centre. As warm, moist air moves upward, cooler grain at the top of the bulk absorbs moisture from the air. Moisture in this rising air may also condense or freeze on the underside of cold roofs (Fig. 1).

Each crop has its own particular storage characteristics and safe storage de-

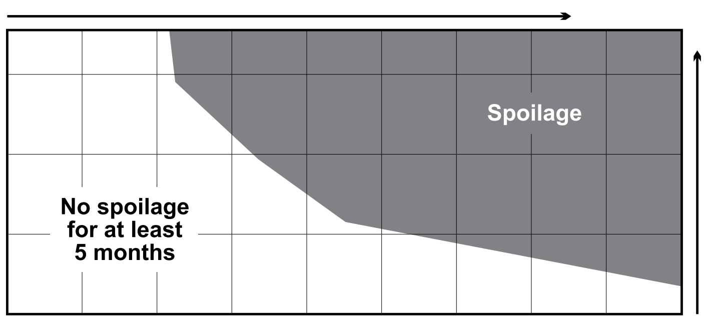

Fig. 6 Canola storage time chart based on seed moisture and temperature at binning. At moisture contents above 13% even cool grain deteriorates rapidly.

pends largely on its moisture content, its temperature and the length and time of storage. By knowing the moisture content and temperature of a crop at binning it is possible to predict its future storability. In Fig. 6, moisture-temperature combinations are shown for storage of canola, which result in either spoilage or no spoilage over 5 months. To move a crop from spoilage in the upper part of the chart to no spoilage below, either dry the canola or cool it by aeration.

To store wheat safely for up to 6 months, temperature and moisture content combinations may be used for prediction (Fig. 7).

Bin monitoring

Need for monitoring

Stored grains are living organisms. The economic value of grains in storage can drop rapidly when they are allowed to deteriorate. Successful in-bin drying requires daily monitoring of bulks and an understanding of the drying and spoilage processes. Thus, to maintain the value of grains during storage, measure their moisture and temperature conditions regularly, so that remedial action can be taken if it appears that they will spoil before drying takes place.

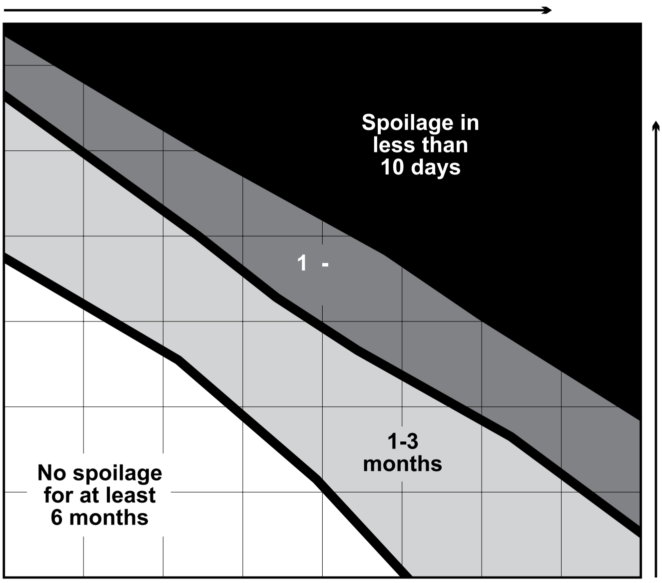

Fig. 7 Wheat storage time chart showing zones in which spoilage occurs in less than 10 days, within 10-30 days, within 1-3 months, and no spoilage for at least 6 months.

Monitoring of bulks can be done by entering the bins, observing the condition and odour of the surface grain, and, with a probe, removing samples from deep in the bulk. This activity can be time-consuming, difficult and dangerous and is therefore frequently neglected. Active spoilage is indicated by changes in temperatures, concentrations of carbon dioxide or both. Off-odour (musty), visible mould (green, blue, yellow, white) or clumped grain may be present.

Bulk temperature

The most common and readily available method of monitoring for spoilage is to measure temperatures throughout the bulk with permanently or temporarily installed electrical sensors (Fig. 8). One such system consists of a cable and a hand-held, battery-operated monitor. The cable hangs down the centre of the bin with temperature points every 1.2 m and hangs down the outside of the bin with the connector at eye level. The top temperature point should be about 0.3 to 0.6 m below the top grain surface (after the grain settles). The monitor is plugged into the connector and the bulk temperatures are read off and recorded.

Measuring temperatures regularly throughout the bulk during aeration can locate the cooling front. Turn the fan off when the bulk temperature is cooled to the outside temperature and turn it on again when the outside temperature drops about 5°C below the bulk temperature.

When grain spoils from the growth of moulds or insects, oxygen is consumed while heat, carbon dioxide and water are produced. The heat can cause the temperature of spoiling grain to rise. Thus, in an unventilated bulk, temperature measurements may be useful in detecting deterioration. But difficulties may arise in using and interpreting temperature results.

- Temperatures of large grain or oilseed bulks change slowly. For example, at the centre of a 6-m diameter bin the temperature can be highest in winter and lowest in summer.
- When a small pocket of grain spoils, the temperature at the centre of the pocket may reach 65°C whereas only 50 cm away the grain may be 10°C. To detect small pockets, temperatures must be measured at many points or at least where spoilage is most probable.
- Low bulk temperatures do not necessarily indicate safe storage conditions. At -5°C, some moulds can begin to grow slowly; above 10°C both moulds and mites can flourish. Most insects, however, require bulk temperatures above 20°C to reproduce rapidly.
- Bulk temperatures above outside air temperatures do not necessarily indicate the occurrence of spoilage. Straight-grade crops can be harvested and placed into storage in excellent condition at warm temperatures. But, when the crop is harvested and stored on a hot day, insects flying in from outside and those

from the walls and floor debris in an unclean bin may start an infestation by multiplying rapidly. Such grain should be cooled by turning or by aeration to prevent insects from breeding. If the crops are stored dry in large, unventilated storage the temperatures near the centre can remain relatively high throughout the cold winter.

Carbon dioxide concentration

A second method of detecting active spoilage caused by either moulds or insects is to measure the concentration of carbon dioxide (CO_2) in the intergranular air. The usual biological deterioration process occurring in stored grain and

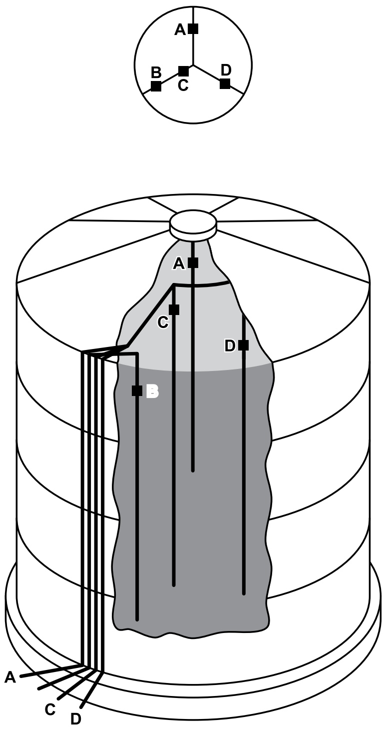

Fig. 8 Bin temperature monitoring system of four sensing cables A-D suspended from the roof. Cables A, B and D are located halfway between the wall and bin centre and C is located close to the centre. *Note*: Cables longer than 8-12 m require support brackets to prevent the roof being pulled down by the cables (McKenzie et al. 1980). The cables should be attached to the floor, otherwise grain will push them sideways providing false readings.

oilseeds consumes oxygen and produces carbon dioxide. The concentration of CO_2 in outside air is about 0.03-0.04% (300-400 ppm). Concentrations above this level in a bin indicate that biological activity (moulds, insects, mites, or grain respiration) is causing the stored crop to deteriorate.

As CO_2 usually spreads into the surrounding bulk, gas sampling points need not be right in the spoilage pockets. But it is preferable to sample at locations where spoilage usually occurs, such as at the centre of the bulk about 1-2 m below the top surface. Occasionally, spoilage will occur around doors because of leaking gaskets or ill-fitting covers, and on the floor by the bin wall due to bin sweating and condensation, or water leaks through roof vents. These localized areas can produce elevated CO_2 levels that may be detected throughout the bin. It is advisable to have several additional sampling locations to determine if elevated levels are localized or throughout the bulk.

Carbon dioxide sampling equipment

Air samples can be withdrawn through small-diameter plastic tubes temporarily or permanently located within the bulk, using a hand pump, syringe, or electric pump. The concentration of the CO_2 can be measured with an electronic detector.

A less expensive alternative is to use gas-analyzer tubes, which change colour according to the amount of CO_2 passed through them (Fig. 9). The tubes can only be used once. Tubes cost approximately $5.00 each (in 2000) and can be obtained from most safety equipment outlets.

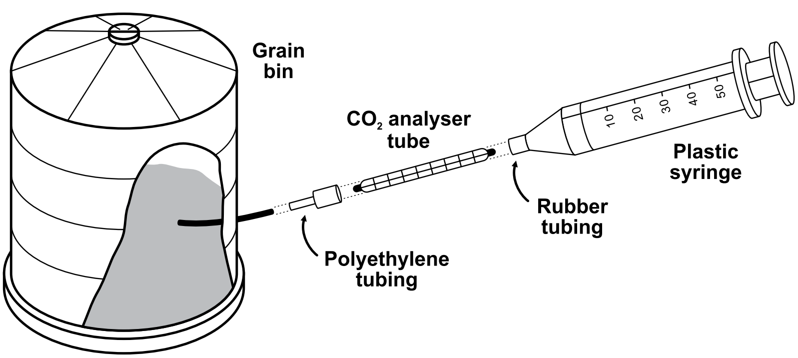

Fig. 9 Device for detecting grain and oilseed spoilage by carbon dioxide measurements.

Identifying the organisms

Common stored-product pests

Of more than 100 species of stored-product insects and mites found across Canada, only a few cause serious damage; the others are fungus feeders, scavengers, predators and parasites.

Beetles and moths, the most-common stored-product insect pests, have four life stages: egg, larva, pupa and adult (Fig. 10). Booklice (psocids) and mites have only egg, nymph and adult stages.

Egg The eggs may be laid either in the crevices of kernels or in the dust and refuse within bins. Some species, such as granary weevils, lay their eggs inside kernels.

Larva The larva is the only stage during which the insect grows. It consumes several times its own weight in food, and as the larval skin cannot stretch, it periodically moults allowing it to increase in size. Cast-off skins found in grains, oilseeds and their products indicate that insects are, or were, present.

Pupa The pupa, which forms after the last larval molt, does not feed. In some species, the pupa is enclosed in a cell, or cocoon, constructed by the larva. During the pupal stage, the insect undergoes extreme internal and external changes that lead to the development of the adult.

Adult Adults of stored-product insects are between 0.1 and 1.7 cm long. They have three pairs of legs and their bodies are divided into three parts: head, thorax and abdomen. The head includes the mouthparts and sense organs; the thorax bears the legs and wings; and the abdomen contains the reproductive organs. Adults

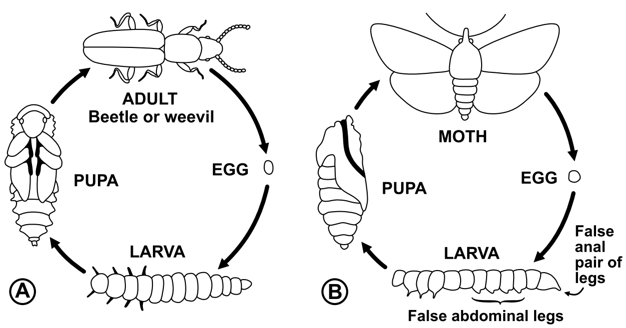

Fig. 10 Life cycles of stored-product insects: *A*, a beetle and *B*, a moth.

move in the spaces between kernels and can penetrate deeply into a bulk of grains or oilseeds, with the exception of moths and spider beetles. Some stored-product insects can fly and are widely distributed. Beetles have poorly developed wings and some species are unable to fly, although the rusty grain beetle, the red flour beetle and the lesser grain borer fly well.

Beetles

Stored-product beetles often appear similar but have differing behaviour patterns and status as pests. It is important to determine which species are present before taking remedial action. A detailed identification guide is now available (Bousquet 1990) to help determine which species are present. The characteristic features of the main beetle species occurring on stored grains and oilseed crops in Canada are as follows:

Rusty grain beetle This beetle (Plate I*a*, *b*) is the most serious pest of stored grain in most regions of Canada. It usually feeds on the germ (embryo) part of a whole seed. Heavy infestations cause grain to spoil and heat. The adult is a flat, rectangular, shiny, reddish-brown beetle, 0.2 cm long and has long, bead-shaped antennae that project forward in a "V". It moves rapidly in warm grain and can fly when the air temperature is above 23°C. Eggs are laid in the crevices of kernels and in grain dust. The tiny larvae penetrate and feed on the germ of damaged kernels. Eggs become adults in wheat in about 21 days at 14.5% moisture content and 31°C.

Flat grain beetle This insect is similar in appearance and feeding habits to the rusty grain beetle except that the males have longer antennae. It is an important pest of stored grain in the northern United States and is now appearing in grain bins in southern parts of the Canadian prairies.

Red flour beetle This pest (Plate II*c*, *d*) develops on stored grains and oilseeds on farms and in primary elevators throughout the Prairie Provinces and most of Canada. The adult is reddish brown and 0.4 cm long. Larvae and adults feed on broken kernels. Complete development from egg to adult occurs in about 28 days under optimal conditions of 31°C and 15% moisture content. Slower development occurs at moisture contents as low as 8%. Adults fly in warm weather or may be blown by the wind into farmhouses or other buildings.

Confused flour beetle The adult (Plate II*e*) resembles that of the red flour beetle and is difficult to distinguish without a microscope or magnifying glass. Larvae and adults feed on flour, animal feed and other ground material. Unlike the red flour beetle, the confused flour beetle is more common in flour mills than elsewhere, and the adults do not fly.

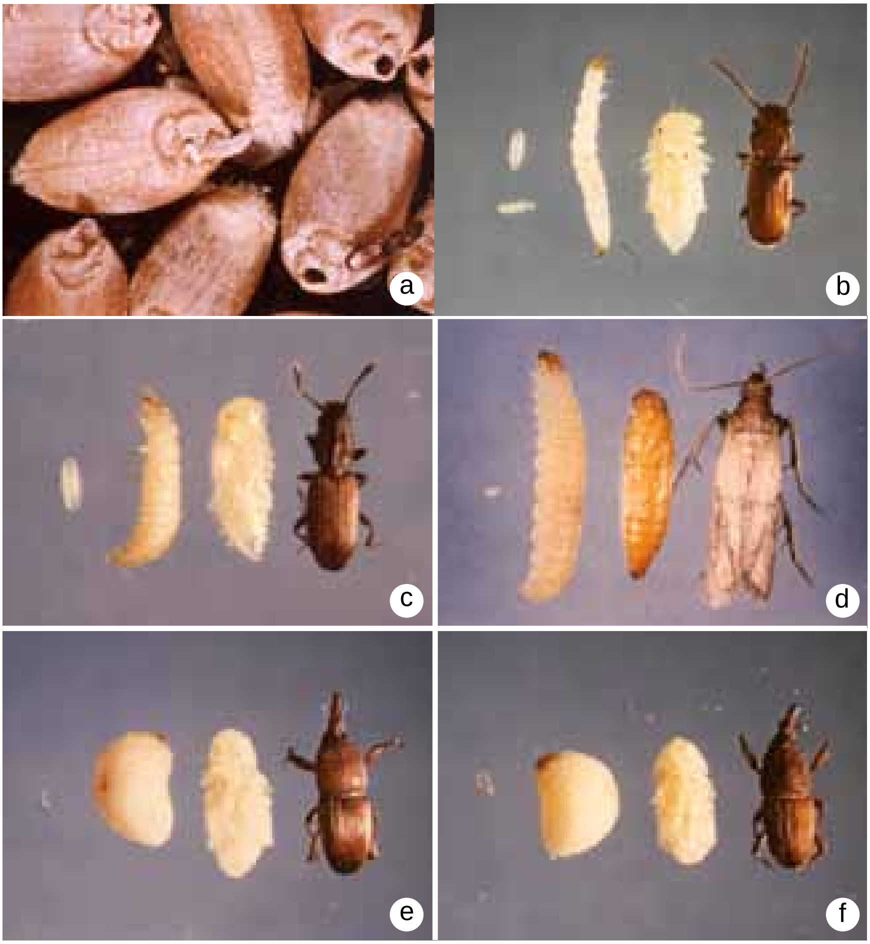

Plate **I*a*** **Wheat kernels infested by rusty grain beetles.**
b **Life stages of the rusty grain beetle (*left* to *right*): eggs, larva, pupa and adult.**
c **Life stages of the sawtoothed grain beetle (*left* to *right*): egg, larva, pupa and adult.**
d **Life stages of the Indianmeal moth ((*left* to *right*): egg, larva, pupa and adult.**
e **Life stages of the granary weevil (l*eft* to *right*): egg, larva, pupa and adult.**
f **Life stages of the rice weevil (l*eft* to *right*): egg, larva, pupa and adult.**

(From Sinha and Watters 1985).

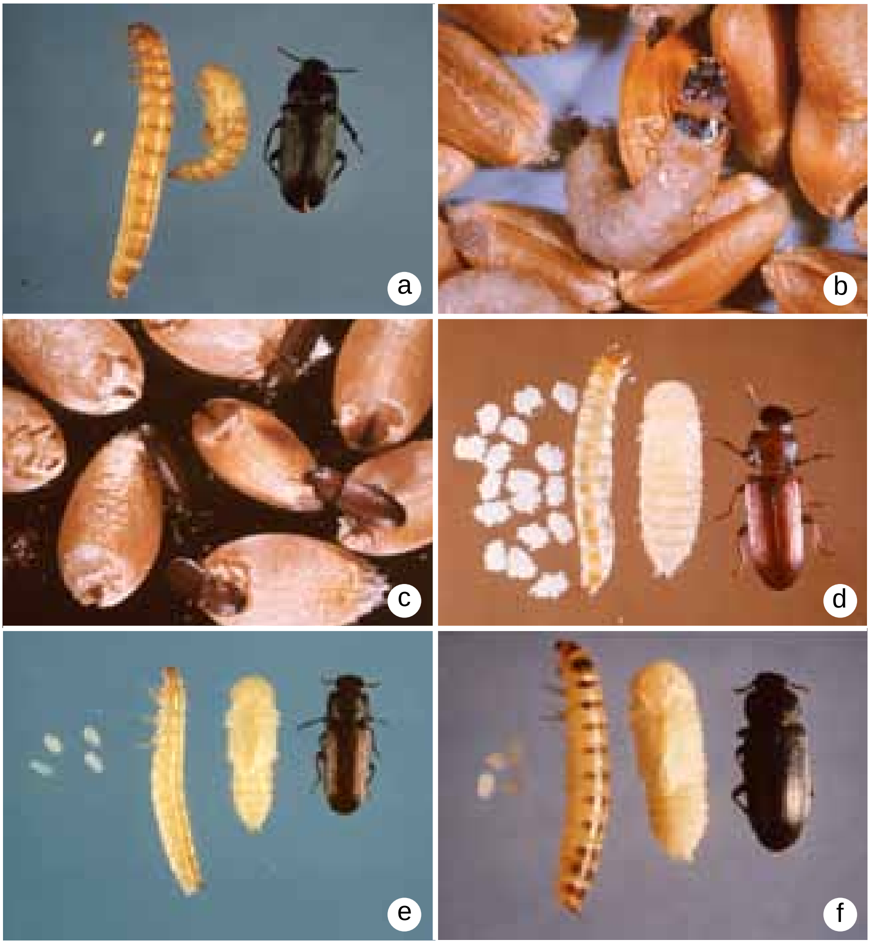

Plate II*a* **Life stages of the yellow mealworm (*left* to *right*): eggs, larva, pupa and adult.**

b **Larva of the cadelle on wheat kernels.**

c **Wheat kernels infested by red flour beetle adults.**

d **Life stages of the red flour beetle (*left* to *right*): eggs, larva, pupa and adult.**

e **Life stages of the confused flour beetle (*left* to *right*): eggs, larva, pupa and adult.**

f **Life stages of the European black flour beetle (*left* to *right*): eggs, larva, pupa and adult.**

(From Sinha and Watters 1985).

Plate III Some pest (*a*-*c*) and nonpest (*d*-*f*) insects of grains and oilseeds:
- ***a*, Mediterranean flour moth;**
- ***b*, meal moth (adult);**
- ***c*, meal moth (larva);**
- ***d*, antlike flower beetle;**
- ***e*, strawberry root weevil; and**
- ***f*, Dermestid beetle**

(courtesy of Lloyd Harris, Saskatchewan Agriculture, Regina, SK).

American black flour beetle This beetle is similar to, and larger than the red flour beetle, but black in color. It is commonly found in empty granaries but rarely infests farm-stored grains and oilseeds in large number.

Fungus beetles These pests usually infest tough or damp grains and oilseeds and feed on associated dust and moulds. Dry seed bulks stored next to tough or damp seed bulks may also become infested. The foreign grain beetle, the square-nosed fungus beetle, and the sigmoid fungus beetle are the most common fungus-feeding insects found in stored grain and oilseed crops. Because certain species of fungus beetles resemble the rusty grain beetle and are about the same size, apply chemical control measures only after the insects are correctly identified. The foreign grain beetle is similar to the rusty grain beetle but is able to climb up glass whereas the rusty grain beetle cannot.

Fungus beetles in stored grains and oilseeds are cause for as much concern as are rusty grain beetles, because they indicate that high moisture and moulds are present and that the crop may be going out of condition. The grains or oilseeds must be dried to break up tough or damp pockets. As fumigation will not stop spoilage by moulds or heating, take measures to move the bulk immediately, or it may spoil resulting in significant losses.

Sawtoothed grain beetle These beetles (Plate I*c*) are more common in oats than in wheat, barley or canola, particularly in southern Ontario and Quebec. The adult is brown, is about 0.3 cm long, and has six tooth-like projections on each side of the thorax. In warm grain it takes about 22 days to develop from egg to adult under optimal conditions of 31 to 34°C and 14 to 15% moisture content.

Granary weevil This weevil (Plate I*e*) is one of the most destructive pests of stored grain in the world. It is scarce on the prairies but occurs in Ontario and grain terminals in Vancouver. The adults have a distinctive snout, with which they bore into grain kernels. The female deposits a single egg in a hole in each kernel and then seals the opening with a gelatinous plug. The larvae feed on the endosperm and complete their development within the kernel. The pupae develop into adults that chew holes in the side of the kernels as they emerge. Development from egg to adult takes 25 to 35 days under optimal conditions of 26 to 30°C and 14% moisture content. The granary weevil adult is about 0.3-0.4 cm long and cannot fly. When disturbed, they fold their legs under their body and appear to be dead.

Rice weevil This weevil (Plate I*f*) has been found in southwestern Ontario storage and in some prairie elevators in recent years. It is 0.2 to 0.4 cm long and has four distinct reddish orange spots on the wing covers, which are folded over the abdomen. It completes development from egg to adult in 28 days at 30°C and 14% moisture content. Adult rice weevils can fly, and attack a wide range of cereals other than rice; larvae develop and pupate within the kernel.

Lesser grain borer This insect is a major pest of wheat in the plains of the USA. Adults are dark brown, cylindrical, 0.2 to 0.3 cm in length and the head is invisible when viewed from above. Adults are strong flyers. Larvae bore into the seed. In warm grain development takes 25 to 30 days. The lesser grain borer is found occasionally in grain, and has been caught in pheromone-baited flight traps across the Canadian prairies and at terminal elevators in Vancouver and Thunder Bay. However, this insect is rare in Canadian stored grain and it is unlikely that it can survive the entire winter in farm bins in Western Canada.

Hairy spider beetle This beetle is mainly a pest of wheat flour and animal feeds but may also infest stored grain near the surface. Adults and larvae have strong jaws, which they use to chew large, irregular holes in the endosperm of kernels. The adult is 0.35 cm long and has long, spiderlike legs and long, thin antennae. This beetle has only one generation a year. Three or four larvae often cement five to eight kernels together to form a cluster, where they feed and grow for up to 5 months; then each constructs its own pupal cell, from which the adult emerges.

Yellow mealworm These insects (Plate II*a*) are the largest found in stored grain. They are not common pests on farms. They first infest animal feeds and then move into stored grain that is going out of condition. The adults are black beetles about 1.5 cm long; the larvae are yellow and 0.2 to 2.8 cm long. Yellow mealworms prefer dark, damp places in a granary or a feed bin. The adults live for several months and the larvae may take 1 to 2 years to change into pupae under harsh conditions. Because of their relatively large size, they are easily visible and often appear to be more numerous than they actually are. Their presence indicates poor storage and sanitation conditions.

Psocids (booklice)

These insects are slightly larger than grain mites. The adult is soft-bodied and about 1.0 mm long. It has a large head and long antennae, and some species have wings and may be confused with small flies (Fig. 11*C*). The female lays about 100 eggs in 3 weeks, which develop into adults during the summer. The egg develops through nymph to adult in about 21 days at 27°C and 13% moisture content; some adults can live for 51 days without feeding. In most years psocid cause no major problems, although they can feed on damaged kernels and are found in tough or damp grain. Occasionally, they occur in large numbers in widespread

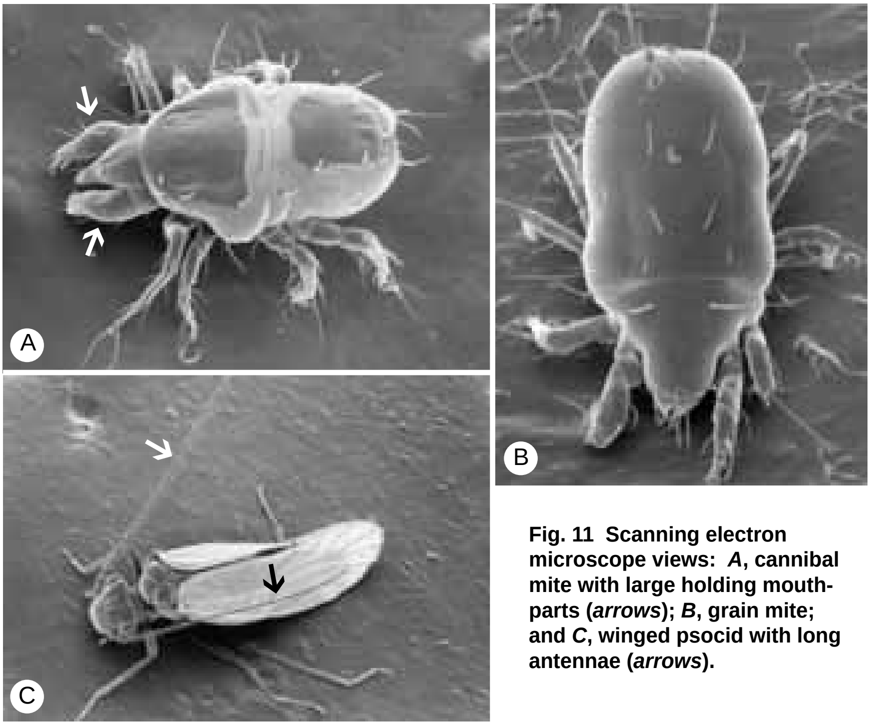

Fig. 11 Scanning electron microscope views: *A*, cannibal mite with large holding mouthparts (*arrows*); *B*, grain mite; and *C*, winged psocid with long antennae (*arrows*).

areas without any warning but do not cause serious damage to the stored crops. They are usually found with other insects or mites that are more serious pests of stored grains and oilseeds, often feeding on their eggs.

Moths

These pests are common in central Canada and on the east and west coasts. Adult moths do not feed, but their larvae have strong mouthparts and cause extensive surface damage to stored grain. Low winter temperatures usually control moth infestations, which are confined mainly to the surface layers of tough or damp grains that may be heating.

Indianmeal moth This moth (Plate I*d*) is common in central Canada primarily on corn and processed feeds and foods, and throughout the country in warehouses and stores.

Meal moth This moth (Plate III*b, c*) is moderately cold-hardy and can overwinter and thrive during warm months in unheated farm granaries across the Prairie Provinces. It usually occurs in patches of moist, mouldy grain. The larvae are cream-colored, have black heads, and are about 2-cm long when full-grown. They produce a silklike substance that webs the kernels together in clumps. The moth has

Table 2 Stored-product beetles found in Canada

Common Name	Scientific Name	Adult colour	Adult length (mm)	Antennae	Can climb glass	Can fly	Shortest egg to adult (days)	Food	Occurance in Eastern Canada	Occurance in Western Canada
American black flour beetle	*Tribolium audax*	dark brown, black	3-4	clubbed	no	no	25	flour	spotty	rare
cadelle	*Tenebroides mauritanicus*	dark brown, black	6-10	clubbed	no	yes	70	broken cereals, damp grain	spotty	spotty
confused flour beetle	*Tribolium confusum*	reddish brown	2-4	clubbed	no	no	20	flour	common	common
European black flour beetle	*Tribolium madens*	dark brown, black	4-5	clubbed	no	yes	25	flour	spotty	rare
flat grain beetle	*Cryptolestes pusillus*	reddish brown	2	thread	no	yes	22	broken cereals	spotty	spotty
foreign grain beetle	*Ahasverus advena*	brown	2	clubbed	yes	yes	21	mould	common	common
granary weevil	*Sitophilus granarius*	dark brown, black	3-4	clubbed	yes	no	28	cereal seed	spotty	rare
hairy spider beetle	*Ptinus villiger*	brown	2-4	thread	yes	no	58	flour, feed	spotty	spotty
lesser grain borer	*Rhyzopertha dominca*	dark brown	2-3	clubbed	no	yes	25	cereal seed	rare	rare
psocids	*Lepinotus reticulatus* *Liposcelis bostrychophilus*	light brown	1	thread	yes	yes no	21	mould	common	common
red flour beetle	*Tribolium castaneum*	reddish brown	2-4	clubbed	no	yes	20	broken cereals, flour	common	common
rice weevil	*Sitophilus oryzae*	dark brown, black	3-4	clubbed	yes	yes	24	cereal seed	spotty	spotty
rusty grain beetle	*Cryptolestes ferrugineus*	reddish brown	2	thread	no	yes	21	broken cereals	common	common
sawtoothed grain beetle	*Oryzaephilus surinamensis*	brown	3	clubbed	yes	yes	20	broken cereals	spotty	spotty
yellow meal worm	*Tenebrio molitor*	brown, black	12-17	thread	no	rarely	120	mouldy grain	common	common

spotty = consistent but-isolated local infestations
rare = found only occasionally

Table 3 Stored-product moths found in Canada

Common Name	Scientific Name	Adult colour	Adult length (mm)	Antennae	Can climb glass	Can fly	Shortest egg to adult (days)	Food	Occurance in Eastern Canada	Occurance in Western Canada
brown house moth	*Hofmannophila pseudospretella*	brown	8-11	thread	yes larvae	yes	365	grain products, dry goods	yes	BC ports only
Indianmeal moth	*Plodia interpunctella*	cream and brown	8-10	thread	yes larvae	yes	25	grain, nuts, dried fruits, dry goods	common	common
meal moth	*Pyralis farinalis*	brown and tan	15-20	thread	yes larvae	yes	42	mouldy grains, dry goods	ports	ports
Mediterranean flour moth	*Ephestia kuehniella*	gray and black	10-15	thread	yes larvae	yes	30	flour	rare	rare
whiteshouldered house moth	*Endrosis sarcitrella*	white	8-11	thread	yes larvae	yes	24	grain products, dry goods	ports	ports

Table 4 Stored-product mites found in Canada

Common Name	Scientific Name	Adult colour	Adult length (mm)	Antennae	Can climb glass	Can fly	Shortest egg to adult (days)	Food	Occurance in Eastern Canada	Occurance in Western Canada
cannibal mite	*Cheyletus eruditus*	white	0.4-0.6	-	yes	no	19	mites, insect eggs	common	common
glossy grain mite	*Tarsonemus granarius*	orange, yellow	0.1-0.2	-	yes	no	5	mould	common	common
grain mite	*Acarus siro*	white, tan	0.3-0.6	-	yes	no	14	cereal germ	common	common
longhaired mite	*Lepidoglyphus destructor*	white	0.3-0.5	-	yes	no	19	cereal, mould	common	common
mould mite	*Tyrophagus putrescentiae*	white	0.3-0.5	-	yes	no	9	mould	common	common

a wingspread of 2.5 cm. The fore wings are light brown, with dark brown patches at the bases and tips. Each wing has two wavy, white stripes. The life cycle takes about 2 months to complete in summer.

Brown house moth, whiteshouldered house moth, and Mediterranean flour moth These moths (Plate III*a*) commonly occur in grain terminals on the east and west coasts.

Mites

Mites are the smallest of the stored-product pests. They are common in grain stored at 14-17% moisture content but, because of their microscopic size, often go unnoticed. Mites, belonging to the same class as spiders and centipedes, are fragile creatures that are hard to see with the naked eye (Figs. 11, 12). Unlike an adult insect, which has a distinct head, thorax, abdomen, and six legs, an adult mite has a saclike body with eight legs; a larva has six legs. Mites are cold-hardy; most feed on broken grain, weed seeds, dockage and moulds. They are therefore well adapted for infesting stored products. Some mites, such as the cannibal mite, feed on their own members, other mites or insect eggs. They breed in tough and damp pockets of cereals and canola. About eight kinds of mites are common in farm granaries and elevators. Some give a strong, minty odour to infested grains and oilseeds. Their life cycle consists of the egg, a six-legged larva, two or three eight-legged nymphal stages, and the eight-legged adult. Some mites change into a nonfeeding developmental stage called a hypopus during which they become resistant to low winter temperatures, drying, starvation and most fumigants; they may be mobile or inactive. This stage can last for prolonged periods until developmental conditions improve.

Grain mite This mite (Figs. 11*B*, 12*A*) attacks the germ (embryo) of seeds, which reduces germination, and spreads fungi (moulds), which are also eaten. Heavily infested grain becomes tainted and unpalatable as animal feed. In some cases, dairy cattle and other farm animals develop gastric disorders and other symptoms after eating mite-infested feed. Adults are 0.3 to 0.6 mm long and females are larger than males. This mite is pearly white to yellow brown and has a smooth, glistening body with four long hairs arising from the rear end. Grain mite populations can increase up to sevenfold in 1 week in stored grains and oilseeds, particularly during the fall. Adult females can lay about 500 eggs during a lifespan of 42 days. The grain mite can develop from egg to adult in 14 days at 20°C and 14% moisture content. Adults and all immature stages except the nonfeeding developmental stage die in about 1 week when exposed to -18°C. Eggs can survive exposure to -10°C for about 12 days or 0°C for 2 to 3 months.

Longhaired mite This species (Fig. 12*D*) is the most common stored-product

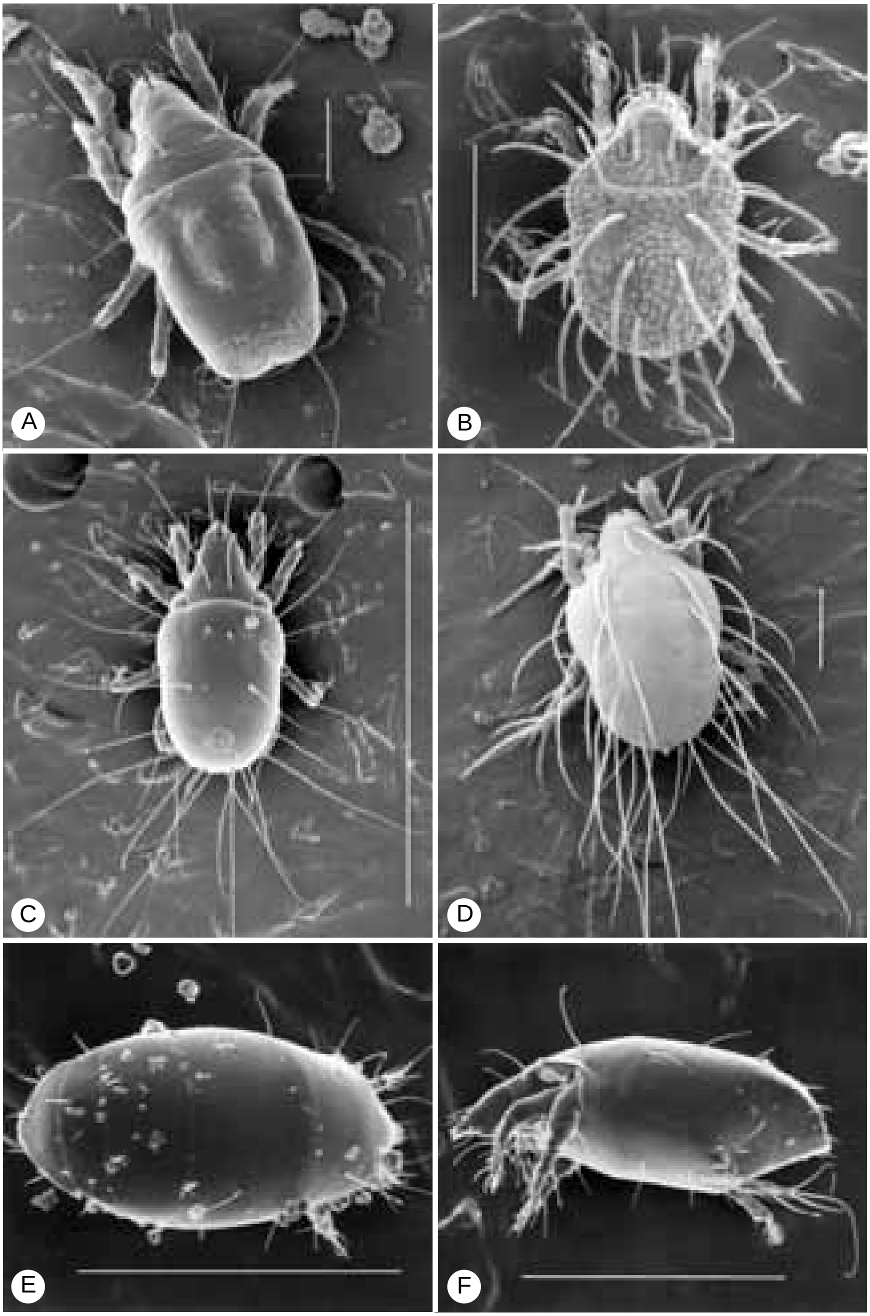

Fig. 12 Some major stored product mites as viewed by scanning electron microscope: *A*, the grain mite; *B*, warty grain mite; *C*, mould mite; *D*, longhaired mite; *E*, glossy grain mite female viewed from above; and *F*, glossy grain mite female viewed from the side. (Magnification is shown by the bar on each photograph, which represents 0.1 mm.)

mite. It is cold-hardy and can live in both straight-grade and tough grains and oilseeds. It moves rapidly with a jerky gait and feeds on broken grain, grain dust and fungi. The adult is white and about 0.3-0.5 mm long and has many stiff hairs that are longer than its body. In farm granaries, chronic infestations of this mite generally occur between June and November. It can survive for more than 7 days at -18°C.

Cannibal mite As the name suggests, this mite (Fig. 11*A*) feeds on its own kind, and also on the grain mite, the longhaired mite, and insect eggs and larvae. Because cannibal mites are not abundant enough to eliminate the mite pests that damage grains or oilseeds they are not very useful for biological control of grain-feeding mites. They have a diamond-shaped, white body with a chalky white line running the length of the body, pincerlike grasping appendages near the mouth, and long legs. They are 0.4 to 0.6 mm long. Cannibal mites are active in bulk grain in all seasons, usually in low numbers. In most tough grains and oilseeds they can breed between 12 and 27°C.

Glossy grain mite This mite (Figs. 12*E, F*) is a common fungus-feeder found in aging farm-stored grains and oilseeds. It develops from the egg to adult stage in 7 days under optimal conditions of 30°C and 17% moisture content. The mite feeds on certain moulds so its presence indicates that grain is becoming mouldy and going out of condition. The adult is clear white and less than 0.2 mm long. It can live for 17 days at 30°C and 90% relative humidity.

Storage fungi (moulds)

These organisms, occurring mainly as spores in the soil and on decaying plant material, contaminate grains and oilseeds with low numbers of spores during harvesting.

Storage fungi are usually inactive at low grain-moisture levels. However, when the moisture is higher, as in tough, damp or accidentally wetted grain, the spores germinate. Several species of *Aspergillus* and *Penicillium* are found on grains. Each fungal species requires a specific moisture and temperature level for germination and development, and develops in a definite sequence. The first fungus to develop breaks down nutrients in the seed through its enzymatic activity and produces moisture, which allows other fungi to germinate in their turn.

Storage fungi on grains and oilseeds affect their quality by causing heating and spoilage, packing or caking, reduced germination, and production of off-odours and mycotoxins. For further information on moulds and their effects on stored products, see *Storage of cereal grains and their products*, 4th Edition, Chapter 9 (Sauer 1992). Health hazards to humans and animals from the dust-like spores include “farmer’s lung” and allergies.

Mycotoxins

Mycotoxins are naturally-occurring fungal products which are poisonous when eaten or inhaled. These toxins occur in grain-based feeds, foods and dusts. *Aspergillus* and *Penicillium* moulds growing on stored cereals will start producing mycotoxins after about eight weeks of favorable temperature and moisture conditions. Mycotoxins can occur anywhere in Canada where grain is stored.

Although highly toxic in the pure form, mycotoxins are not usually present in dry grain, unless it becomes wet. When present at low concentrations, usually at parts-per-million, they are quickly detectable with modern test kits using the enzyme immunoassay principle. The health of farm animals can be impaired by mycotoxins in feed at the parts-per-million level or less, with livestock showing reduced productivity and increased mortality. Producers suspecting mycotoxin poisoning should save a sample of the feed, and consult their local veterinarian.

Mycotoxins usually develop when stored cereal grains become contaminated with *Aspergillus* and *Penicillium* moulds, following faulty storage or accidental dampening from seepage and condensation. In storage tests on damp grain, specific mycotoxins have been identified. Ochratoxin and citrinin are generally found in cereals contaminated with *Penicillium*, and sterigmatocystin is found during heavy growth of *Aspergillus versicolor.* The risk of these toxins forming at levels high enough to harm livestock depends on the particular crop:

- low risk: oats, hard red spring wheat, medium-protein wheat, 2-row barley
- moderate risk: corn, 6-row barley, hulless barley
- high risk: amber durum wheat.

Although the aflatoxins are well-known contaminants of grains and oilseeds from tropical countries and the USA, surveys of Canadian stored crops indicate that these toxins are not present.

During years of high mid-summer rainfall, additional mycotoxin problems can develop before harvest and storage. Fungi of the *Fusarium* type can infect standing wheat and barley and produce white or pink shriveled kernels, which are characteristic of fusarium head blight disease. The most common mycotoxin is deoxynivalenol (DON), but more poisonous mycotoxins from *Fusarium* may also be present. DON is quickly detectable by modern test kits using the enzyme immunoassay principle. Swine are affected by parts-per-million levels of DON in their feed, but other livestock show considerable resistance. *Fusarium* also reduces yield and grade of cereals and adversely affects the baking quality of wheat and the malting quality of barley, but requires very high moisture for growth and will generally not increase in storage.

For further information, see *Mycotoxins in agriculture and food safety* (Sinha and Bhatnagar 1998).

Controlling infestations

To keep infestations from spreading to other granaries, pests should be controlled as soon as they are discovered. The type of control implemented will depend on the condition of the grain, bulk temperature, kinds of insects or mites present, and the time of year.

Cooling and cleaning the product

An effective method to control insect infestations in winter is to lower the grain temperature. This can be done by mixing and transferring infested crops from one granary to another which will lower grain temperatures about 10°C in the winter; or by transferring part of the crop to a truck or small pile exposed to low air temperature, leaving it to cool for one or more days and then returning it to the granary. However, aeration systems are much more effective at lowering the grain temperature. Insects do not develop or feed at temperatures below 10°C. At temperatures below 0°C, the insects will die eventually. Control of the rusty grain beetle will be obtained:

- after 1 week at a grain temperature of -20°C
- after 4 weeks at a grain temperature of -15°C
- after 8 weeks at a grain temperature of -10°C
- after 12 weeks at a grain temperature of -5°C

Because the rusty grain beetle is the species most resistant to low temperature, most other insects in stored grains and oilseeds will also be controlled by these combinations of temperature and exposure periods. The low temperatures listed here do not kill fungi or all mites.

Cleaning the grain also checks infestations. To control surface infestation of moths, mites and spider beetles, remove and destroy webbed and infested patches, rake the bulk surface to break up any crust, and then dry the bulk.

Pneumatic grain-handling equipment Most free-living adult and larvae insect pests are killed during bin unloading by using a “grain-vac.” Insects are killed by abrasive contact and impact as the grain and insects are moved through the discharge tube. Better control is achieved when there is a 90° bend in the tube; this causes more contact of insects with the sidewalls of the tube.

Diatomaceous earth Control of rusty grain beetle can be achieved by using a nontoxic dust made from prehistoric diatoms. When rusty grain beetles come in contact with this dust, the waxy covering on their skin is absorbed, leaving them prone to dehydration and death. The product is applied to grain as it is augered into the bin, and is most effective when applied to dry grain at harvest. Control can take up to five or six weeks.

Treating with insecticides

> **WARNING** Resistance to insecticides (notably malathion) is becoming more common in stored-product insects across Canada notably in the Indianmeal moth in central Canada and in the red flour beetle, confused flour beetle and rusty grain beetle throughout most of the country. Repeated use of one kind of insecticide in the same storage area increases the chance of development of insecticide resistance on the part of an insect pest. Use more than one control and prevention method, and *use an insecticide only when it is absolutely necessary*.

To control insects occurring in residues in empty granaries, use only an insecticide that has been approved for use in granaries, and take precautions in its handling and use. Approved insecticides are selected largely on the basis of the following:

- low toxicity to mammals and high toxicity to insects
- freedom from taint or odour on food
- non persistent environmental effects
- safe, economical and easy use
- presence of negligible residues or toxic products in food

Some insecticides are more effective and longer lasting than others. Premium-grade malathion, cyfluthrin, pyrethrum with piperonyl butoxide and diatomaceous earth are at present the insecticides registered for empty-bin treatments. Long-term protection of stored cereal can be achieved by adding premium malathion or diatomaceous earth.

As insecticide sprays and dusts act only on contact with insects and do not penetrate piles of grain or dust on floors, remove residues from the granary *before* applying the insecticide.

Dissolve emulsifiable concentrates of malathion in clean water to form a milky emulsion and spray it on metal and wood surfaces immediately after mixing to avoid the insecticide separating from the water. Emulsifiable concentrates break down rapidly on concrete, but are effective for up to a year on wood or steel. Do not use these sprays near electrical switches or fuse boxes.

Wettable powder sprays can be applied to concrete, brick, metal or wood surfaces (Fig. 13*B*). Mix wettable powder formulations of malathion with clean water in a separate container before filling the sprayer. Wettable powders applied on painted surfaces leave white specks.

In cold weather, oil solutions of insecticides are better than water-based sprays because they will not freeze. Oil solutions can be prepared by mixing insecticide in deodourized kerosene following label instructions and can be used near electrical switches. Wood or metal surfaces can be sprayed and empty bins fogged, but avoid treating plastic or rubber surfaces with oil solutions.

Insects beneath the floor or within wall spaces may be controlled with insecticide powders or dusts, because these places are hard to treat with liquid insecticides. These powders or dusts are usually commercial formulations of malathion on treated wheat flour. Use a dust applicator or sweep the dust into cracks in the floor.

Oilseeds absorb contact insecticides from treated granary surfaces. Therefore, avoid treating granaries in which oilseeds are to be stored. If the granary is infested, sweep it well, destroy the sweepings, and treat sparingly only the junctions of the floor and walls.

If stored-product insects are visible on the outside wall of the granary, spray the walls and surrounding ground. Even if insects are not readily visible, it is a sound practice to spray not only grain spillage, but also the ground around the granary and underneath raised granaries.

Fig. 13 Application of *A*, fumigant tablets to grain and *B*, contact insecticide to an empty granary. Note use of full-face gas mask, rubber gloves, coveralls and hard hat.

Cautions for spray operators

- Read insecticide labels and follow instructions on them.
- Examine the sprayer and hoses for leaks.
- Avoid spillage of insecticide.
- Use a protective mask with approved filters when applying insecticide in enclosed areas such as empty granaries.
- Wear protective clothing, hard hat, goggles, rubber work boots and rubber gloves during preparation and spraying.

Use of concentrates

The amount of water needed to dilute emulsifiable concentrates or wettable powder formulations depends on the amount of insecticide in the concentrate and the dosage of insecticide recommended to control the pest. Use the following example to calculate how much water to add to a 50% emulsifiable concentrate to obtain a 1% spray solution of malathion.

$$(50 - 1)/1 = 49/1 = 49$$

Therefore, add 1 part (0.1 L) of a 50% emulsion to 49 parts (4.9 L) of water to obtain a 1% spray.

Use a 1% spray of malathion to control rusty grain beetles in empty farm granaries. Apply the spray evenly with a portable compressed-air sprayer at 5 L/100 m^2 using a nozzle with a 0.4-mm diameter orifice for emulsifiable concentrates or oil solutions and a 0.8-1.2-mm diameter orifice for wettable powder solutions.

Grain treatment

Grain treatment is not a substitute for good housekeeping; however, special formulations of premium-grade malathion are available for treating cereals for long-term (8 months to 1 year) protection from insects. Either liquid insecticide is sprayed on the grain, or dust composed of treated wheat flour is mixed with the grain at rates that are dependent on its flow through the auger.

Follow the instructions on the label Chemical odours will be produced that lower the selling price of grain if insecticides are applied at rates in excess of those recommended. Insecticide-treated grain should neither be sold for 7 days nor used for feed for 60 days after treatment.

To treat the grain with a 1% spray of premium-grade malathion, apply it at 0.8 L/t of wheat. Use Table 5 to determine the amount and rate of malathion for application. The treatment is effective as a protectant, but the grain should be stored in good condition and contain less than 14% moisture, otherwise the insecticide will break down quickly, reducing its residual activity.

Fumigation

Fumigants generate toxic gases that are used to control insects in stored grain. They are available for farm use only as solid formulations. Fumigants are also toxic to humans and farm animals and, therefore, must be applied only by trained people. Avoid inhaling the vapours, and follow the directions on the container (see section on "Cautions for fumigators"). CO_2 is registered for fumigation of grain, but bins must be made airtight; welded steel hopper bins can be made airtight for about $300.00 and the cost of fumigation with dry ice (CO_2) is comparable to phosphine treatment, only slower.

Table 5 Amount and rate of premium-grade malathion required for application [1]

Flow rate (wheat)		Application rate (1% spray)	
t/h	t/min	L/h	L/min
3	0.05	2.4	0.04
6	0.10	4.8	0.08
9	0.15	7.2	0.12
12	0.20	9.6	0.16
15	0.25	12.0	0.20

[1] The Canadian Grain Commission does *not* recommend the use of grain protectants for the following reasons:
- insect problems may not arise
- alternative control measures, such as aeration or grain movement, are available
- chemical residues remain in the grain.

The solid fumigant aluminum phosphide, which generates phosphine gas in the presence of air moisture, should be applied only when the following conditions are met:

- Licensed personnel must apply fumigants.
- The grain temperature is at least 10°C. Fumigants are most effective at temperatures higher than 20°C. If the grain is below 5°C do not fumigate. Cool the grain to decrease the severity of the infestation by moving it to another bin or by aerating.
- The infested grain is stored in a granary that can be tightly sealed to retain the gas for at least 5 days by plugging cracks, crevices and other openings.

- Rapid control of an infestation is needed before selling the grain.
- Full-face gas masks in good condition and with the appropriate canister for phosphine, cotton gloves and protective clothing are available to wear during application.
- Gas-detector tubes or other detection equipment are available.

Application

In calculating fumigant dosage on the basis of bin volume, include the head-space above the grain. Use correct number of tablets or pellets as recommended by the manufacturer. Add tablets or pellets of solid fumigant (aluminum or magnesium phosphide) either to the grain stream as it is discharged from an auger into a sealed bin or by probing them into the grain at regular intervals once the bin is filled. Treat small bins of about 27-tonne capacity by dropping the fumigant through metal pipes inserted into the grain (Fig. 13*A*). Select about 12 evenly spaced points on the surface of the grain and mark them with wooden stakes. Insert a pipe 3-cm in diameter and 1.5 m long at each point and drop a tablet into the grain every 15 cm as the pipe is withdrawn. Start at the far end of the bin and work towards the door. Push some tablets into the auger hole before sealing.

In bins that cannot be tightly sealed at the top, cover the grain with polyethylene sheeting to reduce loss of fumigant and to improve effectiveness of treatment.

Cautions for fumigators

When using fumigants, follow the directions on the label closely and especially take the following precautions:

- Always wear a full-face gas mask either when applying fumigant to binned grain, to grain during augering or when entering a fumigated bin. Respirators are ineffective on bearded men because a tight seal cannot be made around the face.
- Always fit a new canister in your mask before starting fumigation. Use the type of canister recommended for phosphine gas. A canister does *not* protect people exposed to heavy concentrations inside buildings (for gas levels above 2% in air) and does *not* supply oxygen.
- Always work with at least one other person.
- Wear dry gloves of cotton or other breathable material. Aerate used gloves and other contaminated clothing in a well ventilated area before laundering.

- Wear coveralls and a hard hat.
- If an individual shows symptoms of overexposure to a fumigant, move that person to fresh air and call a doctor immediately. Symptoms of fumigant poisoning are dizziness, blurring vision, vomiting and abdominal pain.
- After applying the fumigant to a granary, nail or lock the doors, seal ventilators, and post warning signs on the door.
- Fumigated areas must be aerated to 0.3 ppm hydrogen phosphide or less prior to re-entry by unprotected workers. Because fumigated grain can take several weeks to aerate during cold weather, check for residual gas with gas detector tubes from outside the bin before entry and inside during any prolonged period of work in the bin.
- Do *not* feed fumigated grain to livestock unless the grain has been shown to be gas free by detector tubes or other analyses.
- Always consider wind direction. If there is a dwelling or livestock close to and downwind from the structure to be fumigated, postpone fumigation until the wind subsides or changes direction.
- Do *not* fumigate when winds are strong.
- For your safety, position yourself upwind during application of fumigant to grain being augered into a bin. Avoid standing downwind from a bin under fumigation.
- Phosphine gas may react with certain metals, especially copper, brass, silver and gold to cause corrosion at high temperatures and humidity. Take precautions to remove or protect equipment containing these metals, such as electric motors, wiring and electronic systems.

Pulse crops

Insects

Insects are rarely a problem in stored pulse crops. The exceptions are weevils of the family Bruchidae which can infest seed in the field and continue to multiply during storage (*Bruchus brachialis* Fahr., the vetch weevil; *Bruchus pisorum* (L.), the pea weevil; *Bruchus rufimanus Boh.,* the broadbean weevil; *Acanthoscelides obtectus* (Say), the bean weevil).

Fababeans *(Vicia faba L.)*

Relative storage risk: Low

Moisture content standards:

Dry:	up to 16.0%
Tough:	16.1 to 18.0%
Damp:	over 18.0%

Safe storage guidelines The maximum recommended moisture content for storing sound fababeans is 16% in Canada and 15% in Britain. Fababeans of 14.2% moisture content that had not undergone frost damage were safely stored for 2 years in Manitoba. Low-quality, frost-damaged beans that had been overwintered and had a moisture content above 15% often heated during the following summer.

Drying guidelines Drying at a maximum of 32°C is recommended. Drying should be done in two stages if more than 5% moisture content is to be removed to attain a 16% storage moisture content. Allow a few days between each stage to permit internal moisture to move to the surface. Do not dry beans rapidly at high temperatures because this cracks the seed and reduces viability. The beans may also become overdried on the outside and underdried within. Underdried beans result in a pasty meal, which on prolonged storage becomes rancid and heated. At drying temperatures above 40°C, the skin wrinkles or splits, particularly with high moisture beans. Avoid cracking the seed coat as microorganisms can then gain entrance and cause spoilage.

Degrading factors Fababeans are degraded when they contain heated and/or rotted beans, or have a distinctly heated or musty odour. Entire beans and pieces of beans are considered in the grading. Fababeans are graded *Sample* if they contain over 1% heated and/or spoiled beans, or have a distinctly heated or musty odour.

Appearance of heated and spoiled beans Heated beans and/or spoiled fababeans are those which are materially discoloured as a result of heating or rotting. Seed coats are dark brown to black, and the cotyledon tissue on dissected beans is either tan or brown.

Storage problems Beans are normally harvested when the pods are black and stems have shriveled. Because water loss is slow from the thick fleshy pods and large seeds, a prolonged period of ripening and drying may be required before combining, particularly in cool climates. If the crop is harvested too soon, the beans in the topmost pods will be immature. They will also be higher in moisture content than those in lower pods. Because of problems associated with prolonged ripening, late harvesting, frost damage, and prolonged drying, fababeans are frequently binned in a nonuniform state and consequently need to be carefully monitored during storage.

Field beans *(Phaseolus vulgaris L.)*

This heading includes white pea beans, also known as white beans or navy beans (most important), light and dark red kidney beans, black beans, pinto beans, pink beans, small red beans, Great Northern white beans, yellow eye beans and cranberry beans.

Relative storage risk: Low

Moisture content standards:

Dry:	none
Tough:	none
Damp:	over 18.0%

Safe storage guidelines A moisture content of 18% or less is recommended for safe storage of field beans. For long-term storage, a moisture content of 18% is too high, even at 5°C for beans required for seeding purposes (Table 6). The maximum moisture content for safe storage of pea beans for up to 1 year is 17.0%. Beans should be harvested when most of the pods are dry and the beans have hardened but before the seeds begin to shatter. The optimum moisture content for combining beans is 16 to 18%. At moisture content levels lower than this, damage can be severe and costly, as broken or cracked beans can only be used for livestock feed.

Drying guidelines Drying is necessary when beans are harvested damp because of poor weather or because of excessive harvesting losses due to shattering. Maximum drying temperatures for beans are 27 to 32°C. Dry beans slowly and,

Table 6 Estimated number of weeks for decreased germination to occur in brown beans

Storage temperature (°C)	Moisture content (wet basis, %)							
	11	12	13	14	16	18	20.5	23
	Maximum safe storage (weeks)							
25	31	22	16	11	7	4	2	0.5
20	55	40	28	19	13	7	3.5	1.5
15	100	75	50	30	20	12	6	3
10	200	140	95	60	38	20	11	4.5
5	370	270	170	110	70	39	20	9

if necessary, remove excess moisture in two stages (see fababeans). Great care must be taken during drying otherwise splits develop, even at relatively low temperatures. Hairline cracks, a degrading factor, increase at elevated temperatures. During drying keep the relative humidity of the heated air above 40%.

Degrading factors Beans are degraded when they contain heated or mouldy beans, or have a heated or distinctly musty odour. Beans are graded *Sample* if they contain over 1% heated beans or have a heated or distinctly musty odour, or if they contain over 1% mouldy beans. Mouldy beans are characterized by the presence of dark blue exterior moulds that have developed in crevices on machine-damaged beans, and yellow to black interior moulds that have developed in the concave centre area common to light and dark red kidney beans.

Appearance of heated kernels Heated pea beans have a dull-coloured seed coat varying from cream to mahogany. The colour is more intense in the hilum area. Cotyledons vary in colour from tan to dark brown when viewed in cross section. Very light cotyledons are classed as damaged rather than as heated. Heated light and dark red kidney beans have a dull, dark red to black seed coat. Beans must be split to determine the degree and intensity of heat damage.

Storage problems Mechanical handling damage is a problem which becomes more severe at low temperture and moisture levels. To reduce damage, use belt conveyors or front-end loaders rather than augers to handle beans wherever possible. Avoid dropping beans from excessive heights, particularly onto concrete floors.

Peas (*Pisum sativum* var. *arvense* (L.) Poir.)

Relative storage risk: Low

Moisture content standards:

Dry:	up to 16.0%
Tough:	16.1 to 18.0%
Damp:	over 18.0%

Safe storage guidelines Peas are harvested when they are mature and hard in the pod. Yellow-seeded cultivars are harvested beginning at 16% moisture content. Green-seeded cultivars are harvested at 18% moisture content, or higher, to maintain good colour, then dried down to 16%, or lower, for safe storage.

Drying guidelines The maximum drying temperatures are 45°C for seed required for seeding purposes, 70°C for commercial use, and 80 to 100°C for feed. Temperatures higher than 45°C will harm germination of seed peas, especially green peas.

Degrading factors Peas are graded *Sample* if they contain over 0.2% heated seeds, or have a heated, fire-burnt or distinctly musty odour.

Appearance of heated seeds Heated peas have dull seed coats and discoloured cotyledons, ranging in colour from light tan to dark brown.

Storage problems Peas of about 15% moisture content may develop a surface crust during the winter as a result of moisture migration and snow seepage, particularly when they are stored warm without aeration. The seeds tend to clump and if left undisturbed become blackened as a result of mould activity. To prevent clumping, periodically walk across the top of the bin or move the top 30 cm of stocks with a shovel.

Before moving the first load in the spring, examine the top surface of the stocks. If there is any black crust remove it with a shovel, otherwise the first load will be ruined by admixture. Crusting is a particular problem in overfilled steel bins, and it also occurs in stocks stored in Quonset huts. It can be prevented by using a front-end loader to divide the stocks and disturb the surface layers. Because of their size and shape, peas exert a greater lateral pressure than wheat; therefore, if grain bins are also used for storing peas they may require reinforcement.

Soybeans (*Glycine max* (L.) Merrill)

Relative storage risk: Moderate

Moisture content standards:

Dry:	up to 14.0%
Tough:	14.1 to 16.0%
Damp:	16.1 to 18.0%
Moist:	18.1 to 20.0%
Wet:	over 20%

The maximum permissible moisture content limits for soybean grades (U.S.) 1, 2, 3 and 4 are 13, 14, 16 and 18% respectively.

Safe storage guidelines In dry fall weather, mature soybeans dry in the field from about 15% moisture content in the early morning to 10% at noon. They absorb moisture again during the following night to repeat the cycle the next day. Soybeans can be harvested at a low moisture but only at the expense of added field losses and excessive mechanical damage. These effects can be minimized if beans are harvested at a higher moisture content before pods are completely mature, then dried to a safe moisture content for storage.

The safe moisture content for commercial seed is 13% for up to 1 year and 10% for up to 5 years. These guidelines do not take into consideration such things as accumulation of fines under the spout lines. Soybeans are more difficult to store than shelled corn at the same moisture content and temperature. This is because the equilibrium moisture content of soybeans at a relative humidity of 65% and 25°C is 2% less than for shelled corn.

Moisture content (%)	Market stock	Seed stock
10-11	4 years	1 year
10-12.5	1 to 3 years	6 months
13-14	6 to 9 months	Questionable, check germination
14-15	6 months	Questionable, check germination

Storage fungi can slowly invade soybeans stored at 12 to 12.5%, with the rate of invasion increasing above this moisture content level. Invasion of soybeans with 12.5 to 13.0% moisture content is unlikely to result in any loss of processing quality within a year even if the temperature is favourable for the growth of fungi; although it may cause some loss of germination. The invasion of soybeans at moisture content levels of up to 13.0% by storage fungi can, however, be dangerous because it may result in a sudden unexpected, and perhaps uncontrollable, increase in fungus growth and heating.

For continued silo storage, soybeans that are already lightly or moderately invaded by storage fungi are at higher risk than sound beans, and progress toward advanced spoilage more rapidly. Once the seeds have been moderately invaded by storage fungi, the fungi may continue to grow and cause damage at slightly lower moisture contents and temperatures than they would in sound beans.

Drying guidelines The maximum safe drying temperatures are 43°C for soybeans intended for seeding purposes, and 49°C for commercial use.

Degrading factors Soybeans are degraded when they contain heat-damaged, mouldy or rancid beans, or have a heated, distinctly musty or unpleasant odour. Heated beans are degraded numerically according to established grade specifications. Mouldy and rancid beans are considered in combination with heated beans for grading purposes. Soybeans are graded *Sample* if they contain over 5% heated beans or have a distinctly heated or musty odour.

Appearance of heated, mouldy and rancid soybeans Heated soybeans have an olive to dark brown seed coat and, when bisected, have tan to dark brown cotyledons. Mouldy soybeans are wrinkled, misshapen, medium to dark brown and often have a superficial covering of grey mould. They may also have a spongy texture and an unpleasant odour. Rancid soybeans have a deep pink discolouration.

Storage problems Most cases of serious loss of quality in stored soybeans occur because managers in charge of the beans do not know precisely the conditions prevailing in different portions of the bulk. The seed moisture contents and temperatures within the bulk must be known at all times and maintained at low levels to prevent mould development for safe storage. The condition of the stocks at the beginning of storage has an important bearing on their future keeping quality. Storage problems are aggravated by binning beans already lightly or moderately invaded by storage moulds, the presence of significant amounts of cracked and split beans, and the presence of fines in the bin spout lines. The cracked and split beans and fines (mainly weed seeds) form focuses for heating and subsequent deterioration. Spoilage commonly begins in soybeans in the spout line because the high-moisture weed seeds pack densely, preventing air penetration during aeration. Even if the beans at binning contain only 2 to 5% fines, the spout line may consist of 50 to 80% fines.

Sweating, which occurs when cold grain is removed from storage and exposed to air that has a high relative humidity and is more than 8 to 10°C warmer than the grain, is also of concern. Under these conditions, moisture from the air actually condenses on the beans, and when rebinned the cumulative effect of this sweat, or moisture, can cause heating problems in storage.

There is a genuine danger of self-ignition in soybeans because, unlike temperatures during heating of cereals which do not usually exceed 55°C, temperatures during heating of soybeans can exceed 200°C. The heat-damaged seeds lose at least 30% of their dry weight when temperatures reach 200°C.

Further information

For more information on the control of infestation in farm-stored grain, contact the following:

- Protection of Stored Grains and Oilseeds Study, Cereal Research Centre, Agriculture and Agri-Food Canada, 195 Dafoe Road, Winnipeg MB R3T 2M9, telephone: (204) 983-5533 http://www.agr.gc.ca/science/winnipeg/

- Department of Biosystems Engineering, University of Manitoba, Winnipeg http://www.umanitoba.ca/faculties/agricultural_and_food_sciences/biosystems_engineering/home.html

- the entomologist, Canadian Grain Commission, 303 Main Street, Winnipeg MB R3C 3G8 http://www.cgc.ca

- provincial entomologists and extension specialists

This document is available via the Internet at the Cereal Research Centre's web page at http://www.agr.gc.ca/science/winnipeg/

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Common and scientific names of major pests in stored grain

American black flour beetle	*Tribolium audax* Halstead
brown house moth	*Hofmannophila pseudospretella* (Stainton)
cadelle	*Tenebroides mauritanicus* (Linnaeus)
cannibal mite	*Cheyletus eruditus* (Schrank)
confused flour beetle	*Tribolium confusum* Jacquelin du Val
European black flour beetle	*Tribolium madens* (Charpentier)
flat grain beetle	*Cryptolestes pusillus* (Schönherr)
foreign grain beetle	*Ahasverus advena* (Waltl)
glossy grain mite	*Tarsonemus granarius* Lindquist
grain mite	*Acarus siro* Linnaeus
granary weevil	*Sitophilus granarius* (Linnaeus)
hairy spider beetle	*Ptinus villiger* (Reitter)
Indianmeal moth	*Plodia interpunctella* (Hübner)
lesser grain borer	*Rhyzopertha dominica* (Fabricius)
longhaired mite	*Lepidoglyphus destructor* (Schrank)
meal moth	*Pyralis farinalis* Linnaeus
maize weevil	*Sitophilus zeamais* (Motschalsky)
Mediterranean flour moth	*Ephestia kuehniella* (Zeller)
mould mite	*Tyrophagus putrescentiae* (Schrank)
psocid	*Lepinotus reticulatus* Enderlein, *Liposcelis bostrychophilus* Badonnel, and other species
red flour beetle	*Tribolium castaneum* (Herbst)
rice weevil	*Sitophilus oryzae* (Linnaeus)
rusty grain beetle	*Cryptolestes ferrugineus* (Stephens)
sawtoothed grain beetle	*Oryzaephilus surinamensis* (Linnaeus)
sigmoid fungus beetle	*Cryptophagus varus* Woodroffe & Coombs
squarenosed fungus beetle	*Lathridius minutus* (Linnaeus)
warty grain mite	*Aeroglyphus robustus* (Banks)
whiteshouldered house moth	*Endrosis sarcitrella* (Linnaeus)
yellow mealworm	*Tenebrio molitor* Linnaeus

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Conversion factors for metric system

Imperial units	Approximate conversion factor	Results in	
Length			
inch	x 25	millimetre	(mm)
foot	x 30	centimetre	(cm)
yard	x 0.9	metre	(m)
mile	x 1.6	kilometre	(km)
Area			
square inch	x 6.5	square centimetre	(cm^2)
square foot	x 0.09	square metre	(m^2)
square yard	x 0.836	square metre	(m^2)
square mile	x 259	hectare	(ha)
acre	x 0.40	hectare	(ha)
Volume			
cubic inch	x 16	cubic centimetre	(cm^3, mL, cc)
cubic foot	x 28	cubic decimetre	(m^3)
cubic yard	x 0.8	cubic metre	(m^3)
fluid ounce	x 28	millilitre	(mL)
pint	x 0.57	litre	(L)
quart	x 1.1	litre	(L)
gallon (Imp.)	x 4.5	litre	(L)
gallon (U.S.)	x 3.8	litre	(L)
Weight			
ounce	x 28	gram	(g)
pound	x 0.45	kilogram	(kg)
short ton (2000 lb)	x 0.9	tonne	(t)
Temperature			
degrees Fahrenheit	(°F-32) x 0.56 or (°F-32) x 5/9	degrees Celsius	(°C)
Pressure			
pounds per square inch	x 6.9	kilopascal	(kPa)
Power			
horsepower	x 746	watt	(W)
	x 0.75	kilowatt	(kW)
Speed			
feet per second	x 0.30	metres per second	(m/s)
miles per hour	x 1.6	kilometres per hour	(km/h)
Agriculture			
gallons per acre	x 11.23	litres per hectare	(L/ha)
quarts per acre	x 2.8	litres per hectare	(L/ha)
pints per acre	x 1.4	litres per hectare	(L/ha)
fluid ounces per acre	x 70	millilitres per hectare	(mL/ha)
tons per acre	x 2.24	tonnes per hectare	(t/ha)
pounds per acre	x 1.12	kilograms per hectare	(kg/ha)
ounces per acre	x 70	grams per hectare	(g/ha)
plants per acre	x 2.47	plants per hectare	(plants/ha)

Canada