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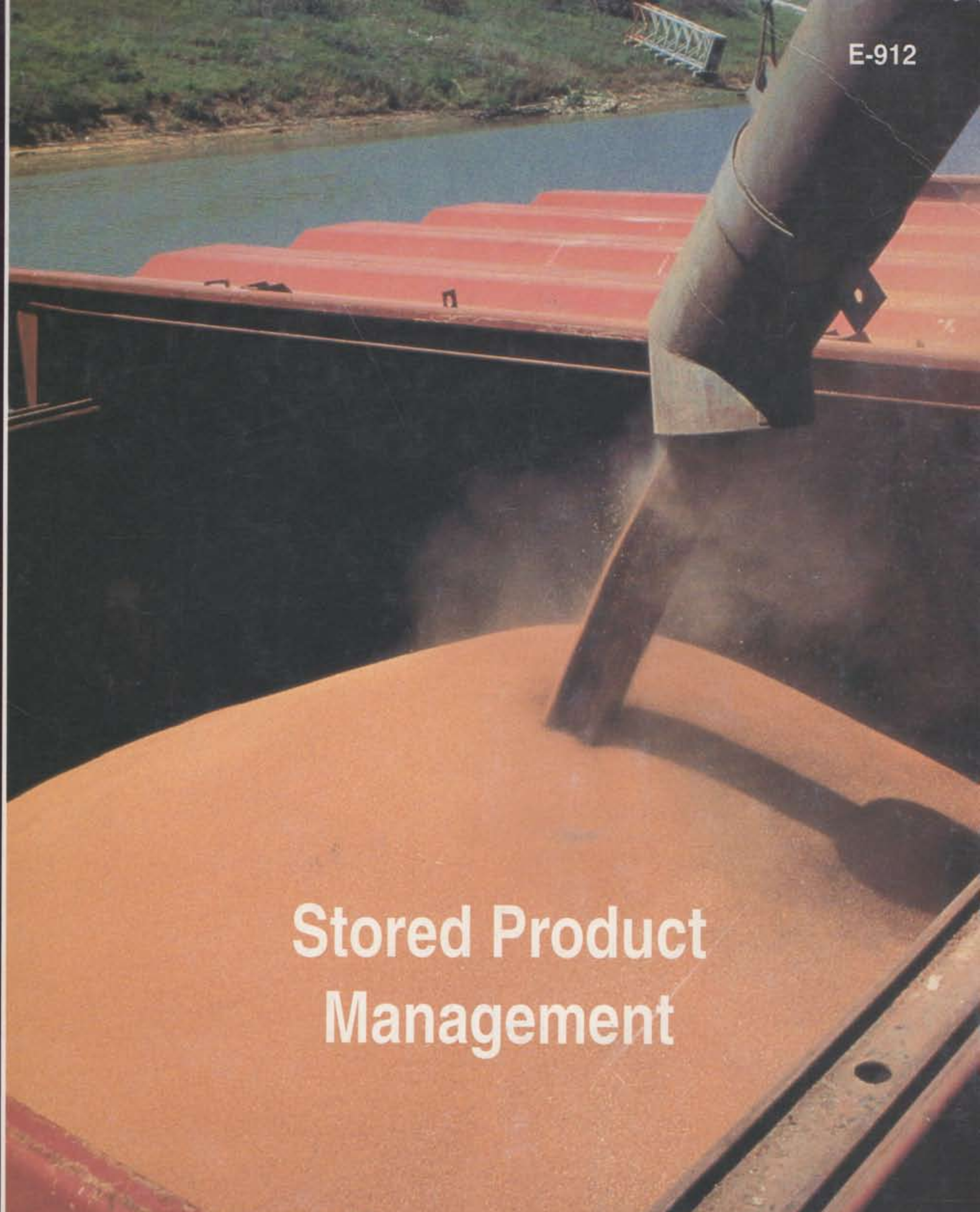

Stored Product Management

Oklahoma Cooperative Extension Service

Division of Agricultural Sciences and Natural Resources • Oklahoma State University

U. S. Department of Agriculture • Federal Grain Inspection Service

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U. S. Department of Agriculture • Animal and Plant Health Inspection Service

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(Revised from *Management of Grain, Bulk Commodities, and Bagged Products*, E-912)

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(continued)

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Foreword

This publication was made possible by the efforts of the USDA's Grain Insect Interagency Task Force (GIITF), a committee whose function is to promote good grain quality through policy development and education. The manual was developed to provide information on grain marketing and management practices to growers, handlers, processors, inspectors, and buyers. Clear, concise chapters containing relevant information on the marketing system and management practices can be used to improve product quality and food safety. GIITF's goal is to increase the awareness of all participants in the grain industry, from farmer to consumer, of their role in assuring a high standard of quality.

GIITF is administered by USDA-FGIS and is composed of members from USDA-APHIS, USDA-ARS, USDA-ASCS, USDA-ES, USDA-FGIS, EPA, and FDA. Financial contributions from USDA-APHIS, USDA-ES, and USDA-FGIS made possible the publication of this book. In addition, support from the Division of Agricultural Sciences and Natural Resources, Oklahoma State University, contributed greatly to the development of this publication.

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Stored Product Integrated Pest Management

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Who's Responsible for Quality and Safety?

Grain marketing in the United States is based on the free-enterprise system and is not controlled by the government, as is the case in many other grain-producing countries. In the United States, the government serves as an unbiased third party and is not directly involved in grain marketing. Three United States agencies work together and provide services necessary for grain inspection.

The USDA-FGIS (Federal Grain Inspection Service) must inspect grain at export. The FGIS is a non-regulatory agency that inspects and grades grain based on standards and procedures established in cooperation with marketers. Alterations in grain standards can only be accomplished through dialogue among congressional committees, the FGIS, and grain marketers. Specifically, U.S. law states that government agencies shall:

1) Define uniform and acceptable descriptive terms to facilitate grain trade;
2) Provide the necessary information to help determine grain storability;
3) Offer users of such standards information to help determine end-product yield and quality;
4) Provide the framework necessary to establish grain quality improvement incentives;
5) Reflect the economic value-based characteristics for the end users of grain; and
6) Accommodate scientific advances in testing and new knowledge concerning factors related to, or highly correlated with, the end-use performance of grain.

USDA-APHIS (Animal Plant Health Inspection Service) is a regulatory agency most known for its quarantine programs and its policies regulating imports. APHIS also issues Phytosanitary Certificates that verify that grain shipments are free of quarantined pests or weed seeds.

The Food and Drug Administration (FDA) works in cooperation with the FGIS through a Memorandum of Understanding. The FDA is a regulatory agency which is responsible for keeping the U.S. food supply wholesome. The FDA can condemn grain contaminated with high levels of insect damaged kernels (IDK), mycotoxins, or pesticides, or commodities contaminated with animal or insect filth (insect fragments) above the established tolerances. These must be kept out of the food supply by the FDA.

One of the aims of this handbook is to clarify the jurisdictions and responsibilities of the numerous agencies involved in facilitating grain marketing in the United States. As one learns more about the system, it becomes apparent that grain quality is an issue with which every government agency, trade group, and grower should be concerned. The perception of U.S. grain as a high-quality product must be maintained in order for the U.S. to compete in a world economy that is experiencing a grain surplus.

Many groups involved with the grain industry attempt to hold one component responsible for grain quality, whether it is the producer, exporter, terminal elevator, or subterminal elevator. Yet, when the system is examined, it is apparent that everyone involved in the grain system must share responsibility or stewardship to prevent: 1) contamination by illegal pesticides, mycotoxins, or other hazards; 2) accidental poisonings; and 3) grain quality deterioration. All components must responsibly use fumigants and other treatments to ensure worker safety and the safety of the food supply. If a truckload of contaminated grain is not detected at a local elevator, it may cause significant contamination at that elevator, the terminal elevator, or at export. More significantly, lack of stewardship can threaten the security of the entire food system and create losses in world markets that are already made unstable by over-production.

The purpose of this handbook is to provide grain growers, handlers, marketers, and inspectors with precise and up-to-date information on each group's responsibilities. Also, the handbook is designed to provide access to techniques and technologies for maintaining high grain and commodity quality. The concept of Integrated Pest Management (IPM) is emphasized. IPM is a multi-disciplinary approach to managing stored-product pests. This approach combines numerous tactics, including proper sanitation, aeration, chemical control, reduced atmospheres, biological control, insect traps for detecting insect populations, and decreased pesticide usage. These tactics help to ensure worker safety and reduce residue levels. It is hoped that this handbook will provide exposure to IPM concepts and contacts, references, and other information to help individuals associated with grain marketing do their best to maintain a high-quality product. □

Part I: Grain Marketing

1

Grain Storability: An Overview

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There is one primary reason to store grain—to increase net return. If the net return cannot be increased by storing grain, storage is a waste of time and effort, and becomes a risk.

Some managers may say that they store grain for "tax reasons." However, this statement does not justify the storage of grain since taxes cannot turn a loss into a profit. Taxes may reduce the impact of a loss, but only a limited percentage may be written off by taxes.

Managers often store grain because on-farm storage facilities are available. On-farm storage facilities may reduce storage costs, and thus increase the odds of greater net returns. However, unless the market offers a sufficiently higher price, storing grain will result in a decline in net returns.

Table 1. Annual on-farm per bushel storage cost.

	Bin Capacity (Bushels)			
	3,000	**5,000**	**10,000**	**20,000**
	(Cents/bushel)			
Fixed Costs				
Depreciation	5.5	4.4	3.2	2.8
Interest	2.1	1.7	1.2	1.1
Total Fixed Costs	7.6	6.1	4.4	3.9
Variable Costs				
Electricity	0.8	0.8	0.8	0.8
Chemical	2.0	2.0	2.0	2.0
Maintenance	4.2	3.7	2.5	2.0
Insurance	4.0	3.0	2.6	2.5
Labor	1.0	0.9	0.8	0.7
Total Variable Costs	12.0	10.4	8.7	8.0
Total Costs (excluding shrinkage and interest on grain)	19.6	16.5	13.1	11.9

One grain producer summed up the major drawback of storing grain with the statement, "The returns from storage may be measured in pennies. The losses from losing just one bin of grain is measured in dollars."

On-farm storage of grain requires investments of capital, time, and management practices. Producers who store grain must invest time to market the grain and to periodically check the condition of the grain. In addition, they must continually improve their marketing and storage skills.

Storage construction costs, commercial storage costs, government programs, marketing alternatives, risks of quality loss, storage management, and marketing ability are all important factors when making grain storage decisions. The economics of constructing storage facilities, the cost of storing grain in existing facilities, and a comparison of on-farm versus off-farm storage will be addressed in this chapter.

Storage Costs

Both fixed and variable storage costs are calculated for 3,000-, 5,000-, 10,000-, and 20,000-bushel bins. Fixed costs are only applicable if new construction (or major modification) of storage facilities is being considered. If quality storage facilities are in place, then variable costs, including shrinkage and grain quality loss, are the costs to be considered in the storage decision (Table 1).

Shrinkage is loss in volume or weight of the grain placed in the bin. This loss may be due to spillage, broken grain factions, aeration moisture removal, fines lost in handling, or other factors causing a reduction in the total weight. Quality loss is defined as a reduction in USDA grade and may be caused by insects, moisture, mold, or other factors that may lead to grain deterioration.

Opportunity cost is the interest cost incurred while holding grain and is a function of the grain price, the interest rate, and the length of time the grain is stored. For example, if the wheat price is $2.80 per bushel and the interest rate is 12 percent per year (one percent per month), the opportunity cost per bushel per month is 2.8 cents. Although opportunity cost is a function of the marketing decision, the storage decision should not be made without including the opportunity cost.

Costs due to shrinkage and quality loss are also variable costs. These per bushel costs are directly related to the grain price, volume change, and quality change.

On-farm Storage Costs

Storage costs are normally calculated on a per bushel per year basis, based on full bins. If bins are partially full, per bushel storage costs will be higher.

Costs are shown for 3,000-, 5,000-, 10,000-, and 20,000-bushel round, corrugated-steel, flat-bottom bins (Table 1). Costs include construction, an aeration system, and an unload auger. Drying units were not included in wheat bin costs. Costs for larger motors ($2,200) for the aeration and drying systems were included for corn bins.

Straight-line depreciation over 30 years, a zero salvage value, and 12 percent annual interest were used to calculate fixed costs. Costs were estimated for each year of the 30-year period. Average annual costs were then calculated on a net present value basis.

Total construction costs were $4,915 ($1.64/bushel) for the 3,000-bushel bin; $6,629 ($1.33/bushel) for the 5,000-bushel bin; $9,509 (95 cents/bushel) for the 10,000-bushel bin; and $16,675 (83 cents/bushel) for the 20,000-bushel bin.

Per bushel fixed (depreciation and interest costs) and variable costs decline as bin size increases. Thus, per bushel total costs (fixed plus variable costs) decline as the amount of grain stored and bin size increases.

Per bushel total fixed costs are estimated to be 7.6 cents per bushel for a 3,000-bushel bin; 6.1 cents per bushel for the 5,000-bushel bin; 4.4 cents per bushel for the 10,000-bushel bin; and 3.9 cents per bushel for the 20,000-bushel bin (Table 1). Depreciation makes up about 72 percent of fixed costs.

Variable costs include conveying and aeration electricity, chemicals, maintenance, insurance, and labor (Table 1). The total variable costs shown do not include costs due to shrinkage, quality loss, or opportunity cost. Variable costs were 12.0 cents per bushel for the 3,000-bushel bin; 10.4 cents per bushel for the 5,000-bushel bin; 8.7 cents per bushel for the 10,000-bushel bin; and 8.0 cents per bushel for the 20,000-bushel bin.

Total storage costs per bushel per year, excluding shrink and quality loss, were 19.6 cents for a 3,000-bushel bin; 16.5 cents for a 5,000-bushel bin; 13.1 cents for a 10,000-bushel bin; and 11.9 cents for a 20,000-bushel bin.

Storage Costs—Wheat

Table 2 shows potential storage costs for Hard Red Winter wheat in the Great Plains. Total fixed and variable storage costs presented in Table 1 were used. Shrinkage and quality loss are estimated to be two percent. With $2.80 wheat, the cost of two percent shrink and quality loss is 5.6 cents per bushel ($2.80 x 0.02).

With full bins and $2.80 wheat, total storage costs per bushel are 25.2 cents for wheat in a 3,000-bushel bin; 22.1 cents for a 5,000-bushel bin; 18.7 cents for a 10,000-bushel bin; and 17.5 cents for a 20,000-bushel bin.

If a producer already has storage bins, only variable costs are applicable in a stored-grain decision. Thus, a wheat farmer's storage decision would be based on 17.6 cents with a 3,000-bushel bin; 16.0 for a 5,000-bushel bin;

Table 2. Annual storage costs for wheat.

	Bin Capacity (Bushels)			
	3,000	**5,000**	**10,000**	**20,000**
	(Cents/bushel)			
Fixed Costs	7.6	6.1	4.4	3.9
Variable Costs[a]	12.0	10.4	8.7	8.0
Shrink				
2% @ $2.80/bu.	5.6	5.6	5.6	5.6
[2% @ $3.50/bu.]	[7.0]	[7.0]	[7.0]	[7.0]
Variable Costs + Shrink				
@ $2.80/bu.	17.6	16.0	14.3	13.6
[@ $3.50/bu.]	[19.0]	[17.4]	[15.7]	[15.0]
Total Costs				
@ $2.80/bu.	25.2	22.1	18.7	17.5
[@ $3.50/bu.]	[26.6]	[23.5]	[21.1]	[18.9]

[a]Variable costs do not include cost due to shrinkage.

14.3 for a 10,000-bushel bin; and 13.6 for a 20,000-bushel bin at $2.80 wheat.

This implies that to economically store wheat, a producer with a 10,000-bushel storage bin and a harvest price of $2.80 must receive at least 14.3 cents ($0.143) more per bushel when the wheat is sold than if the wheat was sold at harvest. For example, if a producer placed 10,000 bushels in on-farm storage on July 1, the November 1 wheat price would have to be $2.94 ($2.80 + $0.143) to cover storage costs. With a wheat price of $3.50, the November 1 wheat break-even price would be $3.66 ($3.50 + $0.157).

A storage decision cannot be made without considering opportunity cost. If the wheat were placed in the government loan program at an interest rate of six percent per year or one-half percent per month and the wheat price was $2.80, the opportunity cost would be about 1.4 cents per bushel per month ($2.80 x 0.005), or 5.6 cents for four months. Thus, the actual break-even storage price would be about $3.00 ($2.80 + $0.143 + $0.056) per bushel.

Storage Costs—Corn and Sorghum

Both fixed and variable costs will be higher for corn and sorghum than for wheat. Fixed costs are higher because of the need for larger fans, fan motors, and dryers. Variable costs are higher because of additional labor, maintenance, electricity, and fuel required to dry corn and sorghum. There is also a much higher potential for heat damage during drying and a higher mold risk due to elevated harvest moisture. Thus, there is more risk with corn or sorghum than with wheat. Some years, sorghum fields dry to suitable storage moisture levels so risks are usually lower than for corn.

Estimates of fixed and variable costs for corn storage and costs due to shrink and interest are shown in Table 3. Fixed costs included an additional $2,200 for a gas dryer and an LP gas tank. Interest and depreciation costs were also higher because of the higher investment.

Per bushel variable costs, excluding shrinkage, were 15.8 cents for 3,000-bushel bins; 14.0 cents for 5,000-bushel bins; 12.2 cents for 10,000-bushel bins; and 11.4 cents for 20,000-bushel bins (Table 3).

Shrinkage for corn was estimated to be 3.5 percent. With $2.10 corn, shrinkage cost is 7.4 cents per bushel. For corn prices at $2.70 per bushel, shrinkage costs would be 9.5 cents per bushel.

If corn is in the government feed grain loan program, the interest rate would be about six percent per year, or one-half percent per month. With $2.10 corn, the opportunity cost would be about one cent per bushel per month.

Table 3. Annual storage costs for corn.

	Bin Capacity (Bushels)			
	3,000	**5,000**	**10,000**	**20,000**
	(Cents/bushel)			
Fixed Costs[a]	10.4	8.4	5.9	4.7
Variable Costs	15.8	14.0	12.2	11.4
Shrink				
3.5% @ $2.10/bu.	7.4	7.4	7.4	7.4
[3.5% @ $2.70/bu.]	[9.5]	[9.5]	[9.5]	[9.5]
Variable Costs + Shrink				
@ $2.10/bu.	23.2	21.4	19.6	18.8
[@ $2.70/bu.]	[25.3]	[23.5]	[21.7]	[20.9]
Total Costs				
@ $2.10/bu.	33.6	29.8	25.5	23.5
[@ $2.70/bu.]	[35.7]	[31.9]	[27.6]	[25.6]

[a]Includes a $2,200 high-temperature gas heater and a 1,000-gallon LP tank.

A corn price of $2.70 would result in 1.4 cents per bushel per month opportunity cost.

To decide whether to store corn, a producer with an existing 10,000-bushel storage bin would only consider variable cost, shrinkage, and opportunity cost. Variable costs and shrinkage would be 19.6 cents per bushel at $2.10 corn. Thus, if corn were stored eight months, the price of corn would have to increase about 28 cents per bushel for the producer to break even ($0.196 + $0.08). The opportunity cost for $2.10 corn is eight cents per bushel ($0.01 x 8 months). With $2.70 corn, the opportunity cost would be 14 cents per bushel ($2.70 x .005) and the break-even price increase would be 36 cents per bushel ($0.217 + $0.14).

On-farm vs. Commercial Storage

It is difficult to compare on-farm storage costs to commercial storage costs. The major reason is that commercial storage rates are normally calculated on a daily basis and on-farm storage costs are calculated on an annual basis. For example, the average commercial per bushel storage cost for wheat in Oklahoma is .085 cents per day (2.6 cents per bushel per month). This cost applies no matter how long the wheat remains in storage. Once on-farm stored wheat is in the bin, storage costs are relatively fixed.

There also are marketing advantages and disadvantages for grain stored on-farm, and a different set of advantages and disadvantages for grain placed in commercial storage.

If it is known in advance that the grain will be stored for a longer period of time, on-farm storage can prove to be less expensive than commercial storage. Additional storage time will cost very little for on-farm storage, while commercial storage adds about 2.6 cents to the cost per month. As a result, longer storage time may give an advantage to on-farm storage. Government programs that subsidize construction of on-farm storage bins or government loan programs and the farmer-owned reserve may also support on-farm stored grain.

On-farm storage may give producers more marketing flexibility than commercial storage. Most commercial elevators charge an in-out charge on top of the storage cost if the grain is not marketed through that elevator. If producers have alternate markets (i.e., mills, river port markets, or other terminal outlets), then it may be possible to obtain a higher price than is available at local elevators. If these markets are not available or if the producer does not spend time merchandizing the grain, the advantage may be with commercial storage.

Producers also must consider transportation costs and timeliness of marketing. Transportation costs include moving grain from the field to the on-farm facilities and from the on-farm bins to the commercial elevator.

For producers, commercial storage has the advantage of guaranteed quantity and price. The quantity and USDA grade are established when the grain is delivered to the elevator. The USDA grade listed on a warehouse receipt is what the producer is guaranteed. The grain can be sold by delivering a warehouse receipt rather than grain. Also, loans for the total number of bushels may be obtained with a warehouse receipt; whereas, with on-farm stored grain, loans are based on about 80 percent of the measured grain.

Summary

Grain storage is an individual decision. Some producers are making on-farm storage pay. Producers considering building on-farm storage should study grain storage management technology before purchasing bins and losing available options.

The Oklahoma Farmer Stockman (1977) published the following list of questions that producers should ask before building on-farm storage:

1) Is the surrounding area deficient in commercial grain storage facilities?
2) During harvest, is transportation a hold-up?
3) In the months following harvest, is it common for wheat prices to increase sufficiently to cover storage cost?
4) Is grain being put in the government loan or reserve program?
5) Can weekly checks of stored grain be made and actions taken if necessary?

These questions and the economics of storing grain affect the on-farm storage decision. □

2

How Grain Moves Through the Marketing System

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Grain Production[1]

Wheat, corn, and soybean production from 1971 to 1990 are shown in Table 1. Annual wheat production averaged 1.5 billion bushels during the first four years of this period. By 1979, yearly production had increased to 2.1 billion bushels and peaked at 2.8 billion bushels by 1981, with production reaching 2.7 billion bushels in 1990.

From 1971 to 1975, corn production averaged 5.5 billion bushels per year. Production increased to 7.9 billion bushels by 1979. In 1983, corn production was drastically reduced as a result of the payment-in-kind program, but in 1985 production peaked at 8.9 billion bushels. In 1988, corn production dropped to only 4.9 billion bushels because of severe drought. Corn production was back up to 7.9 billion bushels in 1990.

Yearly soybean production averaged 1.3 billion bushels per year from 1971 to 1976. Output peaked at 2.3 billion bushels in 1979 and averaged around 1.9 billion bushels until 1987. Production was reduced to 1.5 billion bushels in 1988 due to the drought and rebounded to 1.9 billion bushels in 1989 and 1990.

Wheat[2]

Forty-two states in the United States produce wheat. There are six major classes of wheat and these vary in end use.

Wheat varieties grown in the United States are either "winter wheat" or "spring wheat," depending on the season each is planted. Winter wheat is sown in the fall and has some preliminary growth before cold weather arrives. The plants have a special gene that allows them to lie dormant through the winter. In the spring, they resume growth and grow rapidly until summertime harvest. Spring wheat, produced in northern states where winters are too severe for fall-sown wheat, is sown in the spring as soon as the

Table 1. U.S. wheat, corn, and soybean production, 1971 to 1990 (millions of bushels).

Year	Wheat	Corn	Soybeans
1971	1,618.6	5,641.0	1,176.1
1972	1,546.2	5,573.0	1,270.6
1973	1,170.8	5,647.0	1,547.5
1974	1,781.9	4,701.4	1,216.3
1975	2,126.9	5,829.0	1,547.4
1976	2,148.8	6,266.4	1,287.6
1977	2,045.0	6,425.5	1,767.0
1978	1,775.5	7,081.8	1,869.0
1979	2,134.1	7,938.8	2,268.0
1980	2,380.9	6,644.8	1,798.0
1981	2,785.4	8,201.6	1,989.0
1982	2,765.0	8,235.1	2,190.0
1983	2,419.8	4,174.7	1,636.0
1984	2,594.8	7,674.0	1,861.0
1985	2,425.1	8,876.7	2,099.0
1986	2,086.8	8,252.8	1,940.0
1987	2,105.0	7,064.0	1,905.0
1988	1,821.0	4,928.7	1,548.8
1989	2,036.6	7,527.2	1,923.7
1990	2,743.6	7,934.9	1,903.8

[3]Source: U.S. Department of Agriculture, "Crop Production," Agricultural Statistics Board, National Agricultural Statistics Service, CrPr 2-2, Washington D.C., various issues.

[1]Source: U.S. Congress, Office of Technology Assessment, Enhancing the Quality of U.S. Grain for International Trade, OTA-F-399 (Washington D.C.: U.S. Government Printing Office, February 1989).

[2]Source: The Wheat Grower. September-October, 1990. Wheat Facts 1990.

ground is workable, and grows continuously until it is harvested.

The many varieties of wheat grown in the winter and spring are grouped into six basic classes. Each class of wheat has its own similar family characteristics, especially as related to milling and baking, and other food use. The six classes are:

- **Hard Red Winter Wheat.** An important bread wheat. Accounts for the majority of the U.S. wheat crop. Produced in the Great Plains states, a large interior area extending from the Mississippi River west to the Rocky Mountains, and from the Dakotas and Montana down to Texas. Fall seeded. Wide range of protein content. Good milling and baking characteristics. No subclasses.

- **Soft Red Winter Wheat.** Grown in the eastern third of the United States. High yielding. Relatively low protein. Provides flour for cakes, pastries, quick breads, crackers, and snack foods. No subclasses.

- **Hard Red Spring Wheat.** Another important bread wheat. High protein content and excellent milling and baking characteristics. Spring seeded. Grown in north central United States (North Dakota, South Dakota, Minnesota, Montana, Idaho, and Washington). Subclasses include Dark Northern Spring, Northern Spring, and Red Spring.

- **Durum.** The hardest of all U.S. wheat. Provides semolina for spaghetti, macaroni, and other pasta products. Grown in the same northern area as Hard Red Spring, mainly in North Dakota. Some also grown under irrigation in southern California and Arizona. Subclasses are Hard Amber Durum, Amber Durum, and Durum.

- **Soft White Wheat.** Used in the same ways as Soft Red Winter (for bakery products other than bread). Grown mainly in the Pacific Northwest; grown to a lesser extent in California, Michigan, Wisconsin, and New York. Includes both winter and spring varieties. High yielding. Relatively low protein. An important export wheat, particularly to the Far East. Subclasses include Western White and Club White.

- **Hard White Wheat.** Used in ways similar to Hard Red Winter, although it also is used in products, such as flat breads, oriental noodles, and tortillas. Protein content varies. Grown primarily in California and Kansas. No subclasses.

- **Unclassed Wheat.** Any variety of wheat which is not classifiable under other criteria provided in the wheat standards. There are no subclasses in this class.

- **Mixed Wheat.** Any mixture of wheat consisting of less than 90 percent of one class and more than 10 percent of one other class, or a combination of classes which meets the definition of wheat.

Corn

Corn is produced in 47 states, but the six states of the corn belt—Iowa, Illinois, Indiana, Nebraska, Minnesota, and Ohio—produced about 70 percent of the crop in 1985. Corn production has increased in more northern states as a result of new, short-season hybrid corn.

Animal feed is the major use for corn, accounting for well over 50 percent of the corn grown in the United States. Other domestic utilizations include food, alcohol, seed, and industrial uses, which have grown steadily over the years. Over 30 percent of the total production is exported.

Due to high levels of starch and low levels of crude fiber, corn produces high-energy feed. Corn by-products, such as corn gluten feed and meal, brewer's dried grain, and distillers' dried grains, also are used for the processing of animal feeds.

Corn used for human consumption is prepared by dry and wet milling processes. Dry milling separates corn into components of hulls, germ, and endosperm by two processes: tempering-degerming and alkaline dry milling. These processes make flaking grits that are used for breakfast cereals, baking, and the snack food industry.

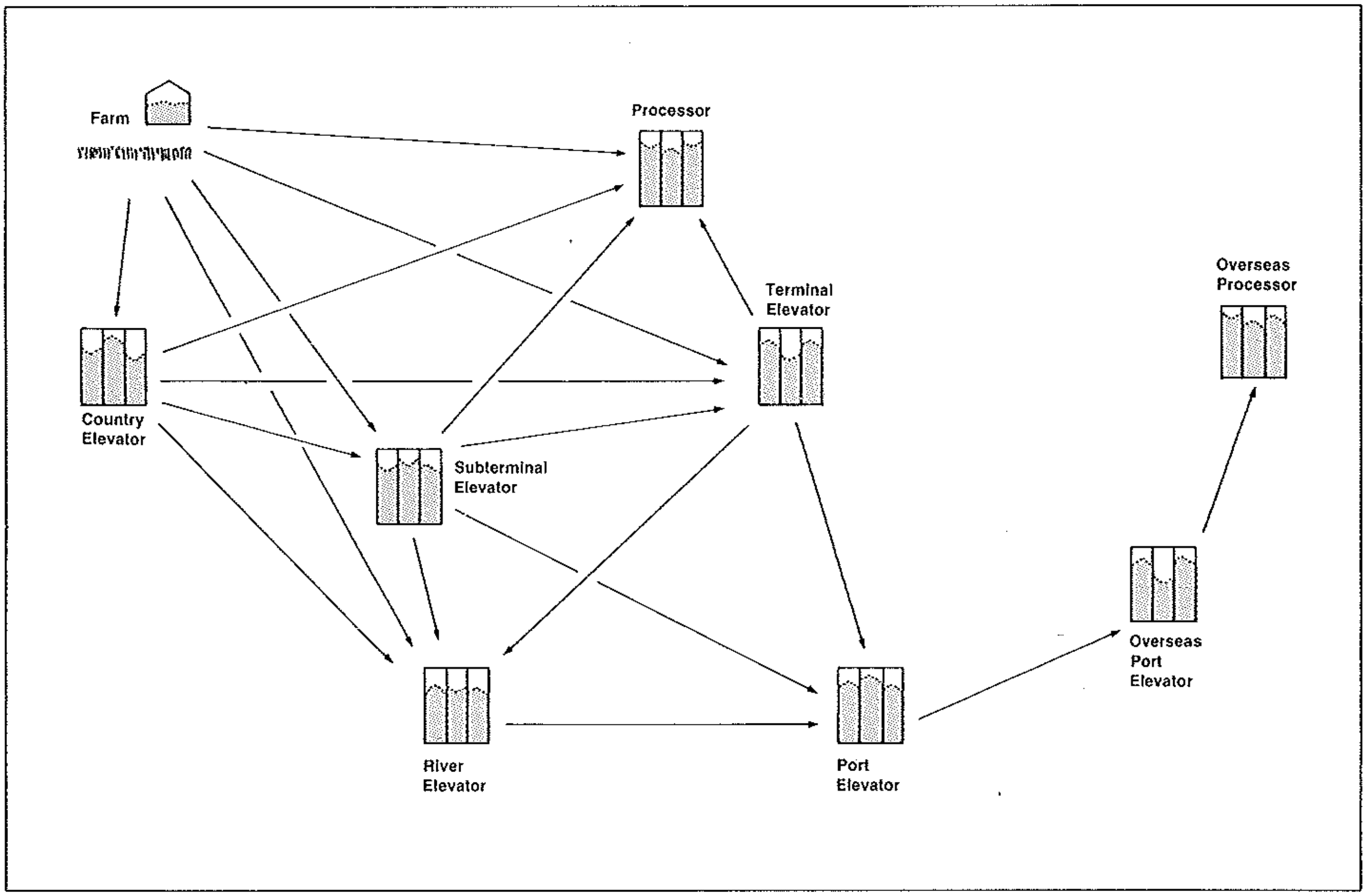
Corn syrups and sugars are manufactured from corn starch as a result of wet milling and are used for human foods, beverages, industrial products, and livestock feeds. In addition, crude oil extracted during starch recovery is used for many of the same purposes as the sweeteners. The water used to soak corn in wet milling is used by the pharmaceutical industry and in the production of liquid animal feeds.

Soybeans

Soybeans are produced in 29 states. Six states account for two-thirds of the production—Illinois, Iowa, Indiana, Missouri, Ohio, and Minnesota. In 1985, production in Illinois and Iowa accounted for 33 percent of the total crop.

The domestic utilization of soybeans in food, animal feeds, and for seed accounts for 60 percent of the crop, while export accounts for 40 percent. Soybeans are used primarily for oil extraction, and the residues are used in high-protein meal for use as a supplement in animal feed.

Figure 1. General flow of grain from the farm through the system.



Grain Flow[4]

Grain is moved many times as a result of the United States marketing system (Figure 1). After harvest, a producer may clean, dry, aerate, and store the grain on the farm before taking it to market. The expected storage time will govern largely how the producer handles the grain prior to storing (Figure 2). Grain is loaded off of a truck and elevated by the bucket elevator to a height from which it can flow by gravity to a storage bin or to a dryer and aeration bin before storage. The moisture content of wheat and soybeans normally is low enough for safe handling and storage without artificial drying. However, corn typically has a high moisture content at harvest and must be dried to about 14 percent moisture to safeguard against invasion by storage fungi and bacteria.

Depending on a producer's position within the market, grain may move from the field or farm storage to either a country elevator, terminal elevator, or processor (Figure 3). Elevators receive truckloads of grain from producers which are checked for quality and segregated according to specific quality parameters. The grain then is conditioned through drying, cleaning, or blending to meet specific load-out quality requirements. Subterminal elevators collect grain from growers or from rural elevators and send the grain to inland terminal elevators, river elevators, or processors by rail. Terminal and river elevators ship grain by railcar to port elevators. Rivers, such as the Mississippi River, are major thoroughfares for grain transportation. River elevators load grain into barges that travel downstream to port elevators (Figure 4).

Subterminal, terminal, and port elevators in the United States are similar in that they unload, weigh, sample, store, blend, and load out grain. As necessary, grain is cleaned, dried, treated for insect infestation, or otherwise conditioned to maintain quality and meet load-out quality requirements. Grain is unloaded from barges by bucket elevators, and hopper cars are unloaded by gravity dis-

[4]Source: U.S. Department of Agriculture, "The Physical Distribution System for Grain" Office of Transportation, Agr. Info. Bull. No. 457, Washington D.C., revised June 1990.

charge. After unloading, grain is weighed in a hopper scale, sampled by automatic sampler, and sent to storage. Some elevators have a track scale for weighing railcars to determine grain weight. Probe samples of grain may be taken before unloading a barge or railcar.

In most elevators, grain can be moved from storage bins and sent through a cleaner, dryer, scale, automatic sampler, and back into storage. In this manner, grain can be blended from various bins, and the blended product sampled and placed into storage.

Marketing of Grain and End-use Values

The U.S. grain market offers a vast assortment of products capable of meeting virtually any end-user need (Figure 5). The pasta plant can find the finest durum wheat. The gourmet bakery can buy the finest flours made from high-quality spring and winter wheats. The flour mill can order different wheat qualities to meet the various needs of its customers, such as the largely automated bakery or the

Figure 2. Flow of grain at the farm.

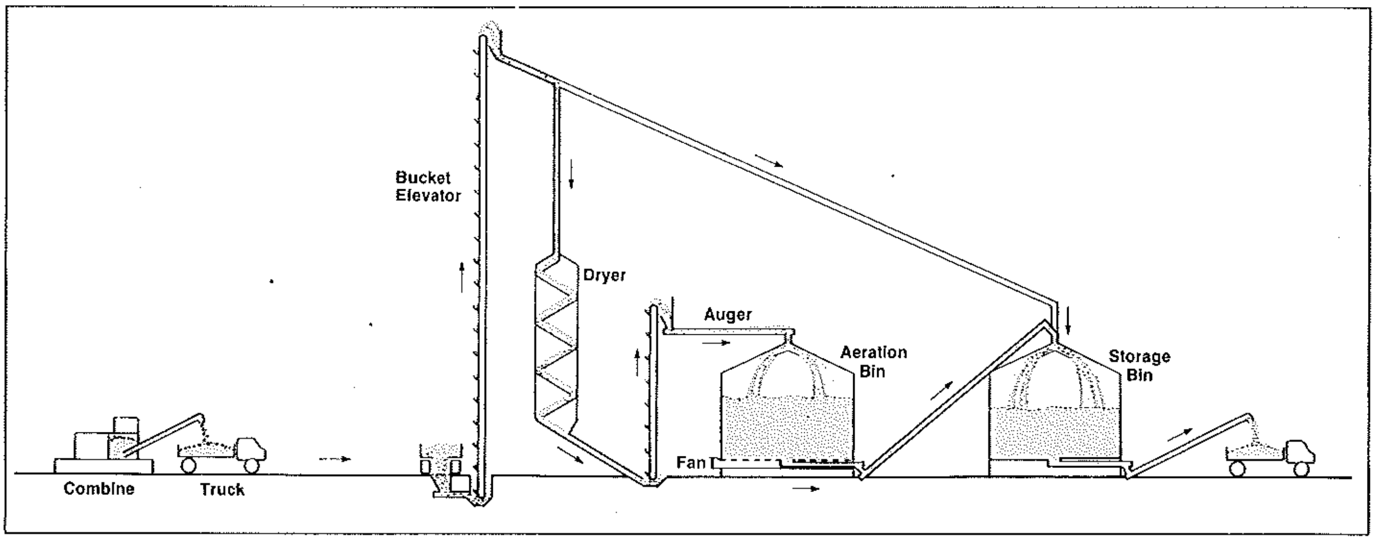
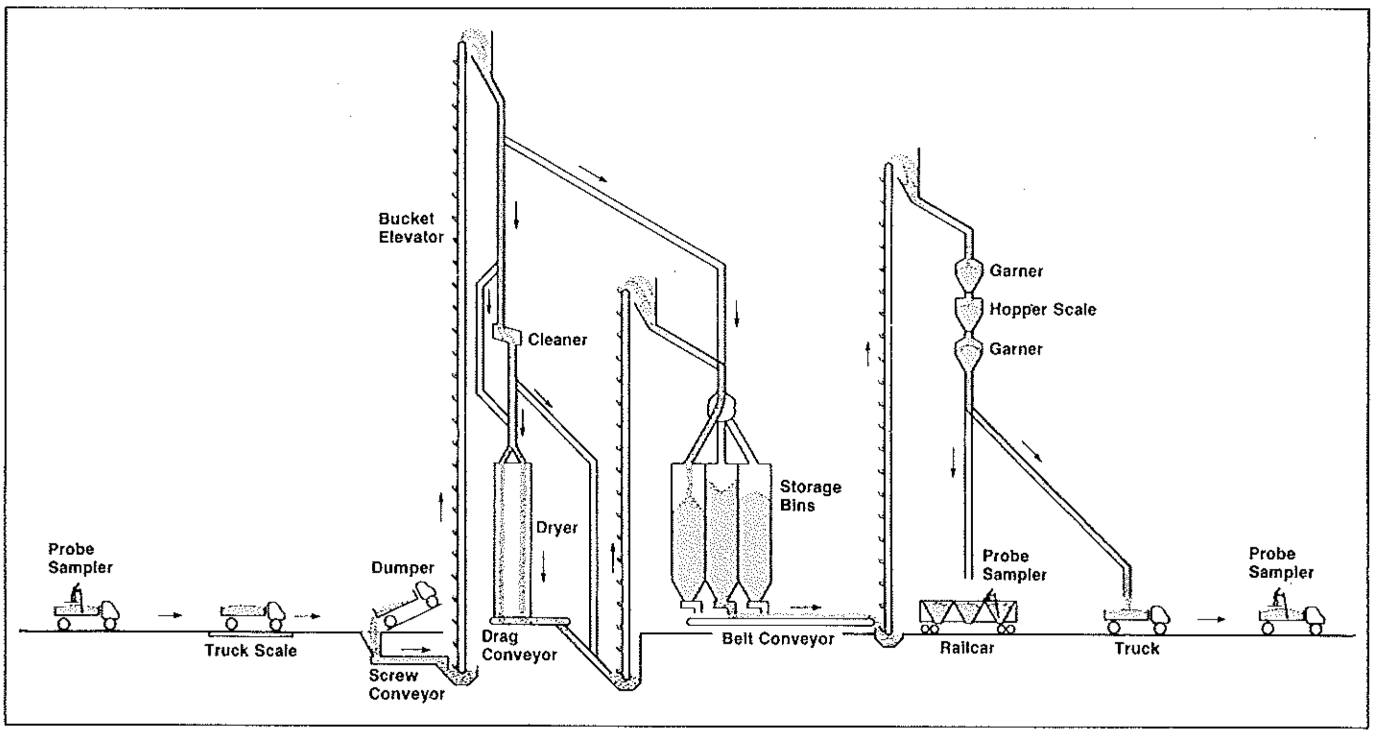


Figure 3. Flow of grain through the country elevator.



food processor producing special microwave products. The feedlot dealer has access to an enormous selection of feed ingredients suited to the particular needs of the livestock or poultry.

The sophistication of the market has evolved over time with advances in technology and changing consumer demands. Improved breeding programs, harvesting techniques, transportation capabilities, and handling practices all contribute to the market's ability to produce, harvest, and deliver a quality product.

The demands for grain quality change as producers look for greater diversity in crop selection, and food processors seek to improve their efficiency or to enter new market niches. Processors may require a more uniform-quality raw product or a more tolerable product performance to improve overall operational efficiency. Conversely, entering a new market niche may require greater product diversity or unique quality associated with a particular variety. The methods used to purchase the required raw product differ based on the quality requirements and product availability. The grain quality needed may be available anywhere—from the open cash market or through direct contracting with a producer.

In the U.S. grain marketing system, quality requirements are communicated using the official U.S. Standards for Grain. As needed, buyers and sellers supplement the quality criteria in the grading standards with contract specifications. Buyers and sellers often rely on grades and class names, such as, "U. S. Number 1 Hard Red Spring Wheat," to select and communicate quality requirements. The grade and class assure the buyer that the product received will reflect the quality and performance requirements generally desired. Widely recognized and reliable grades enable trading without personal inspection by either the buyer or the seller.

Legislative action and industry consensus have shaped

Figure 4. Flow of grain through the U.S. port elevator.

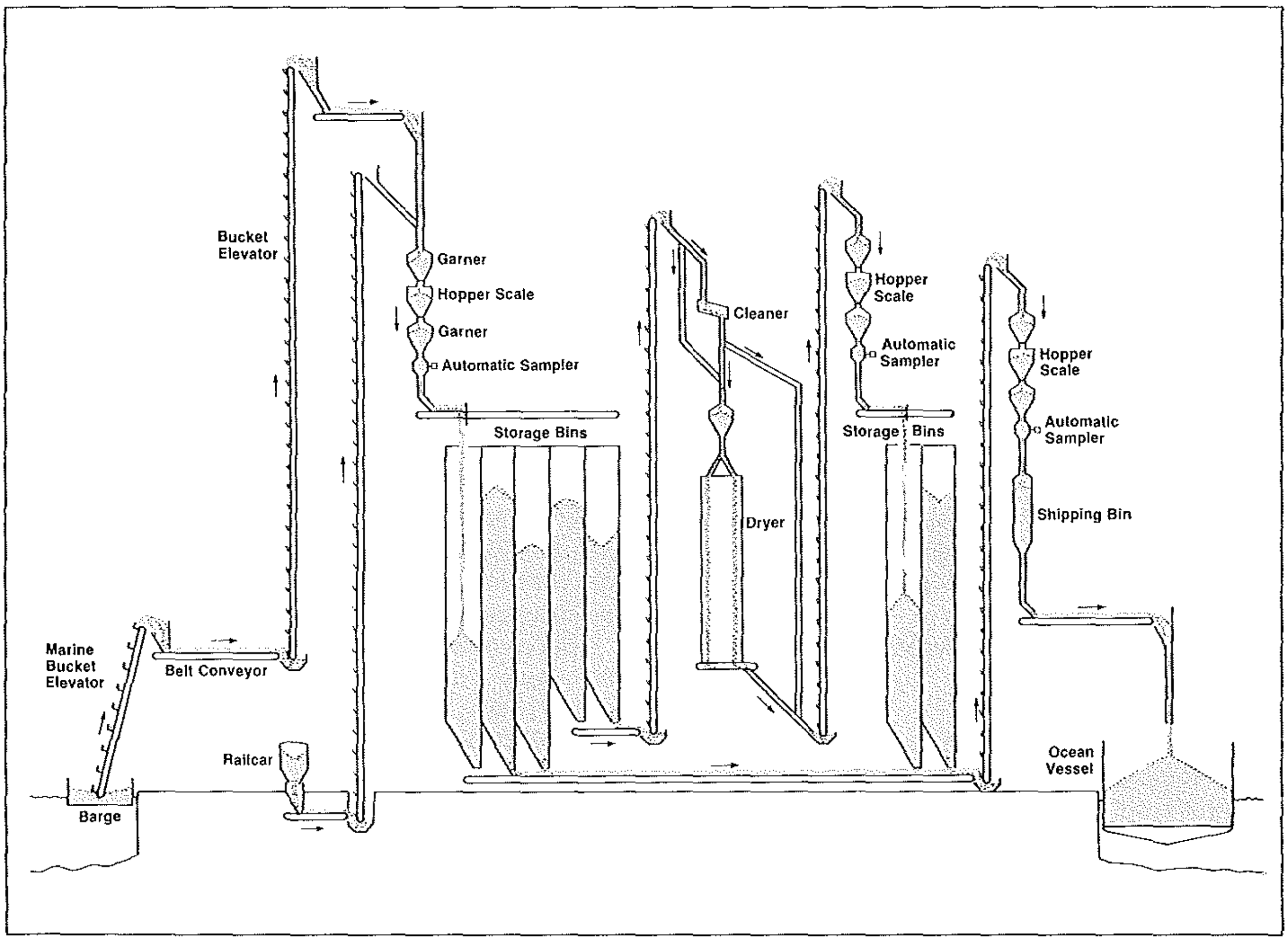


Figure 5. End-use of grain.

how the grading standards interact with the U.S. grain marketing system. Since 1916, the standards have enabled the buyer and the seller to compare quality using equivalent forms of measurement. These measurements primarily have defined the physical and biological condition of the grain. Limited information has been provided that measures the intrinsic qualities of grain, such as the protein, oil, and starch content. However, as marketing practices change and testing technology improves, the need to measure intrinsic qualities may increase.

The law authorizing the establishment of federal grain grading standards, the United States Grain Standards Act, requires that the standards:

1) define uniform and accepted descriptive terms to facilitate trading;
2) provide information to aid in determining grain storability;
3) offer users of grain standards the best possible information from which to determine end-product yield and quality of grain;
4) provide the framework necessary for markets to establish grain quality improvement incentives;
5) reflect the economic value-based characteristics in the end uses of grain; and
6) accommodate scientific advances in technology for measuring grain quality.

Grain standards exist for 11 grains and oilseeds—barley, corn, flaxseed, oats, rye, sorghum, soybeans, sunflower seed, triticale, wheat, and mixed grain. Each standard categorizes quality into numerical grades and a Sample grade, the lowest quality designation. The Number 1 grade represents the premium quality grain produced. The Number 2 category typically includes the chief trading quality. Most grain produced meets the Number 2 grade or better and reflects the level of quality desired by the major end users. The lower numerical grades offer an intermediate quality grain or oilseed, and the Sample grade designation identifies qualities unsuited for normal end users. Special grade designations also are included in the standards to describe unusual quality characteristics. Some of these include infested, smutty wheat, treated wheat, waxy corn, and garlicky wheat. The numerical and Sample grade criteria delineated in the standards provide quality parameters which allow producers, intermediate users, and end users to establish value, and determine the benefits and risks involved in marketing.

Defining quality often creates considerable controversy. For most products, quality is determined by the response of those purchasing the product. For a farmer, grain quality refers to both pre- and post-harvest quality. The agronomic characteristics of a variety must suit the producers needs, and the harvested grain must meet the needs of the miller or processor. Those using grain for feed have a variety of quality requirements, depending on whether they are feeding livestock or poultry. These quality requirements for feed likely will differ significantly from those using grain as a food ingredient. The need to store grain prior to using it for feed or food introduces further quality considerations. However, regardless of how or when grain is used, its post-harvest quality does not improve. Harvesting, as well as subsequent handling, drying, transportation, and storage, represents potential causes for quality deterioration.

Figure 6 illustrates how post-harvested grain quality can be divided into two basic categories: physical condition and composition. Physical condition is further divided into soundness and purity. Soundness consists of the general condition of the grain, such as test weight per bushel, moisture content, and color. Soundness also includes defects, such as broken or cracked kernels and kernels damaged by mold, insects, moisture, or excessive heat. Purity refers to material or substance other than the natural kernel. Foreign materials, insects, mycotoxins, and chemical residues are impurities or contaminants.

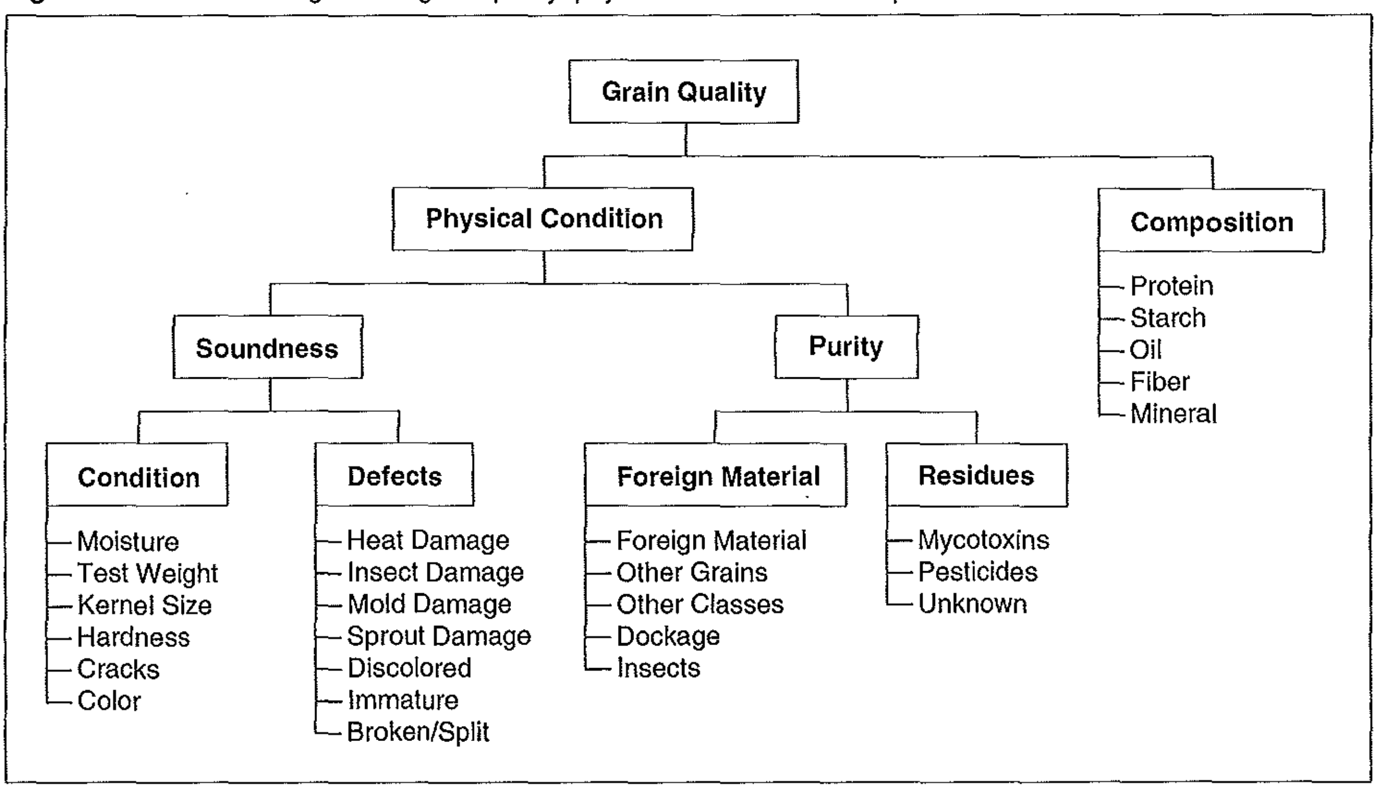
The composition quality category refers to the inherent makeup of the grain. The amount of protein, oil, and starch contained in the grain or oilseed falls into this category. These quality attributes are important to the end user, but are not widely used for marketing purposes. The value of grain and oilseeds has been assessed largely based on the assigned grade. Protein in hard wheats is an exception, whereby the protein content directly influences the market value of Hard Red Winter and Hard Red Spring wheats.

The genetics of a variety or hybrid, growing environment, and other agronomic conditions influence the physical condition and composition of grain prior to harvest. Heavy rainfall after the kernels have matured may cause mold growth, sprouting, discoloration, and a weathered appearance of the grain. Inadequate soil nutrients or adverse environmental conditions may result in underdeveloped kernels. The kernels are subjected to further physical trauma and the introduction of foreign material during harvesting. Consequently, by the time grain enters the commercial market, its quality may vary significantly. The challenge of the marketplace is to assess the value of the grain and move it to the ultimate users or consumers in the most efficient manner available. This is accomplished, in part, through the use of grading standards and a national inspection system.

The market has relied on the physical condition of grain to determine the value of grain. The current standards establish minimum and maximum limits for each numerical grade based on factors, such as broken kernels, foreign material, test weight per bushel, and damaged kernels. Further, the Sample grade designation is used for grain with an unacceptable odor, or grain that contains stones, animal filth, toxic substances, or other inferior conditions. Neither the grade standards nor the market has used compositional factors to assess grain value, with the exception of protein content in wheat and oil content in sunflower seeds.

Technological advances have opened new possibilities that allow for the accurate and timely measurement of quality attributes that previously required time-consuming chemical laboratory procedures. The way these new testing capabilities will be used in the marketplace is as yet undefined. Since end users have varying quality needs, the importance of a particular quality factor may vary throughout the market. The ability of the market to select, segregate, and transport grain on the basis of additional quality factors, as well as the economic advantage to the end users, will govern whether the market begins using this new information to determine the value of grain. Simply incorporating more quality factors into the grading standards will not change market practices. Caution must be taken to ensure that changes to the standards serve the best interest of the grain market. The diverse uses of grain make it impractical to have standards that reflect all end uses. Correctly adjusting the standards requires the collective effort of the entire grain community.

Figure 6. Two basic categories of grain quality: physical condition and composition.



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3

Comparison of Grain Marketing in Major Grain-producing Countries

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This chapter evaluates handling practices, technologies, institutions, and government policies affecting grain quality. Major differences exist between countries in the use of technologies, inspection, and policy (Tables 1 through 5). The remainder of the chapter focuses on the comparison of the U.S. system to other grain-producing countries. This chapter comes from a study by the Office of Technology Assessment, Congress of the United States. Two published reports containing the results of the study are available for purchase. They are "Enhancing the Quality of U.S. Grain for International Trade," and, "Grain Quality in International Trade: A Comparison of Major U.S. Competitors."

Differences Between the U.S. and Other Grain-marketing Systems

Policy

The United States farm price policy affects grain quality in at least two ways: 1) it provides economic incentive for both yield and quality, and 2) it provides economic incentive for on-farm storage. In other countries, premiums and discounts are not reflective of market conditions. In the U.S., even with price differentials, the economic incentive is for yield, and low-quality grain moves into government loan storage programs.

On-farm storage is a unique characteristic of the U.S. and Canadian systems. This allows grain to enter the market channel with a greater likelihood that it will be handled and stored with a minimum of quality deterioration. Other countries do not provide incentives for on-farm storage. In fact, Australia has built its entire system around the concept of managing the grain to maintain quality.

Another distinguishing characteristic of the U.S. system is that grain has the potential for carry-over from one year to the next—sometimes for as long as three to four years. Other countries do not have the storage capacity for such carry-over. This forces the marketing of most grain within a year of production and nearly eliminates any problem regarding quality.

Institutions

The U.S. grain system has three major institutional characteristics regarding quality:

1) lack of a seed variety development and release program,
2) lack of a variety identification mechanism, and
3) no minimum receival standards for grain.

These major, fundamental differences from other grain-exporting countries have a considerable influence on quality.

Seed Variety Development and Release. Plant breeding programs for corn, soybeans, and wheat are in use in both the public and private sectors in the United States. A loose mechanism exists for the development and release of new varieties. Committees, particularly at land-grant schools, can evaluate new varieties, but there is no state or federal involvement in any formal way. The government basically sets no formal criteria for release. The criteria come indirectly through the price support program, which emphasizes yield and the agronomic characteristics to achieve higher yields. In contrast, governments of other countries have formal input into the criterion for development, release, and approval of new varieties. For wheat, quality is a major criteria considered in the release of new varieties.

Variety Identification. In some countries (mainly in France and Australia), not only is variety controlled for use by farmers, but variety is also important as a factor in determining end-use value. An important feature of the French marketing system is that variety is often a contract term. In practice, varieties are specified as either an individual variety, a category of varieties, or excluded varieties. Given that varieties are generally not distinguishable by visual inspection, various mechanisms are used at the first point of receipt to ensure the integrity of variety specification. First, in most cases, the cooperative receiving the grain in France has sold the seed to the producer and knows its variety. Second, producers must declare the variety at the time of sale via an affidavit. Third, the buyer can perform a rudimentary testing procedure or request an electrophoresis test from a laboratory to verify the variety. By knowing the varieties at the time of receipt, country elevators are capable of binning by varieties or categories of varieties and selling on that basis. The United States has no mechanism for variety identification and instead relies on grade structure for segregating quality. This is becoming more difficult, since new varieties, especially of wheat, are not easily distinguishable.

Grain Receival Standards. As noted earlier, the United States is the only country that does not have minimal receival standards for grain. Producers can deliver any quality of grain and it will be accepted with appropriate discounts. In other countries, grain that does not meet the established minimum quality may be rejected at the first point of sale. Keeping low-quality grain out of the market channel eliminates most quality problems at the export elevator and reduces the opportunity for blending diverse qualities. Once low-quality grain is in the system, it is much more difficult to keep it segregated from higher-quality grain or to keep it from being blended with grain destined for export.

Technologies and Grain-handling Practices. The policies and institutional structure of the U.S. grain system provide the framework for various grain-handling practices. The technologies for producing and handling are quite similar everywhere. The main difference is that the United States is slightly more efficient in their use. Differences do exist, however, as to when the technologies are used in the marketing channel.

A case in point is cleaning. Most countries, except the United States, clean grain at the first point of receipt. Canada and Australia are two exceptions, but for different reasons. However, upon studying the economic feasibility of cleaning grain in the country versus at export, Canadians will probably change their practices. Australia does not clean grain because, unlike in the United States, farmers deliver grain that does not need to be cleaned. Basically, no economic incentive exists to clean grain in the United States.

The other major handling practice in which the United States differs from all other exporters is in blending. Blending of grain over wide margins of quality to create a uniform product for sale is necessitated by the lack of any minimum receival standards. Blending does exist elsewhere, but not to the same extent. Blending in other countries is done over narrow ranges in quality. These countries basically have a uniform quality moving through the system at all times. The U.S. system lacks uniformity in quality throughout the market channel. When grain reaches export, blending is used in an attempt to produce a uniform quality meeting the buyer's specifications. The OTA survey of foreign and domestic buyers of U.S. grain clearly indicates that lack of uniformity between shipments is the buyers' biggest complaint.

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Table 1. Comparison of production technologies of major grain-exporting countries.

Activity	United States	Argentina	Brazil	France	Canada	Australia
Soils and topography ...	Major production areas are on stable soils. Low erosion. Fertility stabilized. Soybeans usually incorporated in a rotation with corn or other crops. Winter wheat grown under dry land conditions.	Flat, fertile soils in the corn belt. Rolling land farther south in wheat and sorghum area. Long rotations, including legume pasture. Soybeans and wheat are often double-cropped.	Expanding production on newly cleared soils. Long slopes, year-round erosion, and leaching create more problems in maintaining fertility. Extensive terracing required. Continuous soybeans not unusual in Parana and Malo Grosso do Sul.	Major production areas for wheat located north and southwest of Paris on stable, low-erosion soils. Rolling land farther south in corn-producing area.	Wheat grown for export in four soil zones in western Canada. All wheat grown under dryland conditions.	Major wheat production areas include southern and eastern coast, and western Australia. Rolling, dry land. Extended rotations with clover.
Cultural practices	Fertilizers, insecticides, and herbicides used as needed. Mechanized soil preparation, seeding, and cultivation.	Limited use of fertilizers on corn, increasing use on wheat. Limited use of herbicides and insecticides. Mechanized tillage seeding and cultivation.	Fertilizers, insecticides, and herbicides used as needed. Mechanized soil preparation, seeding, and cultivation.	High use of fertilizers, insecticides, and herbicides. Mechanized soil preparation, seeding, and cultivation.	Fertilizers, insecticides, and herbicides used as needed. Mechanized soil preparation, seeding, and cultivation.	Phosphatic fertilizers, insecticides, and herbicides used as needed. Mechanized soil preparation.
Harvesting	Self-propelled combines. Wheat crop in Northern plains is swathed before harvest.	Self-propelled combines.	Self-propelled combines.	Self-propelled combines.	Self-propelled combines. Wheat crop is swathed before harvest.	Self-propelled combines.
On-farm storage	On-farm storage available for about 50 percent of corn and soybeans.	Only 5 to 10 percent stored on farms. Only very large farms use on-farm storage.	Virtually no on-farm storage.	Very little on-farm storage.	On-farm storage for the majority of wheat.	Virtually no on-farm storage.

Source: Office of Technology Assessment, 1989.

Table 2. Comparison of handling technologies and practices at first point of receipt of major grain-exporting countries.

Activity	United States	Argentina	Brazil	France	Canada	Australia
Receiving	Truck dumps and hoists for virtually all farm wagons and trucks.	Truck dumps and hoists at larger facilities. A few receiving stations lack hoists. Waiting lines are common at harvest.	Truck dumps and hoists at larger facilities. Many vehicles unloaded by hand.	Truck dumps and hoists for farm wagons and trucks.	Truck dumps and hoists for farm wagons and trucks.	Truck dumps and hoists for farm wagons and trucks.
Drying	The majority of corn is dried and stored on farms. Most of the corn delivered at harvest is dried by first handler in gas-fired dryers. Little drying of soybeans or wheat.	Majority of corn and some soybeans and wheat are dried in high-temperature dryers. Nearly all country elevators have dryers. Usually oil-fired.	Majority of soybeans dried. Wood and coal used for fuel.	Some drying of wheat if harvested about 15 percent moisture. Majority of corn dried with high-temperature dryers similar to those used in the U.S.	The majority of wheat is dried and stored on farm. Propane dryers are most common.	Generally, wheat does not need to be dried. No dryers at bulk handling authority (BHA) facilities.
Cleaning	Generally, grain is not cleaned when it comes off the farm. It is placed in bins according to quality so that it can be blended with grains of different quality when loaded out.	Since there is a premium for No. 1 grain, most grain is cleaned to less than 1 percent foreign material.	Soybeans that exceed Brazilian export quality (foreign material 1 percent) are cleaned. Corn is cleaned to less than 1 percent.	Most wheat cleaned going into country elevator and come cleaned going out. Corn routinely cleaned because of broken kernels.	Very little cleaning done at first point of receipt.	Generally, wheat does not need to be cleaned. No cleaners at BHA facilities.
Storage	Flat and upright storage. Upright predominates.	Flat and upright storage. Determined by relative costs and handling requirements.	Flat and upright storage. Flat predominates.	Upright storage predominates. Grain often turned and sampled for end-use quality tests. Also use flat storage with numerous vertical bins.	Vertical cement bins; flat storage and steel tanks. Vertical predominates.	Upright, flat, and bunker. Predominance of any type varies by state.
Handling	Use augers, conveyors, belts, and vertical legs.	Use augers, conveyors, belts, and vertical legs.	Use augers, conveyors, belts, and vertical legs.	More use of chain conveyors than belts.	Use augers, conveyors, belts, and vertical legs.	Use augers, conveyors, belts, and vertical legs.
Transportation to ports	Trucks for short hauls. Rail and water for long distance.	Truck and rail choice determined by cost and shortage of rail service. Barge available for movement to Buenos Aires.	Truck predominates for all distances. Water available only in southern district moving beans to Rio Grande do Sul.	Grain predominantly transported by truck.	Grain predominantly moved by rail over long distances.	Most wheat is moved by rail, some by truck.

Source: Office of Technology Assessment, 1989.

Table 3. Comparison of handling technologies and practices at export of major grain-exporting countries.

Activity	United States	Argentina	Brazil	France	Canada	Australia
Storage	Vertical storage with multiple bins, high speed in and out. Segregated by quality to expedite blending at time of shipping.	Vertical silos predominate. Few bins for quality segregation.	Vertical and flat storage. Small number of bins limits segregation by quality.	Upright bins predominate; stored according to end-use qualities.	Vertical, cement bins predominate. Blending is very limited—grades must be kept separate.	Vertical storage segregated by quality.
Drying	Most export facilities have large drying capacity. Corn is often dried if received directly from farmer, but soybeans and wheat are seldom dried.	Grain dried by first handler; dryers at export are seldom used.	Grain dried by first handler; dryers at export seldom used.	Very few export elevators have dryers; grain is conditioned by first handler.	Most export facilities have modest drying capacity.	No dryers at export facilities.
Cleaning	Most export facilities have capacity for cleaning. Grain (mostly corn) often cleaned prior to exporting.	Grain cleaned by first handler. Relatively small capacity cleaners.	Grain cleaned by first handler. Little or no cleaning capacity.	Most export elevators do not have cleaners; grain cleaned by first handler.	Most cleaning of wheat is done at export.	No cleaners at export facilities.
Blending	Normal practice. Economic incentive for blending of wide range of quality due to the extremes in quality of grain accepted into the system.	Limited blending because of uniform grain received and lack of physical facilities for blending.	Limited blending because of uniform grain received and lack of physical facilities for blending.	Some blending of wheat moving to export, but no incentive to blend wide margins of differing qualities.	Blending at primary elevators, but at export only 2 percent of higher grade can be a blend from a lower grade.	Limited blending at export but only for a few factors.

Source: Office of Technology Assessment, 1989.

Table 4. Comparison of institutions and regulations affecting grain quality of major grain-exporting countries.

Activity	United States	Argentina	Brazil	France	Canada	Australia
Seed variety control	No state or federal control. Release of varieties influenced to some extent by land-grant universities. The market largely determines adoption of varieties.	Committee of government and industry must approve agronomic properties. Quality factors of minor influence.	Committees with broad representation direct research and approve varieties. Quality is potential criterion, but not currently effective.	Formal mechanism exists that regulates release of varieties based on agronomic and quality criteria.	Formal mechanism used to license new varieties. Agronomic and quality criteria given equal weight in testing new varieties.	Formal mechanism followed as a prerequisite for release of varieties. Quality and agronomic criteria are used.
Grain receival standards	None. All types of quality are accepted with appropriate discounts for low-quality grain.	Grain not meeting a specific minimum quality (Condition Camara) is rejected at first point of sale.	Soybeans not meeting a minimum quality are rejected at first point of sale.	Grain not meeting export contract specifications can be rejected by surveying company or receiving elevator.	Developed eight grades for CWRS to differentiate quality. Lowest grade goes to feed market.	Wheat must meet minimum quality standards. If not, it is allocated to feed market.
Marketing by variety	No mechanism exists for variety identification.	Variety is not identified in marketing channel.	Variety is not identified in marketing channel.	Very common. Variety often specified in wheat contracts.	Licensed grain must be visually distinguishable.	Very common—use variety control scheme to facilitate segregation by classes.
Grain inspection authority	Federal Grain Inspection Service (FGIS, U.S. Department of Agriculture).	Junta Nacional de Granos—Government agency responsible for agriculture.	Private inspection agencies.	Private inspection agencies.	Canadian Grain Commission.	Export Inspection Service of Department of Primary Industry.
Grade standards	Official standards established by the FGIS.	Official standards established by Junta.	Official standards are not used in export. Quality is based on Association Nacional dos Exportadores de Cereais contract.	No official standards. Only official quality criteria are requirements for intervention mechanism.	Grain standards established by Canadian Grain Commission.	Official standards established by Department of Primary Industry.

Source: Office of Technology Assessment, 1989.

Table 5. Comparison of government policies affecting grain quality of major grain-exporting countries.

Policy	United States	Argentina	Brazil	France	Canada	Australia
Price	Loan rate is principal price policy. Includes premiums and discounts for major grains, but has not been responsive to market conditions.	Government establishes minimum prices for farmers and exporters. Government also establishes premiums for high-quality grain.	Government establishes a minimum price to planting. It is adjusted during the crop year to account for inflation and political pressure.	Key policy is European Community Intervention price, which includes premiums and discounts for quality factors. Lower qualities of wheat equated to feed values.	Initial producer price is the principal price policy. Separate prices established for each grade of grain. Lower qualities of wheat equated to feed values.	Guaranteed minimum price (GMP) is key price policy. It is established by class and provides differentials for quality. Lower qualities of wheat equated to feed values.
Farm storage	Farm policy in past decade has encouraged extensive on-farm storage and inter-year storage.	Government policy through pricing does not encourage on-farm or inter-year storage.	No incentive for farmers to store on farm.	Farm policy through the Common Agricultural Policy (CAP) has not encouraged development of extensive on-farm storage. Also relatively limited inter-year storage due to CAP.	Producer deliveries are regulated to primary elevators via quotas. On-farm storage is substantial.	Use of GMP provides no incentives for delivery in post-harvest period, leading to minimal use of on-farm storage.

Source: Office of Technology Assessment, 1989.

4

Stored Grain Losses Due to Insects and Molds and the Importance of Proper Grain Management

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Richard Meronuck, University of Minnesota

According to a 1990 survey of extension specialists throughout the United States, stored grain losses exceeded $500 million for the year. Most of these losses resulted from infestation by several species of insects and damage by numerous molds and mycotoxins.

Most of the insects currently infesting grain are species that thrive primarily on mold, such as the rusty grain beetle, *Crypotelestes ferrugineus* (Stephens); the foreign grain beetle, *Ahasverus advena* (Waltl); and the hairy fungus beetle, *Typhaea stercorea* (Linnaeus) (Barak and Harein 1981, Subramanyam and Harein 1989). These species thrive anywhere in the environment where adequate temperatures and moisture conditions support mold growth. Undoubtedly, old grain within a bin or spilled grain near a bin site are common sources of insect reinfestation. These mold-feeding insects do not rely on weevils or borers to infest grain initially because there are sufficient broken kernels and similar debris in the grain mass for externally developing beetles to survive.

Losses resulting from insect infestations are widespread and involve more than loss of quality. Damaged kernels are of lighter weight and result in discounts when marketed. Insect infestation also causes a reduction in nutrients in the grain. Controlling insects with insecticides, including fumigants, rather than using preventative methods incurs great cost. In addition, infestation generally results in dissatisfied customers and related marketing problems that develop from a poor reputation in marketing channels. The most unfortunate consequence of not managing grain properly is the loss of money, time, and effort to produce the grain (i.e., seed, fertilizer, field pest management, harvesting).

In 1987, IDK (insect damaged kernels) was established as a grading factor for wheat. As a result of a memorandum of understanding between the Food and Drug Administration (FDA) and the Federal Grain Inspection Service (FGIS), wheat containing 32 or more IDK per 100 grams would result in the wheat being designated as Sample grade. Restricting the sale of wheat for livestock feed is a significant loss—a loss that some sellers attempted to reduce by claiming the damage occurred in shipment and should be covered by insurance. This claim is not justified since this type of damage (primarily adult insect emergence holes) could not occur in the short shipment period (7 to 14 days). The insects producing IDK damage require 30 to 45 days for development and emergence from the kernels.

Infestation by fungi will cause losses by lowering the grade of grain due to damage by dry matter loss and by odor, both of which relate to a grading factor. The higher

Table I. Rate of dry matter loss (DML) in soybean seeds as related to kernel moisture content, temperature, and time.

		DML(%) Through Time			
Temp (C)	Initial MC(%)[a]	0-60 Days	61-120 Days	121-180 Days	Total at 180 Days
15	13.94	0.00	0.06	0.18	0.24
	17.38	0.12	0.17	0.26	0.55
	19.84	0.10	0.19	0.96	1.25
25	14.18	0.00	0.16	0.23	0.39
	17.13	0.30	0.32	0.68	1.30
	20.37	1.05	1.23	1.74	4.02

[a] Each figure is an average of four tests.

Table 2. Dry matter loss (DML) resulting from invasion by storage fungi on corn held 180 days at beginning moisture contents of 14.5 to 19.5 percent.

Days Stored	Moisture Content (%) At Start (Av.)	At Test Period Av.	At Test Period SD	DML(%) Av.	DML(%) SD
30	14.5[a]	14.6	0.11	ND[b]	—
	15.5	15.7	0.09	0.37	0.18
	16.5	17.1	0.31	0.82	0.37
	17.5	18.2	0.05	1.06	0.09
	18.5	19.4	0.07	1.29	0.11
	19.5	20.5	0.16	1.56	0.21
				r^2=0.949[c]	
60	14.5	14.6	0.24	ND	—
	15.5	15.7	0.22	0.18	0.35
	16.5	17.7	0.12	1.66	0.03
	17.5	18.8	0.25	2.03	0.29
	18.5	20.2	0.22	2.61	0.31
	19.5	21.3	0.24	3.58	0.94
				r^2=0.978	
90	14.5	14.5	0.06	ND	—
	15.5	15.9	0.20	0.46	0.17
	16.5	17.6	0.20	1.76	0.18
	17.5	19.3	0.22	2.86	0.37
	18.5	20.9	0.23	3.69	0.37
	19.5	22.4	0.23	4.55	0.37
				r^2=0.994	
120	14.5	14.4	0.10	ND	—
	15.5	15.9	0.18	0.55	0.16
	16.5	17.8	0.46	2.17	0.35
	17.5	19.9	0.50	3.69	0.68
	18.5	21.5	0.52	4.80	0.90
	19.5	22.7	0.34	5.37	0.37
				r^2=0.992	
150	14.5	14.6	0.13	ND	—
	15.5	16.1	0.12	0.73	0.14
	16.5	18.4	0.29	2.88	0.28
	17.5	20.4	0.11	4.54	0.38
	18.5	22.4	3.52	5.80	0.74
	19.5	23.7	0.65	6.66	0.57
				r^2=0.994	
180	14.5	14.6	0.09	0.24	0.28
	15.5	16.3	0.17	1.00	0.23
	16.5	18.7	0.41	3.30	0.39
	17.5	21.9	1.46	5.44	0.75
	18.5	23.0	0.04	6.78	0.35
	19.5	24.8	0.22	7.96	0.51
				r^2=0.994	

[a] Initial moisture content of all samples was within ±0.3% of those indicated.
[b] Not detectable.
[c] Regression analysis (r^2 value) of the average moisture content at the test period on the average dry matter loss.

the moisture content over time, the greater the dry matter loss in both soybeans (Lazzari 1988) and in corn (Christensen and Meronuck, 1988) (Tables 1 and 2). By the time the dry matter loss has reached 0.5 to 1.0 percent, the germs of most kernels are heavily invaded by fungi, especially *Aspergillus glaucus*, and it would seem probable that corn in farm or commercial storage that had suffered that amount of dry matter loss would be at risk of developing grade-reducing damage during subsequent storage or shipment.

Perception of United States grain quality, especially in comparison with grain grown in Canada and Australia, stems from the numerical grade system which grades grains as U.S. Number 1, 2, 3, or Sample grade. This system allows buyers to purchase the grain best suited to their needs and the amount they agree to pay. The cut-off levels on grading factors are established by the USDA-FGIS in cooperation with grain industries and Congress. The FGIS is not a regulatory agency as is the USDA-Animal Plant Health Inspection Service (APHIS), and consequently it cannot dictate changes in the grading system to improve export quality.

Adequate management of insects and molds that attack and destroy harvested grain has always received less attention than pest management efforts on crops in the field. There is no justification for such behavior, as losses of grain in storage are often equal to cereal grain losses in the field. In addition, production losses can be reduced by replanting when no such avenue exists following damage after harvest.

Recent drought years and increased world markets have resulted in relatively low carry-over grain stocks. Unfortunately, some stored-grain managers believe that this situation reduced or even eliminated stored-grain pest problems. Consequently, even less attention has been given to these stored-grain pest problems. It also appears that, at least in certain areas, the grain that could meet buyers' standards was marketed, leaving the poor quality grain in storage to continue its degradation as a result of poor stored-grain management practices.

The distorted perception that U.S. grain quality and cleanliness is inferior to Canadian or Australian grain is a direct result of the regulatory intervention within the marketing system in those countries. The U.S. marketing system is not regulated by the U.S. Department of Agriculture with respect to receival standards, export standards, or pricing. Consequently, a wider range of quality enters the U.S. grain marketing systems based on the simple principles of supply and demand. This quality diversity enhances the U.S. marketing system because buyers and sellers may negotiate grain quality and price. As a result, U.S. export quality may differ from other exporting countries, but U.S. exporters are able to fulfill the buyers' quality expectations at acceptable prices.

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Part II: Grain Inspection

5

The FGIS' Role in Grain Inspection

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Introduction

The Federal Grain Inspection Service (FGIS), an agency within the United States Department of Agriculture, is responsible for administering a national inspection and weighing program for grain, oilseeds, pulses, rice, and related commodities. The mission of the FGIS is to facilitate the marketing of these products by: 1) establishing descriptive standards and terms, 2) accurately and consistently certifying quality, 3) providing for uniform official inspection and weighing, 4) carrying out assigned regulatory and service responsibilities, and 5) providing the framework for commodity quality improvement incentives to both domestic and foreign buyers.

Official grain inspection services, for the most part, are permissive in nature in that they are provided only upon request. The United States Grain Standards Act, however, requires the inspection and weighing of all export grain. The mandatory inspection and weighing requirement does not apply to: 1) export facilities which do not export more than 15,000 metric tons of grain, 2) grain exported for seeding purposes, 3) grain shipped from a foreign country to a foreign country through the United States in bond, or 4) grain exported by rail or truck to Canada or Mexico. The FGIS also may waive mandatory inspection requirements on a shipment-by-shipment basis for export grain not sold, offered for sale, or consigned for sale by official grade. Provisions also exist for granting waivers to the mandatory inspection and weighing requirements for export grain in emergency situations.

The nationwide inspection and weighing system the FGIS administers is comprised of FGIS field offices, state agencies, and privately owned agencies. More than 3,000 inspection personnel employed by 33 FGIS field offices/suboffices and 75 official agencies provide inspection services throughout the United States. To ensure that inspection services are accurate, uniform, and consistent, the FGIS develops and publishes inspection procedures, evaluates and approves inspection equipment, monitors the inspection accuracy of FGIS employees and licensed inspectors, periodically tests sampling and inspection equipment for accuracy, provides for review inspections, and investigates service complaints.

Grain Standards

During the late 1800s, the grain markets and production areas in the United States experienced considerable growth. The creation of new markets and distribution centers and the movement of grain into interstate and foreign commerce generated a need for a standardized system of inspecting and grading grain. Early on, in an attempt to facilitate grain marketing, many state agencies and trade organizations developed their own set of standards to communicate the quality and condition of the grain being sold. At one time in the United States, there were 73 separate and distinct sets of grades and grade rules (McDonald 1932). The number of standards in use and the ambiguous way in which they described quality created considerable confusion in the marketplace.

To eliminate confusion and to regain the confidence of the grain merchants, various trade groups tried unsuccessfully to establish a system of standards that could be applied uniformly throughout the United States. Their inability to resolve the issue eventually persuaded federal legislators to intervene. On August 11, 1916, after years of debate, Congress enacted the United States Grain Standards Act (USGSA). The USGSA authorized the Secretary of Agriculture to establish U.S. standards for grain and provide for a uniform inspection and grading system, allowing for the orderly and timely marketing of grain in interstate and foreign commerce.

Table 1. Grain standards established under the USGSA.

Grain	Effective Date
Barley	August 24, 1926
Canola	February 28, 1992
Corn	December 1, 1916
Flaxseed	August 1, 1934
Mixed Grain	July 2, 1934
Oats	June 16, 1919
Rye	July 1, 1923
Sorghum	December 1, 1924
Soybeans	November 20, 1940
Sunflower Seed	September 1, 1984
Triticale	May 1, 1977
Wheat	July 1, 1917

On December 1, 1916, less than four months after the enactment of the USGSA, corn became the first standard to be implemented under the USGSA. Since that time, standards for 11 additional grains have been established (7 CFR Part 810).

These standards provide grain merchants with a reliable, uniform means of communicating grain quality and condition by defining and measuring properties of grain which are important to all segments of the grain industry—from producer to end user.

The 1986 Grain Quality Improvement Act and the 1990 Grain Quality Incentives Act outlined six specific objectives of the U.S. Standards for Grain. The standards are intended to: 1) facilitate trade by defining uniform and accepted descriptive terms; 2) provide information about grain storability; 3) offer information regarding end-product yield and quality of grain; 4) provide the framework for establishing grain quality improvement incentives; 5) reflect the economic value-based characteristics in the end uses of grain; and 6) accommodate scientific advances in testing and new knowledge concerning factors related to, or highly correlated with, the end-use performance of grain.

Changes in production, harvesting, handling, and marketing practices, as well as the development of new varieties and more knowledge of end-use properties, occasionally make it necessary to revise existing standards or establish new standards. For instance, to facilitate the marketing of canola and in response to interest expressed by the U.S. Canola Association and others in the canola industry, the FGIS established U.S. Standards for Canola in February 1992.

To ensure that the standards continue to meet customer and market needs and keep pace with the latest technological advancements, the FGIS reviews the standards every five years. Before the FGIS establishes, amends, or revokes any standards, it publicly announces its intentions and provides the public an opportunity to present its views and arguments. Before making a final decision, public comments from the grain industry, researchers, producers, foreign buyers, and others are considered. Further, to minimize the marketing impact such changes may have, implementation of new or revised standards is delayed for one year after the publication of the final rule unless the FGIS determines that public health, interest, or safety requires that they become effective sooner.

Factors measured under the standards fall into three basic quality categories: wholesomeness, physical characteristics, and intrinsic or chemical properties. Wholesomeness is generally addressed through the Sample grade and special grade designation. Grain that has an unacceptable odor or contains excessive amounts of stones, animal filth, toxic substances, or other inferior conditions is labeled Sample grade. Special grades are used to address grain wholesomeness by identifying special qualities or conditions which may affect the value of the grain, such as insect infestation and the presence of smut.

The physical quality characteristics of grain generally serve as the basis for the numerical grades (Tables 2 through 4). Minimum or maximum limits are established for each numerical grade on factors such as test weight per bushel, foreign material, and damaged kernels. Moisture, while not considered a grade determining factor, also falls into this category.

Information regarding intrinsic properties of grain and other grain attributes, whose importance varies among the different end users, is provided through the standards as official criteria. Official criteria testing is provided upon request. Examples of information offered as official criteria include wheat protein, soybean protein and oil, sunflower seed oil, aflatoxin, and deoxynivalenol (DON). Since the importance of this information varies greatly among the various end users, the results do not affect the grade designation.

Types of Inspection Services

Inspection services offered through the national inspection system are categorized by the type of sample that is used in determining grain quality (7 CFR 800.75). Inspections based on samples obtained by the FGIS or official agency personnel using approved equipment and sampling procedures are considered "official sample-lot" inspections and are the type most commonly requested. This level of

Table 2. Grades and grade requirements for wheat.

Grade	Minimum Limits of— Test Weight per Bushel: Hard Red Spring Wheat or White Club Wheat[1] (Pounds)	Minimum Limits of— Test Weight per Bushel: All Other Classes and Subclasses (Pounds)	Maximum Limits of— Damaged Kernels: Heat Damaged Kernels (Percent)	Damaged Kernels: Total[2] (Percent)	Foreign Material (Percent)	Shrunken and Broken Kernels (Percent)	Defects[3] (Percent)	Wheat of Other Classes[4]: Contrasting Classes (Percent)	Wheat of Other Classes[4]: Total[5] (Percent)
U.S. No. 1	58.0	60.0	0.2	2.0	0.4	3.0	3.0	1.0	3.0
U.S. No. 2	57.0	58.0	0.2	4.0	0.7	5.0	5.0	2.0	5.0
U.S. No. 3	55.0	56.0	0.5	7.0	1.3	8.0	8.0	3.0	10.0
U.S. No. 4	53.0	54.0	1.0	10.0	3.0	12.0	12.0	10.0	10.0
U.S. No. 5	50.0	51.0	3.0	15.0	5.0	20.0	20.0	10.0	10.0

U.S. Sample grade:

U.S. Sample grade is wheat that:

a) Does not meet the requirements for the grades U.S. Nos. 1, 2, 3, 4, or 5; or

b) Contains 32 or more insect damaged kernels per 100 grams of wheat; or

c) Contains four or more stones or any number of stones which have an aggregate weight in excess of 0.1 percent of the sample weight, one or more pieces of glass, three or more crotalaria seeds (*Crotalaria* spp.), two or more castor beans (*Ricinus communis* L.), four or more particles of an unknown foreign substance(s) or a commonly recognized harmful or toxic substance(s), two or more rodent pellets, bird droppings, or equivalent quantity of other animal filth, five or more pieces of animal filth, castor beans, crotalaria seeds, glass, stones, or unknown foreign substances in combination per 1,000 grams of wheat; or

d) Has a musty, sour, or commercially objectionable foreign odor (except smut or garlic odor); or

e) Is heating or otherwise of distinctly low quality.

[1] These requirements also apply when Hard Red Spring or White Club wheat predominate in a sample of Mixed wheat.
[2] Includes heat damaged kernels.
[3] Defects include damaged kernels (total), foreign material, and shrunken and broken kernels. The sum of these three factors may not exceed the limit for defects for each numerical grade.
[4] Unclassed wheat of any grade may contain not more than 10.0 percent of wheat of other classes.
[5] Includes contrasting classes.

Source: FGIS, U.S. Department of Agriculture, 1993.

inspection service is required for all export shipments and is available upon request for domestic grain shipments. Official sample-lot inspection results represent the entire lot and are certified on a white certificate.

The other inspection services—warehouse sample-lot and submitted sample—are based on samples obtained by persons dissociated from the national inspection system. Elevator employees that have been licensed under contract with the FGIS to sample grain using a diverter-type mechanical sampler obtain samples for warehouse sample-lot inspections. These inspection results are certified on a yellow certificate and qualified to indicate that the sample was obtained and submitted for inspection by an elevator employee.

The submitted sample inspection service involves samples obtained by nonlicensed personnel. Since it is impossible for official inspectors to verify the representativeness of a submitted sample, the certificate is qualified to declare that the inspection results only pertain to the amount of sample submitted and are not representative of the lot from which the sample was taken. Pink certificates are used to certify submitted sample inspection results.

Other services related to the inspection of grain which are available under the USGSA include an official sampling service and stowage examination service. The sampling service, which is available on request, consists of official

Table 3. Grades and grade requirements for corn.

Grade	Minimum Test Weight per Bushel	Maximum Limits of—		
		Damaged Kernels		Broken Corn and Foreign Material
		Heat Damaged Kernels	Total	
	(Pounds)	(Percent)	(Percent)	(Percent)
U.S. No. 1	56.0	0.1	3.0	2.0
U.S. No. 2	54.0	0.2	5.0	3.0
U.S. No. 3	52.0	0.5	7.0	4.0
U.S. No. 4	49.0	1.0	10.0	5.0
U.S. No. 5	46.0	3.0	15.0	7.0

U.S. Sample grade:

U.S. Sample grade is corn that:

a) Does not meet the requirements for the grades U.S. Nos. 1, 2, 3, 4, or 5; or

b) Contains eight or more stones which have an aggregate weight in excess of 0.20 percent of the sample weight, two or more pieces of glass, three or more crotalaria seeds (*Crotalaria* spp.), two or more castor beans (*Ricinus communis* L.), four or more particles of an unknown foreign substance(s), eight or more cockleburs (*Xanthium* spp.) or similar seeds singly or in combination, or animal filth in excess of 0.20 percent in 1,000 grams; or

c) Has a musty, sour, or commercially objectionable foreign odor; or

d) Is heating or otherwise of distinctly low quality.

Source: FGIS, U.S. Department of Agriculture, 1993.

personnel sampling an identified lot of grain and forwarding the representative sample, along with a certificate stating that the sample was officially drawn, to a location designated by the applicant for inspection. The stowage examination service involves the visual examination of the stowage area to ensure that the carrier is suitable for storing and transporting grain. Approval of the stowage space is required for official sample-lot inspection services on all export ships and all outbound domestic lots of grain which are sampled and inspected at the time of loading.

Levels of Inspection

The USGSA provides for a review inspection process if the results of an inspection are disputed or questioned (7 U.S.C. 79). When the first inspection service is performed on a lot of grain, it is considered the "original" inspection. This service is provided by the inspection office responsible for inspection service within its assigned geographic boundaries. If the results of the original inspection are questioned by any person having a financial interest in the grain, a review inspection is provided upon request.

Review inspections include: 1) reinspection services, 2) appeal inspection services, and 3) board appeal inspection services. Review inspections are based on file samples retained as part of the original inspection service. Reinspections and appeal inspections, however, may be based on a new sample, provided that the carrier containing the grain has not moved from its location and inspectors can verify that additional grain was not added, removed, or transferred from the carrier, or that anything was added to change the condition of the grain. The same inspection criteria and factors determined as part of the original inspection service are determined during the review inspection.

Table 4. Grades and grade requirements for soybeans.

Grade	Minimum Test Weight per Bushel	Maximum Limits of— Damaged Kernels: Heat Damaged Kernels	Damaged Kernels: Total	Foreign Material	Splits	Soybeans of Other Colors
	(Pounds)	(Percent)	(Percent)	(Percent)	(Percent)	(Percent)
U.S. No. 1	56.0	0.2	2.0	1.0	10.0	1.0
U.S. No. 2	54.0	0.5	3.0	2.0	20.0	2.0
U.S. No. 3[1]	52.0	1.0	5.0	3.0	30.0	5.0
U.S. No. 4[2]	49.0	3.0	8.0	5.0	40.0	10.0

U.S. Sample grade:

U.S. Sample grade is soybeans that:

a) Do not meet the requirements for the grades U.S. Nos. 1, 2, 3, 4; or

b) Contain eight or more stones which have an aggregate weight in excess of 0.2 percent of the sample weight, two or more pieces of glass, three or more crotalaria seeds (*Crotalaria* spp.), two or more castor beans (*Ricinus communis* L.), four or more particles of an unknown foreign substance(s) or a commonly recognized harmful or toxic substance(s), 10 or more rodent pellets, bird droppings, or equivalent quantity of other animal filth per 1,000 grams of soybeans; or

c) Have a musty, sour, or commercially objectionable foreign odor (except garlic odor); or

d) Are heating or otherwise of distinctly low quality.

[1]Soybeans that are purple mottled or stained are graded not higher than U.S. No. 3.
[2]Soybeans that are materially weathered are graded not higher than U.S. No. 4.

Source: FGIS, U.S. Department of Agriculture, 1993.

A reinspection service is provided by the same inspection office that provided the original inspection service. An appeal inspection service is provided by the FGIS office that monitors the activities of the office providing the original inspection service. Board appeal inspection services are provided by the FGIS Board of Appeals and Review located in Kansas City, Missouri. Inspection certificates issued during the review inspection identify that the results of the review inspection supersede previous results for the same identified lot of grain.

Sampling

The importance of sampling and its role in the inspection process cannot be discounted if the quality of a particular lot of grain is to be accurately reflected in the assigned grade. The reliability of the inspection results depends to a great extent on the representativeness of the samples used to make the various quality determinations.

The uneven distribution of grain quality typically found in storage bins and grain carriers, and the randomness with which samples are drawn, greatly influences the representativeness of the sample. While neither of these factors can be eliminated, both can be controlled using proven sampling equipment and procedures. Numerous sampling devices and procedures are used throughout the grain industry to sample grain, but not all devices or procedures are capable of obtaining a representative sample. To be considered representative, the sample should consist of multiple subsamples selected from different sampling sites or at different time intervals during the loading/unloading process. Further, when sampling stationary lots of grain, the sampling device must be capable of sufficiently penetrating the surface of the grain to provide a representative cross-section of the grain mass at the sampling site.

Table 5. Proper probe lengths for use in sampling various containers.

Container[1]	Length of Probe (Trier)
Barges and Bay Boats	12-foot
Hopper cars	10- or 12-foot
Boxcars	6-foot
Trucks	5- or 6-foot
Hopper-Bottom Trucks	6-, 8-, or 10-foot

[1]For containers not identified above, use grain probes that will reach the bottom of the container. Source: FGIS (1993).

The number, frequency, and/or location of samples to be taken from a given lot of grain depends on the type of carrier involved. The FGIS publishes standardized sampling methods and procedures that are designed to optimize the accuracy and cost effectiveness of grain sampling. These devices and procedures are briefly discussed later in this chapter. *Book I, Grain Sampling* is available through the FGIS if additional information is needed.

The only device the FGIS recognizes as being capable of obtaining representative samples from stationary lots of grain is the manual or mechanical probe. The manual probe, or trier, is a double-tubed, compartmented device constructed of either aluminum or brass. To accommodate the various containers commonly used to store and transport grain, manual probes are available in lengths of 5, 6, 8, 10, and 12 feet. The type of carrier dictates which probe length is used (Table 5).

The FGIS recognizes two of the mechanical probes designed for grain inspection purposes: the gravity-fill and core-type probe. The gravity-fill probe is similar to the manual probe in that it is a double-tubed, compartmented probe. The compartments are filled by gravity and the contents pneumatically transported to a collection box. The core sampler consists of concentric tubes that are open at the bottom. As grain is introduced into the tip of the probe, a vacuum created in the system pneumatically delivers it to a collection box.

The number of and location from which probe samples are taken depends not only on the type of carrier being sampled, but also on the amount of sample desired and the general condition of the grain. Figures 1 and 2 illustrate some of the patterns used by the FGIS to sample hopper cars and flat-bottom trucks.

The FGIS uses several sampling devices to obtain samples from a moving grain stream. These online sampling devices include the pelican, Ellis cup, Woodside sampler, and diverter-type mechanical sampler (D/T). The pelican sampling device is designed to obtain samples from a free-falling stream of grain. Made of reinforced leather, the pelican pouch has an opening 18 inches long and two inches wide, and a depth of six inches. A cross-section of the grain is taken by swinging the pelican through the grain stream in one continuous motion approximately once every 500 bushels.

The Ellis cup is constructed of lightweight aluminum and is used to draw samples from grain moving on a conveyor belt. Subsamples are obtained by placing the device (heel first) into the grain stream and withdrawing grain samples from the inside, outside, and middle of the stream. Each set of three samples is considered a subsample. One subsample is taken approximately once every 500 bushels.

The Woodside sampler is a mechanical sampling device that is designed to sample grain from a moving conveyor belt. Small buckets intermittently mounted on three chains—one in the center and both sides of the grain stream—are used to sample the grain. The chains, which are fastened to an upper and lower sprocket, are driven by a special roller located approximately 10 inches from the lower sprocket. Grain passing over the roller becomes suspended in air and falls into the sampling buckets. The grain from the sampling buckets is discarded into a hopper that feeds into a collection container.

Designed to sample grain from the end of a conveyor belt or loading spout, the D/T is widely regarded as the sampling device that provides the most representative

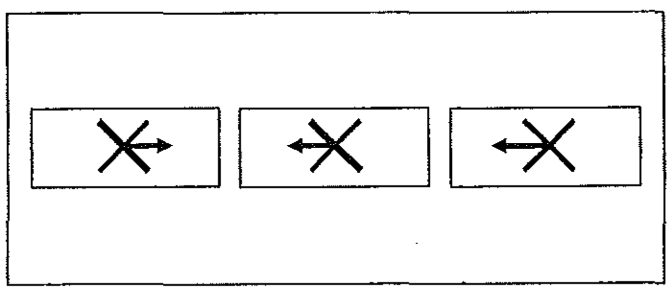


Figure 1. Probing pattern for three-compartment hopper car.

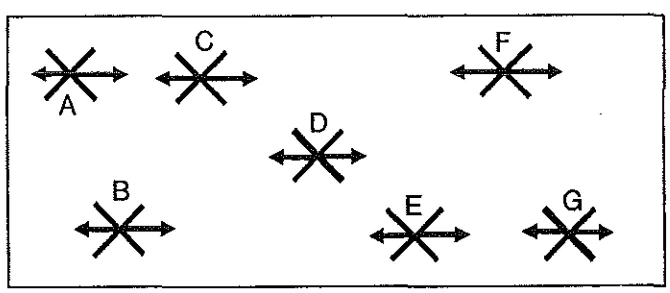


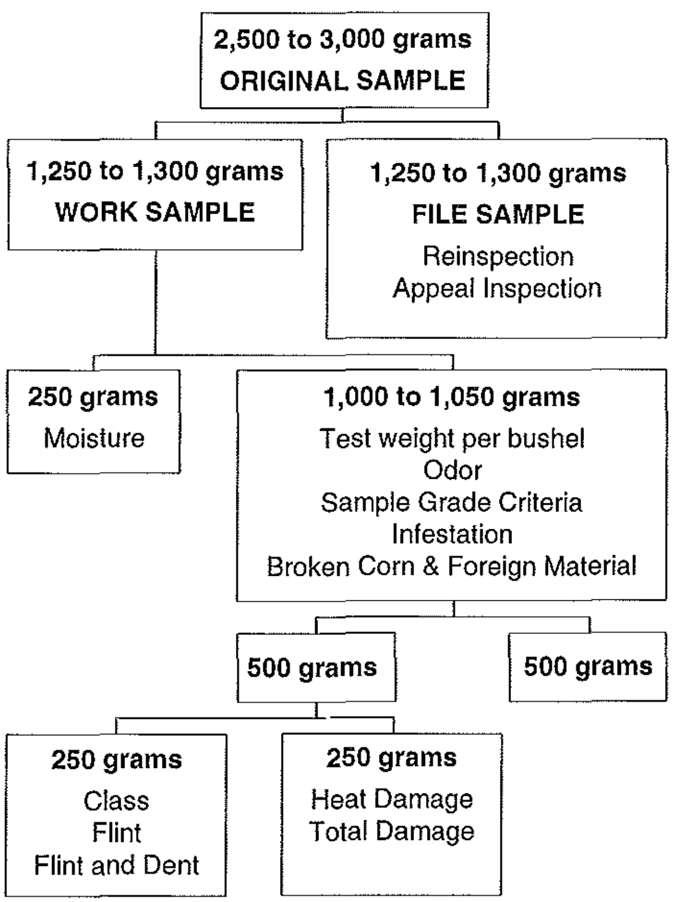
Figure 2. Probing pattern for flat-bottom trailers.

sample. While the designs vary, the basic principle of operation is the same. Powered by compressed air or electricity, D/Ts are pelicanlike devices (3/4 to 7/8 inches wide) that traverse the grain stream at predetermined intervals based on the loading/unloading capacity of the elevator. Normally, the D/T is programmed to traverse the grain stream approximately once every 200 bushels; however, low volume facilities may program it for a maximum of once every three minutes. The amount of grain the D/T pelican obtains is generally too voluminous for inspection purposes. Therefore, D/T samplers are usually equipped with a device to automatically reduce the sample size.

Inspection Process

Individuals authorized or licensed to obtain official samples exercise great care in ensuring that the sample they deliver to the inspection laboratory is representative of the lot from which it was taken. The same care must be taken to ensure that its representativeness is maintained once it is received in the inspection laboratory.

Figure 3. Preparing a sample of corn for inspection.



The time involved in performing some of the analyses for grade makes it impractical to evaluate the total amount of grain available in each sample. For this reason, a Boerner divider or mechanical divider is used by inspection technicians to reduce the original sample to a size that will permit the inspector to grade the grain as quickly as possible without placing the integrity of the inspection results at risk. A comparably sized portion of the original sample is generally retained for use in performing review inspections (reinspection, appeal, and board appeal) when requested by the customer or the FGIS quality-control program, which enables the FGIS to determine how well samplers, inspectors, and inspection equipment are performing under normal working conditions. Figure 3 illustrates how a sample of corn is processed for inspection. After the sample has been divided into the various portion sizes, the inspector completes the inspection process by evaluating each of the factors necessary to grade the sample and certifies the results accordingly. The number and kinds of factors vary according to the kind of grain inspected; however, certain factors such as test weight per bushel, moisture, damage, foreign matter, and odor are common to most grains. Regardless of the grain being marketed, knowledge of these factors is important in predicting the grain's suitability for handling, storage, transportation, and its particular end use.

Test Weight per Bushel

Test weight per bushel is a measure of bulk density and is generally used by the industry to estimate the amount of grain that can be stored, transported, or processed. Some users believe that test weight is useful as a general indicator of grain quality and end-product yield.

Test weight per bushel is not to be confused with the term "legal weight per bushel." Test weight per bushel refers to the weight of a volume of grain required to fill a Winchester bushel measure of 2,150.42 cubic inches. Legal weight per bushel is based on weight rather than volume, and is used commercially to convert the net weight of grain into bushels.

Test weight is generally determined on a sample of approximately 1,000 to 1,050 grams using a special device that measures in pounds per bushel. Corn, soybeans, oats, sorghum, and mixed grain are based on the sample as a whole, while the balance of the grains are mechanically cleaned before making the determination.

Moisture

Moisture content is considered by many to be one of the more influential factors affecting the storability of grain. With this in mind, to better protect against the possible deterioration of grain quality during storage and transport, it is essential that grain handlers be knowledgeable of the moisture content of a given lot of grain. While the moisture content does not influence the grade, it is determined and reported on each certificate for which a grade is assigned.

In the official inspection system, the moisture content of grain is indirectly measured with a dielectric Motomco moisture meter. The instrument is calibrated to provide equivalent results to the USDA air-oven reference method. The moisture content is determined by placing a representative portion into the instrument's test cell and noting the dial reading after the needle has reached its lowest point. Conversion charts, which are standardized for a grain temperature of 77°F, are developed to convert the meter reading to a percentage of moisture. If the grain temperature deviates from 77°F, a correction factor, which is found on the conversion chart, is applied.

Generally, factor determinations are based on approximate portion sizes; however, when determining the moisture content of grain, an exact amount must be used depending on the grain tested. Most grains require 250 grams except for barley (225g), flaxseed (270g), oats (200g), and sunflower seed (150g).

Damage

The determination for damaged kernels is a measure of grain soundness. It provides information relative to the amount of preharvest or postharvest damage, including heat damage, that occurs from unfavorable environmental conditions or poor handling and storage practices. It is not a measure of the mechanical damage that occurs during harvest. The most common types of damage found in grain are mold, germ, and sprout. Other damage generally found in grain includes insect damage, heat damage, weather damage, frost damage, and badly ground damage.

Damage is visually determined on the basis of a representative portion after the foreign matter (dockage and/or foreign material) has been removed. To achieve and maintain a high degree of uniformity throughout the national inspection system, 35mm interpretive line slides were developed which depict the minimum amount of discoloration or deterioration permitted for the various types of damage.

Foreign Matter

Foreign matter, which generally consists of material that is lighter, larger, or smaller than grain, is an undesirable characteristic of grain because of the negative way in which it effects grain storage, drying, and processing operations. If grain handlers and end users are to manage their respective operations efficiently and effectively, they must consider the amount of foreign matter entering their facility.

The manner in which foreign matter is determined varies according to the grain inspected. However, in most cases, foreign matter is mechanically removed by a screening device, then further removed through manual procedures.

Odor

Odor, like damage, is an indicator of grain soundness. The presence of musty and sour odors in grain often is an indication that the condition of the grain is changing. Sour odors emanate from grain that has undergone fermentation. Musty odors in grain are usually caused by the growth of certain molds. While these odors may appear in the early stages of deterioration, they usually occur during the fairly advanced stages of deterioration (Pomeranz 1974). Other odors occasionally found in grain are considered "commercially objectionable foreign odors" (COFO) because they are odors which are foreign to grain and render it unfit for normal commercial usage. Examples of odors that fall into this category are odors of fertilizer, oil products, smoke, decaying animal and vegetable matter, fumigants/insecticides, and skunk. Grain which contains an off odor, regardless of its origin, cannot receive any grade higher than U.S. Sample grade, which is the lowest of the quality grade designations.

The determination for odor may be made on the basis of a representative portion of the sample as a whole or after it has been mechanically cleaned. Due to the subjectivity involved in making odor determinations, a consensus approach of experienced inspectors is used to determine marginal odors as much as possible. Samples containing fumigant or insecticide odors are permitted to air for four hours to determine if the fumigant odor persists. Fumigant/insecticide odors which persist after aeration are considered COFO.

Other Factors

In addition to the grading factors outlined in the standards, other considerations are given to the condition of the grain during the inspection process to ensure that the grain quality of a particular lot is accurately described. For instance, situations occasionally arise which prevent samplers from obtaining a truly representative sample because the grain contains substances that are too large to enter the sampling device. The presence of objects in grain, such as large stones, pieces of glass, and other debris, adversely affects grain quality and must therefore be considered in the quality analysis. Likewise, adverse conditions which are present in the sample but not specifically defined in the standards also must be considered. Consequently, in instances such as these, the grain is considered "distinctly low quality" and is graded U.S. Sample grade.

Inspectors also examine the grain for the presence of substances that affect its wholesomeness and relative value. "Sample grade criteria" include such things as small stones, crotalaria seeds, castor beans, rodent pellets, and glass. Individual thresholds are established based on their detrimental effects. If the established limit(s) is exceeded, the sample is appropriately graded U.S. Sample grade.

At times, depending on its intended use, the condition of the grain is such that it deserves special recognition because of the economic influence it may have on the value of the grain. For this reason, designated "special grades" (e.g., infested, garlicky, ergoty, waxy) are made part of the grade designation to alert grain merchants to the presence of the unusual quality or condition.

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Rev. 1/95

6

The FDA's Role in Grain Inspection

Alan Dowdy, USDA-ARS, U. S. Grain Marketing Research Laboratory
James Rahto, Department of Health and Human Services, FDA

The Federal Food, Drug, and Cosmetic Act gives the Food and Drug Administration (FDA) authority to inspect grain, bulk commodities, and bagged products when introduced into and while in interstate commerce. The primary purpose of inspection is to determine the degree of health hazard, especially from chemical odors or evidence of insect, bird, or rodent contamination (Figure 1). The act is enforced by inspection of facilities that hold, distribute, and process commodities. It also may include microscopic examination and chemical residue analysis of the product and its containers to determine the product's fitness for human or animal consumption.

Because bulk grains are frequently raw agricultural commodities, it is not uncommon for them to contain foreign material, such as dead insects, small stones, or extraneous plant material. These are commonly occurring natural defects of the commodity and pose minimal health risk to the consumer at normal low levels because most are removed by cleaning and conditioning prior to processing. The presence of live insect pests or parasites and predators is considered to be an adulteration if found in stored bulk grains. Excessive insect feeding damage or evidence of bird or rodent contamination in grain may indicate that the commodity has been held under insanitary conditions and may be deemed to be adulterated. For example, wheat containing 32 insect damaged kernels per 100 grams of sample, or at least 9 milligrams of rodent excreta per kilogram of sample, is considered to be adulterated and unfit for human or animal consumption. Grains and feeds may be contaminated with weed berries and seeds that contain toxic substances, such as *Crotalaria* spp. and *Solanum nigrum*, which could render the product injurious to health (Anonymous 1981, 1982). In some instances, grain that violates FDA defect action levels may be reconditioned if the undesirable elements can be removed and the commodity brought into compliance. However, if it cannot be successfully reconditioned, it is illegal to blend violative grain with other grain to bring it into compliance.

Occasionally, treated seeds or grain with chemical odors are introduced into commodities to be used for human or animal consumption. Chemical residue analysis will be conducted on subsamples of grain to determine what compounds are present, whether they are labeled for use on that commodity, and whether they are at acceptable concentrations (Anonymous 1989).

The FDA and the Federal Grain Inspection Service (FGIS) have developed a memorandum of understanding regarding the inspection and standardization of responsibilities in situations where both agencies are involved in the examination of a commodity or facility (Anonymous 1986). The memorandum establishes that during FDA inspections of facilities also monitored by the FGIS, a representative from the FGIS will accompany the FDA inspec-

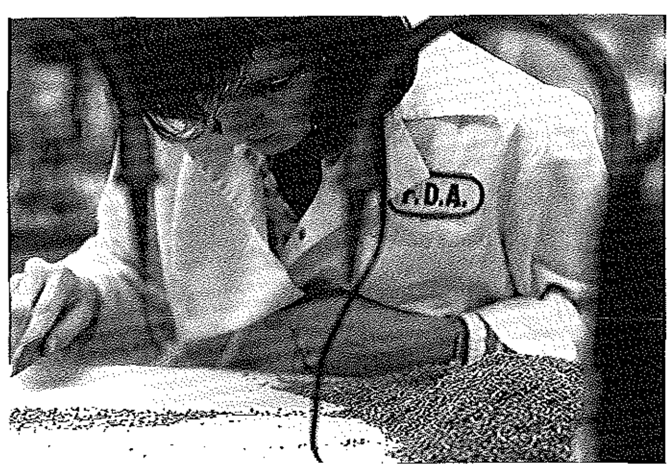

Figure 1. An FDA inspector examines grain for evidence of insect and rodent activity.

tor. Each agency will furnish to the other information regarding quality determinations of specific lots against which action may be taken. Both agencies cooperate in developing sampling procedures, methods of analysis, and guidelines for determining defect action levels.

Compliance Policy Guidelines relating to grain inspection by the FDA are available to industry and the general public under the Freedom of Information Act. Address document requests to: Food and Drug Administration, Freedom of Information, 5600 Fisher Lane, HFI-35, Rockville, Maryland 20857.

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7

The Role of APHIS in Grain Inspection and Export Certification

Leonard M. Crawford, USDA-APHIS
Jonathan M. Jones, USDA-APHIS
Narcy G. Klag, USDA-APHIS

The Animal and Plant Health Inspection Service (APHIS) of the United States Department of Agriculture is the government agency responsible for phytosanitary certification. The following describes the role of APHIS in the phytosanitary certification of agricultural products, including grain, for export.

Scope of Export Certification

Phytosanitary (phyto=plant, sanitary=health) export certification in the United States is performed under the authority of the Organic Act of 1944, as amended. APHIS performs certifications in close conformity with the broad principles of international plant protection contained in the International Plant Protection Convention of the Food and Agriculture Organization (FAO) of the United Nations.

A phytosanitary certificate is a document that provides essential information to the importing country's plant protection service. The certificate informs the country of destination that the agricultural commodity has been officially inspected and is considered to be free from quarantine pests, and practically free from other injurious pests. The certificate further assures that the commodity conforms with the current phytosanitary regulations of the importing country. APHIS maintains summaries of these regulations of foreign countries.

Phytosanitary certificates can be prepared for a wide range of commodities. Plants and unprocessed plant products, including grain, wood, plants, fruits, and vegetables, for export are inspected and certified upon request. Both federal inspectors and inspectors from cooperating state plant regulatory agencies issue certificates. In 1993, certifying officials issued more than 260,000 Federal Phytosanitary Certificates (Figure 1).

Export Certification of Grain

APHIS cooperates with the Federal Grain Inspection Service (FGIS) to provide phytosanitary certification for grain and grain products. Certification is based on an FGIS grain inspection which determines the level of insect infestation in the grain. To be eligible for certification, the level of insect infestation must fall within allowed parameters. Some shipments will be required to be fumigated to meet importing countries requirements. APHIS will issue phytosanitary certificates for eligible grain upon receipt of the required documents. These documents include a ship loading log and/or an official grain inspection certificate issued by the FGIS. The exporter or their agent must also complete an "Application for Phytosanitary Certification" (Figure 2).

The above documents are all that are usually required for phytosanitary certification. Countries may, however, require certification from certain disease organisms and weed seeds as well. APHIS cannot certify for freedom from disease organisms in grain, nor is APHIS able to test for weed seeds at port locations. The Federal Seed Laboratory, located at Beltsville, Maryland, can perform weed seed testing. Tests are performed on composite grain samples drawn by the FGIS throughout the vessel loading process. APHIS will provide phytosanitary certification for those shipments found negative for weed seeds.

When a shipment meets all of the importing country's phytosanitary requirements, APHIS issues a phytosanitary certificate. If a shipment cannot meet the importing country's requirements, an APHIS representative will inform the exporter or their agent of the reason.

APHIS and the FGIS cooperate to ensure the efficient use of resources in expediting grain exports. The FGIS conducts the sampling and inspection of grain for export. APHIS maintains summaries of importing countries' phytosanitary requirements and makes this information available. When a shipment meets all requirements, APHIS issues a Federal Phytosanitary Certificate which confirms to the importing country that its plant health requirements for the grain have been met. ❑

Rev. 1/95

Figure 1. Federal Phytosanitary Certificate.

No phytosanitary certificate can be issued until an application is completed (7 CFR 353). See reverse for additional OMB information

FORM APPROVED
OMB NO. 0579-0052

UNITED STATES DEPARTMENT OF AGRICULTURE
ANIMAL AND PLANT HEALTH INSPECTION SERVICE
PLANT PROTECTION AND QUARANTINE

PHYTOSANITARY CERTIFICATE

FOR OFFICIAL USE ONLY

PLACE OF ISSUE

NO.: FPC 300008

DATE INSPECTED

TO: THE PLANT PROTECTION ORGANIZATION(S) OF

CERTIFICATION

This is to certify that the plants or plant products described below have been inspected according to appropriate procedures and are considered to be free from quarantine pests, and practically free from other injurious pests; and that they are considered to conform with the current phytosanitary regulations of the importing country.

DISINFESTATION AND/OR DISINFECTION TREATMENT

1. DATE	2. TREATMENT
3. CHEMICAL *(active ingredient)*	4. DURATION AND TEMPERATURE
5. CONCENTRATION	6. ADDITIONAL INFORMATION

DESCRIPTION OF THE CONSIGNMENT

7. NAME AND ADDRESS OF THE EXPORTER	8. DECLARED NAME AND ADDRESS OF THE CONSIGNEE
9. NAME OF PRODUCE AND QUANTITY DECLARED	10. BOTANICAL NAME OF PLANTS
11. NUMBER AND DESCRIPTION OF PACKAGES	12. DISTINGUISHING MARKS
13. PLACE OF ORIGIN	14. DECLARED MEANS OF CONVEYANCE
	15. DECLARED POINT OF ENTRY

Any intentional false statement in this phytosanitary certificate or misrepresentation relative to this phytosanitary certificate is a violation of law, punishable by a fine of not more than $10,000, or imprisonment of not more than 5 years, or both. (18 U.S.C. s1001)

ADDITIONAL DECLARATION

16. DATE ISSUED	17. NAME OF AUTHORIZED OFFICER *(Type or Print)*	18. SIGNATURE OF AUTHORIZED OFFICER

No financial liability shall attach to the United States Department of Agriculture or to any officer or representative of the Department with respect to this certificate.

PPQ FORM 577
(JUL 93)

B series are obsolete effective 12/31/93

PART 1 - SHIPPER'S ORIGINAL

Figure 2. Application for Phytosanitary Certification.

No Phytosanitary Export Certificate can be issued until an application is completed (7 CFR 353).

FORM APPROVED
OMB NO. 0579-0052

U.S. DEPARTMENT OF AGRICULTURE
ANIMAL AND PLANT HEALTH INSPECTION SERVICE
PLANT PROTECTION AND QUARANTINE

APPLICATION FOR INSPECTION AND CERTIFICATION OF DOMESTIC PLANTS AND PLANT PRODUCTS FOR EXPORT

INSTRUCTIONS: APPLICANT - Forward original to Officer In Charge where inspection, treatment and certification will be given *(Item 4)*. Complete items 1 thru 11. OFFICER - Complete items 12 thru 17.

1. NAME AND ADDRESS OF EXPORTER	3. NAME AND ADDRESS OF APPLICANT *(or exporters agent)* TEL: (AC)
2. NAME AND ADDRESS OF FOREIGN CONSIGNEE	4. PLACE WHERE ARTICLES WILL BE MADE AVAILABLE FOR INSPECTION AND/OR TREATMENT AND CERTIFICATION *(Port and location)* 5. APPROXIMATE DATE OF DEPARTURE — 6. PORT OF EXPORT

7. DESCRIPTION OF ARTICLES TO BE CERTIFIED

a. QUANTITY AND NAME OF PRODUCE AND BOTANICAL NAME	
b. NUMBER AND DESCRIPTION OF PACKAGES	
c. DISTINGUISHING MARKS	
d. CERTIFIED ORIGIN	

8. DECLARED MEANS OF CONVEYANCE	*I certify that the origin (place where grown) of the articles listed is as represented.*	
9. DECLARED POINT OF ENTRY	10. SIGNATURE *(applicant or exporters agent)*	11. DATE

EXPORT INSPECTION DATA - *(To be filled in by Plant Protection and Quarantine Officer)*

12. LOCATION OF ARTICLES	13. % OF MATERIALS EXAMINED	14. % OF MATERIALS INFESTED
15. FINDINGS AND/OR TREATMENT GIVEN *(Use reverse if necessary)*		
16. SIGNATURE		17. DATE AND TIME INSPECTED

PPQ FORM 572 (FEB 81) *Replaces PPQ FORM 572 (AUG 74) which may be used*

8

Commodity Programs

Eric Parsons, USDA-CFSA

Agricultural commodity programs are designed to improve the economic stability of agriculture and to help farmers adjust production to meet demand. The goal is to avoid severe price swings for farmers and consumers. Assistance is offered through price support loans, marketing loans, and purchases, payments, and related acreage reductions and diversions.

The Agricultural Stabilization and Conservation Service (ASCS) administers commodity stabilization programs for wheat, corn, grain sorghum, barley, oats, rye, oilseeds, rice, tobacco, peanuts, milk, cotton, wool, mohair, sugar, and honey.

The ASCS makes Commodity Credit Corporation (CCC) loans to eligible farmers using the stored crop as collateral. Loans to producers are "nonrecourse." With market prices higher than the loan rate, a farmer can simply pay off the loan and market the commodity. However, if market prices fail to rise above loan levels, a producer can forfeit or deliver the commodity to the government to discharge the loan obligation in full. Thus, commodity loans promote orderly marketing by providing farmers with income while they hold their crops for later sale. Second, farmers get price protection with the option of forfeiting the commodity to the CCC as a sufficient-value repayment. Marketing loans allow producers to repay price support loans at less than announced rates when world prices are less than loan rates, and are mandatory for oilseeds, upland cotton, and rice.

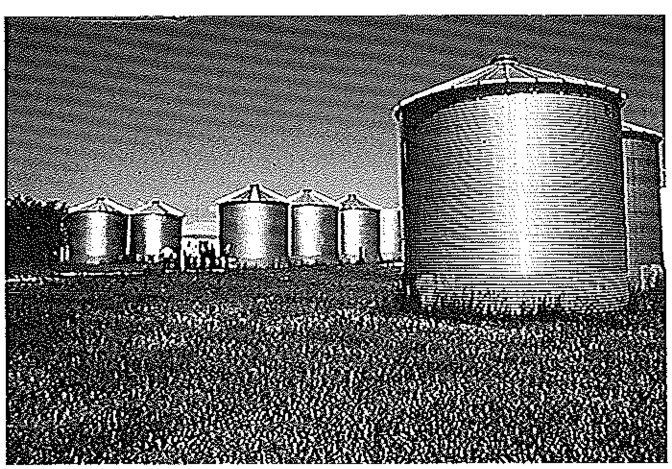

Figure 1. Farmer-owned Grain Reserve Program.

The price support loan is seasonal and can be repaid with interest anytime through maturity. For wheat and feed grains, the Farmer-owned Grain Reserve offers producers the opportunity to extend the crop loan for longer periods. Storage payments are made for grain placed in the reserve (Figure 1).

For most commodities, loans are made directly to producers on the unprocessed commodity through ASCS county offices. Loans and purchases are also made through cooperative marketing associations or through processors. For example, price support loans for eligible tobacco are available through the applicable tobacco growers associations. For burley and flue-cured tobacco, marketings in excess of a quota are subject to penalty and are ineligible for loan.

Price support loans for peanuts are available at two levels: a higher price support level for peanuts grown within the farm poundage quota, and a lower support level for additional peanuts grown on farms with a quota or on farms without a quota.

Price support loans on soybeans (and minor oilseeds) and rye are available for producers of those commodities with no acreage limitations.

For wheat, feed grains, rice, and cotton, another price guarantee is provided by the deficiency payment program. The program participant receives a direct payment, based on the difference between a "target price" set by law and the higher of either the loan rate or the national average market price.

In most cases, to qualify for payments, commodity loans, and purchases, a farmer must participate in the acreage reduction, allotment, or quota programs in effect for the particular crop. For example, deficiency payments are made to those who join the acreage reduction for the crop year. By reducing their production acreage by an established ratio, participants help keep commodity production in line with anticipated needs. The land they are holding from production must be protected from erosion. Under recently enacted flexibility provisions, producers may grow other crops on a portion of their base acreages.

ASCS/CCC Role in Grain Inspection and Storage

In connection with its price support and loan programs, the CCC may acquire quantities of grain. This grain must then be stored until used in a variety of domestic and foreign distribution programs.

The storage of CCC-owned grain is carried out through the use of privately owned grain warehouses that contract with the CCC. The CCC contracts spell out in some detail the requirements placed on the warehousemen to maintain sufficient grain of the proper quality to cover all obligations they may have. Following enactment of the 1990 Farm Act, current contracts require that all grain going into a warehouse be weighed and graded using authorized grain evaluation procedures.

The ASCS also administers the U.S. Warehouse Act. Its purpose is to administer a national permissive program of licensing, bonding, and examining warehouses in order to provide safe storage of agricultural products (Figure 2). Products stored in licensed warehouses are owned by producers and others (including the CCC), many of whom have pledged warehouse receipts with the CCC for price support loans.

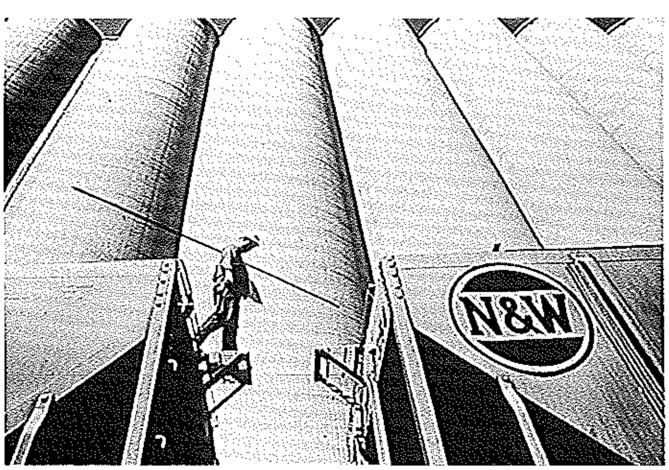

Figure 2. Licensed warehouse.

To qualify for a license, a warehouseman must have a suitable and properly equipped warehouse, a good business reputation, and a minimum net worth. He must furnish an acceptable bond in the amount fixed by the U.S. Department of Agriculture (USDA); employ qualified personnel who are able to weigh, inspect, and grade agricultural products; and have adequate equipment to properly grade and weigh.

Approximately 1,700 grain elevators are currently licensed under the act, which represents a substantial portion of the commercial grain elevator space in this country.

Commodity Purchases and Donations

The government-owned Commodity Credit Corporation (CCC) provides financing for farm programs, and for the purchase, storage, and disposal of commodities in federal stocks. ASCS employees are the administrative agents for the CCC. One large-scale responsibility is the inventory management of the CCC's bulk and processed products.

Managing the billions of bushels and pounds of farm products under loan or forfeited to the CCC requires cooperation with the warehousing and transportation industries, and private marketing channels. With over 10,000 commercial warehouses across the country approved for CCC storage contracts, ASCS commodity managers work closely with the commercial trade.

CCC inventories are not simply held, but must move into trade channels. The ASCS has a major field office in Kansas City with staff to direct commodity corporations. Plugged into telecommunicating trade networks, ASCS merchandisers regularly sell and swap inventories.

Beyond the marketplace, CCC commodities are used for hunger relief, for needy families in the United States, and for overseas assistance. The ASCS coordinates the processing and overseas delivery of over five billion pounds of commodities each year. Donated to "Food for Peace" and programs administered by voluntary organizations, these American farm products and foods help in hunger relief around the world.

Disaster and Emergency Assistance

In the aftermath of a natural disaster, the ASCS can provide a variety of emergency assistance programs to farmers in a disaster-designated area. For example, the agency can furnish CCC-owned feed grains and wheat to eligible livestock producers at reduced prices. In some instances, the agency will share the cost of purchased feed. To help rehabilitate the farmland damaged by a natural disaster, the ASCS can assist farmers with cost-sharing to carry out emergency conservation practices.

The ASCS also administers programs prescribed by the Federal Emergency Management Agency as a result of a presidential declaration of disaster or emergency. In the event of a military emergency, the ASCS is responsible for defense preparedness plans and programs to ensure food production and distribution, as well as the continued availability of farm machinery, feed, seed, and fertilizer.

Information Contacts

- County ASCS offices are listed in telephone directories under "U.S. Department of Agriculture."
- State ASCS offices are usually located in the state capital, or near the state land-grant university.
- Commodity sales and purchases:
  Kansas City Commodity Office
  P.O. Box 20
  Kansas City, Missouri 64141.
- Aerial photography, used by the ASCS as the basic tool to determine crop acreage, is also purchased extensively by other organizations and the public. Order forms and an index are available from your county ASCS office. For more information on services, including high-altitude photography, contact:
  Aerial Photography Field Office
  P.O. Box 30010
  Salt Lake City, Utah 84130.
- Information Division, USDA-ASCS
  P.O. Box 2415
  Washington D.C. 20013. □

9

Foreign Agricultural Service Role in Grain Marketing

Connie Delaplane, USDA-FAS
Roy Barrett, USDA-FAS

Public Law 480

In 1954, the 83rd Congress passed the Agricultural Trade Development and Assistance Act (Public Law 83-480) establishing the U.S. International Food Assistance Program, commonly referred to as "P.L. 480" or the "Food for Peace" program. The three primary objectives of the program are to expand U.S. agricultural exports, to provide humanitarian relief, and to aid the economic development of participating countries. The current program provides two types of commodity transfers: government-to-government concessional sales (Title I) and donations or grants (Title II and the revised Title III "Food for Development" program, which became effective January 1, 1991).

Agricultural commodities valued at nearly $42 billion at the time of export have been shipped under the P.L. 480 program since 1955, the first year of operation, through the end of fiscal year 1989. This represents seven percent of total U.S. agricultural exports for that period. More than 160 countries have received P.L. 480 assistance since 1955, many of which have progressed economically to the point where such assistance is no longer necessary. Japan, Taiwan, Korea, Colombia, and Ecuador are examples of countries which have received P.L. 480 assis-

Figure 1. Current Public Law 480 recipient countries.

tance in the past and which now have become important commercial buyers of U.S. agricultural commodities.

The Commodity Credit Corporation (CCC) finances an array of federal domestic and international farm programs, including Title I, Title II, and Title III. It is a government-owned and operated corporation within the U.S. Department of Agriculture (USDA), and is managed by a board of directors headed by the Secretary of Agriculture. All members of the board and the corporation's officers and staff are officials of the USDA.

Title I—Concessional Sales Program

Under Public Law 480, Title I, the U.S. government finances the sale of U.S. agricultural commodities to countries on concessional credit terms. This means that the credit terms are more favorable to the recipient country than the terms of normal commercial sales. Most Title I agreements require long-term repayments of U.S. dollars at low interest rates. Effective January 1, 1991, the maximum repayment period is 30 years.

Within the U.S. government, the Foreign Agricultural Service (FAS) of the USDA administers Title I agreements. The Secretary of Agriculture determines the kinds and quantities of commodities available for inclusion in agreements.

After a Title I agreement is signed, the FAS issues a purchase authorization at the request of the importing country. The country then issues separate "Invitations for Bids" for the commodity and for the ocean transportation. In accordance with the cargo preference provisions of the Merchant Marine Act of 1936, as amended, at least 75 percent of the Title I tonnage must be shipped on U.S.-flagged vessels. The U.S. government reimburses importing countries for the "ocean freight differential," the amount by which the cost of ocean freight for the commodities required to be carried on U.S.-flagged vessels exceeds the cost of carrying the same commodities on vessels flagged by other countries.

All Title I commodities and U.S.-flagged freight must be secured in the United States on the basis of open public "Invitations for Bids" issued by the importing country. Each Title I commodity and ocean freight transaction must be approved by the USDA. However, it is important to emphasize that the U.S. government is not a party to either the commodity contract or the ocean freight contract. Commodity sales are made by private U.S. suppliers to foreign importers or government agencies, which also contract directly with suppliers of ocean transportation.

Once sales are made, importing countries must open letters of credit for 100 percent of the commodity value at

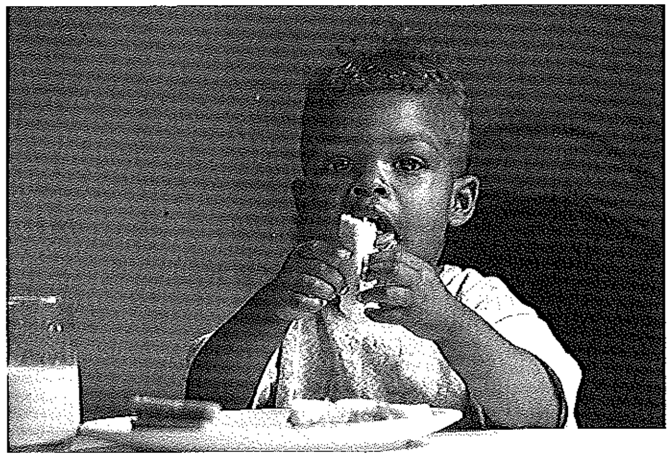

Figure 2. A young child is shown feeding himself.

a U.S. commercial bank. The CCC issues a "letter of commitment" to the same bank. This constitutes a firm commitment by the CCC to reimburse the bank for payments made under letters of credit. The importing country then repays the CCC over the period of time specified in the Title I agreement.

Twenty-six countries purchased commodities under Title I for delivery in fiscal year 1990. The export market value of these commodities was $735 million. Commodities shipped included wheat, wheat flour, corn, rice, vegetable oil, soybean meal, tallow, wood products, and cotton. In terms of dollar value, the five countries to which the largest amounts were allocated were Egypt, $203 million; Pakistan, $80 million; Bangladesh, $60 million; El Salvador, $40 million; and Sri Lanka, $39 million.

Title II—Donations Program

The P.L. 480, Title II program, which is administered by the Agency for International Development (AID), is designed to alleviate nutritional problems throughout the world with speed and efficiency. Over 25 different commodities are purchased by the U.S. government or supplied from U.S. government stocks for the Title II program. These include specially blended products, such as bulgur and corn-soy blend; flour and cornmeal; and whole grains, such as wheat, corn, and sorghum. Most of the Title II commodities are donated through such voluntary agencies as CARE and Catholic Relief Services, and such intergovernmental organizations as the World Food Program.

The Kansas City Commodity Office (KCCO), Agricultural Stabilization and Conservation Service, USDA, carries out the CCC's legislative authority to supply the commodities for approved programs. As in the Title I program, at least 75 percent of Title II commodities must be shipped on U.S.-flagged vessels. Within the parameters of cargo preference legislation, commodities are supplied on the basis of the lowest cost to deliver the commodities to the foreign destinations. This principle not only dictates the vendors from which the commodity is procured, but also the coastal ranges or ports through which shipments are exported. Ocean transportation costs are paid by the U.S. government.

For processed commodities, the KCCO issues invitations for offers to all interested vendors for approximate quantities of each commodity. The KCCO determines the available ocean service and applicable ocean freight rates for use in analyzing bids and determining the lowest delivered cost. The voluntary agencies privately contract with freight forwarders for the booking of their shipments. The KCCO controls and monitors the shipment of all commodities until vessel loading is completed and ocean bills of lading are issued. At that point, title to the commodity passes to the voluntary agency, along with the responsibility for monitoring the progress of the cargo to the final distribution point.

Commodities acquired by the USDA under its price support programs also are used to meet foreign donation needs. Recent examples include wheat, corn, sorghum, and rice. In shipping such commodities from inventory, the KCCO uses the same method described above in making port allocations, except that the CCC's total cost to place the commodity alongside the vessel (f.a.s., or free alongside ship) is used rather than the price quoted by a vendor.

During fiscal year 1990, the products supplied under the Title II, P.L. 480 program provided all or part of the daily nourishment received by approximately 60 million people throughout the world.

Title III—Grant Program

Title III of P.L. 480, as rewritten in the 1990 Farm Bill, authorizes a new government-to-government grant food aid program, which is administered by AID. Title III grant agreements are entered into with least developed countries, generally those eligible on the World Bank's Civil Works Preference List. The commodities which may be provided under this title are the same as under Title I. Also, as is the case under Title I, the ocean freight differential is borne by the U.S. government. In exceptional cases, the U.S. government will pay the full cost of ocean freight. The KCCO procures Title III commodities or furnishes commodities from inventory, and AID arranges for ocean transportation.

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Special thanks to Jorge Hazera for his most valuable assistance in preparing this chapter for publication. ☐

10

OSHA Requirements and Worker Safety

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Grain elevator managers and employees are responsible for complying with Federal Occupational Safety and Health Administration (OSHA) requirements and guidelines (OSHA 1987) when handling and processing grain and fumigating grain storage structures. Individuals are not only responsible for personal safety, but for the safety of co-workers and the public as well.

Commercial Grain Storage Fumigation

Written Hazard Communication Program

Grain elevator employers must develop, implement, and maintain a written hazard communication program in the workplace. The program should include:

1) a list of hazardous chemicals known to be present and in use,
2) copies of container labeling instructions,
3) active chemical material safety data sheets (MSDS),
4) application information and training,
5) non-routine task procedures, and
6) information for outside contractors.

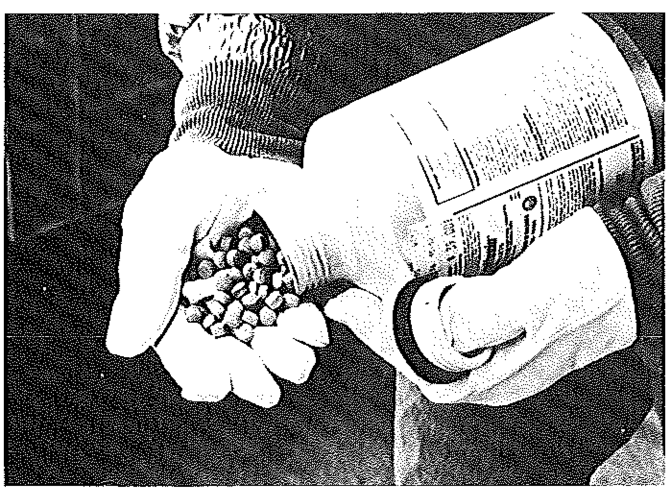

Figure 1. Fumigator wears suitable gloves when handling phosphine pellets.

The employer must make these materials available to employees in written form at the time of initial employment and when requested by the employee.

Hazardous Fumigation Materials

Fumigation substances are restricted to phosphine, chloropicrin, and methyl bromide. Methyl bromide is extremely dangerous and should be applied only by certified commercial fumigators. Aluminum phosphide containers should not be opened in a flammable atmosphere. Before placing phosphine fumigants in any structure, make sure there is no standing water or moisture film in the vicinity of placement (Figure 1).

Personal Protective Equipment

Elevator managers are responsible for providing personal protective equipment, such as a gas mask and canister. They also are responsible for training personnel in proper methods for fitting, maintaining, and using the equipment. However, individuals also are responsible for requesting and using the equipment (Figure 2). Fumigators should wear gloves made of cotton or other suitable material when handling pellets or tablets to avoid direct contact with the fumigant, since heat and moisture from bare hands can activate the phosphine gas release. Properly fitted, full-face masks and unused phosphine canisters must be carried by each worker inside the structure during all fumigation applications. Workers with beards cannot safely wear full-face gas masks and should be excluded from work inside fumigated structures. Two self-contained breathing apparatus (SCBA) with filled oxygen tanks are

Figure 2. Gas mask and canister.

required to be at the fumigation site with personnel trained and fitted to use them.

Atmospheric Monitoring

Concrete and tall steel tanks that are to be entered for fumigation purposes should be checked for an oxygen level of 19.5 percent or higher. Toxic gas and oxygen deficiency are major concerns in fumigation. Following fumigation, phosphine gas levels should be tested after each structure is properly vented before entry to ensure that gas levels are within the acceptable range of 0.3 ppm or less.

Venting Fumigated Storage Structures

After the appropriate five- to seven-day sealed period following the fumigant application, the structure may be unsealed. Each grain storage facility should be ventilated thoroughly to remove gas vapors and reduce toxic gas concentrations to safe levels.

Fumigant Storage, Handling, and Disposal

Phosphine tablets or pellets and chloropicrin should be stored in sealed containers in a cool, dry, locked storage area in a building not routinely occupied by personnel. Chloropicrin liquid should not be splashed on clothing or exposed skin. Empty containers should be triple-rinsed and disposed of properly. Phosphine flasks should be carefully opened out of doors. Keep flasks well away from the face to avoid possible vapor inhalation or eye contact. Empty phosphine flasks should be triple-rinsed with water, then crushed for disposal.

Emergency Action, Communication Plan, and Training

Each elevator should have an emergency action and communication plan. Each member of fumigation teams and other hazardous work teams should know how to activate and coordinate plans in case of emergency. All elevator employees should be trained for emergencies and have copies of the plan. Plan coordinators should be identified, and a listing of phone numbers for key persons should be posted for emergency contacts.

Permanent Record File and Training Documentation

A permanent record file system should be developed and maintained. The records should document the time, date, location, and signature of each person trained. Operations and safety checklists should be completed, dated, signed, and kept in the file. The name of any person employed in a hazardous occupation should be in the file and appropriate training should be documented by date and signature.

Grain Handling Safety Standards

Grain handling safety standards generally apply to all grain elevators, feed mills, flour mills, dust pelletizing plants, and soybean flaking operations.

Housekeeping

Employers at all grain handling facilities are required to develop and implement a written housekeeping program that establishes the frequency and methods determined to best reduce accumulations of fugitive grain dust on ledges, floors, equipment, and other exposed surfaces. In addition, the standards establish priority housekeeping areas for grain elevators. Employers are required to immediately remove any fugitive grain dust accumulation whenever it exceeds one-eighth inch in the designated priority housekeeping areas.

Training

All employers should provide hazardous material handling and worker safety training to employees at least once a year, or when employees change job assignments and are exposed to new hazards. The training should include:

1) general safety precautions associated with the facility operation, including recognition and preventive measures for hazards related to dust accumulations and common ignition sources, such as smoking; and
2) specific procedures and safe practices applicable to each employee's job tasks.

The specific procedures shall address, but are not limited to, communications concerning hazardous situations, confined spaces, bin entry, housekeeping, hot work (welding), preventive maintenance, and lock-out/tag-out of mechanical and electrical equipment.

Emergency Action Plan

All employers should develop and implement an emergency action plan which spells out the specific actions that employers and employees are to follow if a fire, explosion, tornado, chemical spill, or other emergency occurs.

Entry into Bins, Silos, and Tanks

The standards require that employers establish special procedures and provide personal protective equipment to employees who enter bins, silos, and tanks. The following requirements are contained in the standards:

Permits. Employers are required to issue a permit for entering bins, silos, or tanks unless the employer or his representative is present during the entire operation.

Procedures. All mechanical and electrical equipment that presents a danger to employees inside bins, silos, or tanks shall be disconnected, locked-out, and tagged.

Atmospheric Testing and Ventilation. The atmosphere within a bin, silo, or tank that is to be entered should be tested for the presence of combustible gases and toxic agents whenever the employer or employee has reason to believe that they may be present. Further, the atmosphere should be tested for oxygen content unless there is an adequate amount of forced-air ventilation through the structure before and during the period employees are inside a bin, silo, or tank.

Personal Protection Equipment. Employees entering bins, silos, or tanks from the top should wear a body harness with lifeline, or use a boatswain's chair meeting OSHA requirements. Employers also must provide all necessary equipment for emergency rescue operations (Figure 3).

Observers. An observer equipped to provide assistance should be stationed outside the bin, silo, or tank during entry operations. Communication is to be maintained between the observer and the employee inside the bin, silo, or tank.

Preventive Maintenance

The standards require that employers implement a pre-

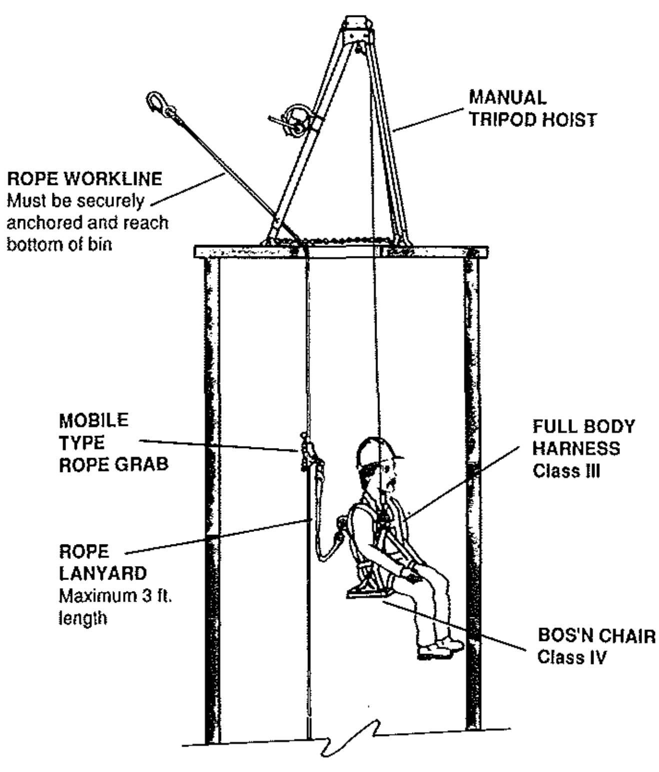

Figure 3. Bin entry equipment.

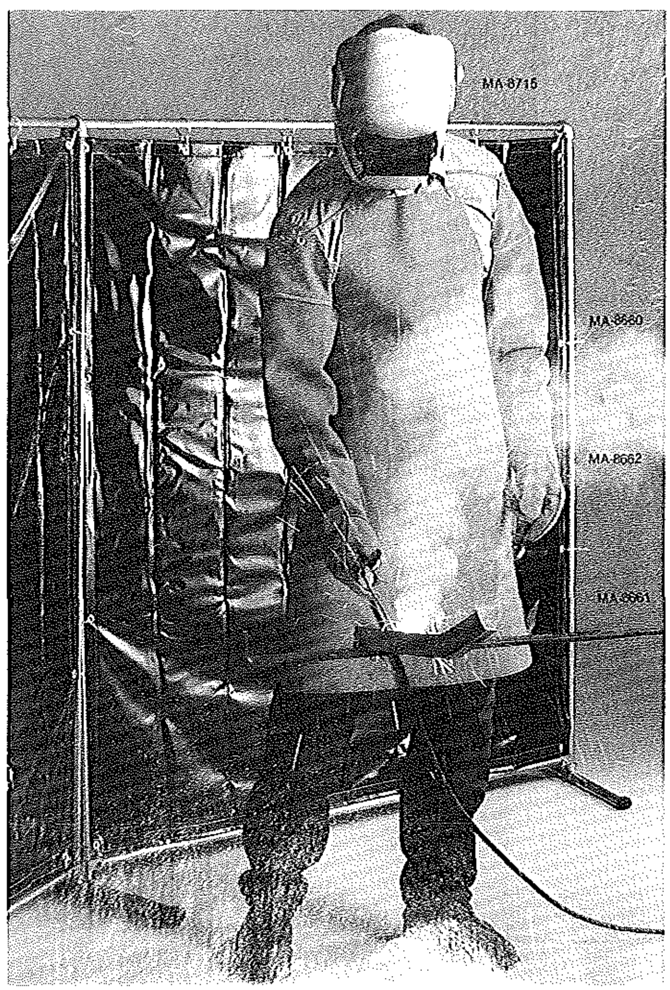

Figure 4. Welding performed inside the grain handling structure requires a permit.

ventive maintenance program consisting of:

1) regularly scheduled inspections of at least the mechanical and safety control equipment associated with grain cleaning and handling, including personnel elevators or manlifts; and
2) lubrication and other appropriate preventive maintenance in accordance with manufacturers' recommendations.

Hot Work Procedural Requirements

Employers are required to issue a permit for all hot work performed inside a grain handling structure unless the employer or his representative is present while the hot work is performed. The standards require that the employer informs contractors about known potential fire and explosion hazards related to the contractor's work and work area and the applicable safety rules of the facility, including emergency procedures (Figure 4).

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11

How to Sample Grain for Insects[1]

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Introduction

Throughout the marketing system, sampling for insects often has been limited to counting the number of adult insects in the grain samples that are taken for the purpose of grain grading. Samples from several locations in the grain mass are combined into a composite sample and a subsample is examined to determine grade factors (USDA 1983, 1988).

Special care is taken in deciding where to take samples and in designing equipment used to subdivide samples to ensure that the subsample will be representative of a lot of grain. The grain trier (Figure 1) was developed to remove enough grain to provide a representative sample of grade factors.

Grain grading involves removing several kilogram samples of grain to determine physical characteristics of the grain—test weight, moisture, class, shrunken and broken kernels, fines, and foreign material. However, most of these grade factors are more evenly distributed in grain than insects. Thus, these samples cannot provide a representative sample of insect populations.

A greater proportion of the grain needs to be sampled by taking more or larger grain samples to estimate insect population size. Insect populations can increase rapidly and change more quickly than other grade factors. Therefore, grain must be sampled more frequently to ensure that infestations have not reached damaging levels. Models predicting insect population growth can be used to reduce the frequency of sampling. However, improvement of insect pest management will require new sampling programs better suited to estimating insect population size.

Sampling Devices

A variety of devices have been developed for taking grain samples and separating insects from grain. The devices most commonly used are the grain trier[2] and the pelican sampler[2] (Figure 1). The grain trier generally is used to take samples from grain being stored in bins or transported in trucks and railcars, while the pelican sampler is used to take samples from a moving grain stream as grain is loaded or unloaded. The pelican sampler often is automated so that samples are taken at regular intervals from the grain stream, then pneumatically conveyed to the grain inspection laboratory.

The vacuum probe[2] is another sampling device that was developed to more easily take larger samples from deep within the grain mass. The vacuum probe pulls air,

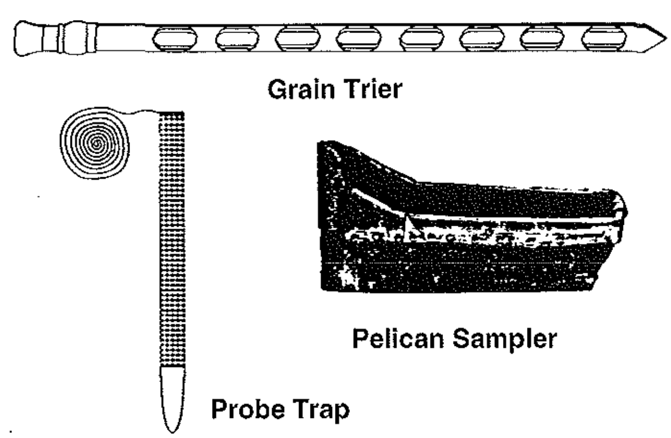

Figure 1. Sampling devices.

[1] Mention of a proprietary product in this paper does not constitute an endorsement of this product by the U.S. Department of Agriculture or Oklahoma State University.

[2] Equipment available from Seedburo Equipment Company, 1022 West Jackson Blvd., Chicago, Illinois 60607.

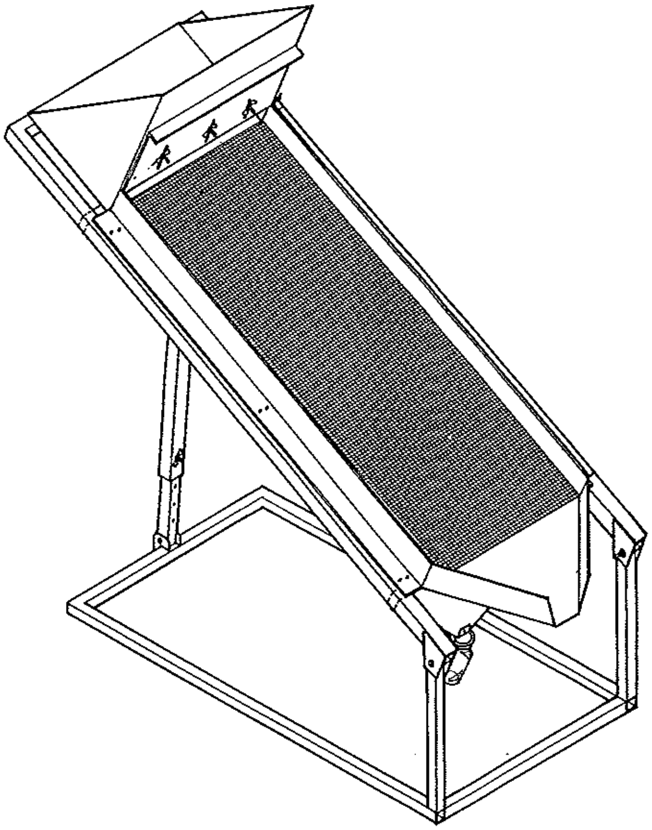

Figure 2. Inclined sieve.

carrying the grain up through an inner tube. Replacement air passes down between this tube and an outer tube. The air with grain then passes into a cyclone collector which allows the grain to fall out.

Insects are usually separated from small grain samples with a hand sieve[2] or from large grain samples with an inclined sieve[3] (Figure 2). Insects will be easier to remove if the layer of grain on the sieve is no more than one-half inch thick. Shaking the hand sieve 20 to 30 times, or three passes over the inclined sieve, will remove the majority of insects.

Insect traps specifically designed for sampling grain insects, such as probe traps[4] (Figure 1), are also available. The probe trap is a perforated tube which is pushed vertically into the grain. Insects moving through the grain are trapped in a collection vial when they fall through the holes in the tube. A new method of acoustical detection[3] under development uses insect sounds to automatically monitor both internal and external feeding insects. This diversity of sampling equipment can provide many options for improving insect detection and for monitoring changes in population size.

Number of Samples

With the small portion of grain inspected for insects, it is often possible to detect the presence of insects, but to inaccurately estimate insect densities (Hagstrum et al. 1985). More samples are needed to accurately estimate insect population size. Management decisions often are based on detection alone and assume that the probability of detection is directly related to insect density.

The number of one-kilogram samples of grain required for 95 percent certainty of detection decreases rapidly as insect density in the grain increases (Table 1). The probability of detection also increases as more samples are taken. For instance, if only one sample is taken, the probability of detecting a mean density of two insects per kilogram of grain is only 76 percent. When 10 samples are taken, there is a 100 percent probability that an insect infestation with a density of two insects per kilogram will be detected.

Increasing the number of samples also increases the accuracy of the estimates (i.e., the probability of estimates being close to the actual mean insect density) (Figure 3). With only one sample, estimates of a population with an actual mean density of two insects per kilogram can vary from 0 to 4.3. Increasing the number of samples narrows the range of estimates of insect population density. With fewer samples, a manager could either underestimate populations and not apply control when it is needed, or

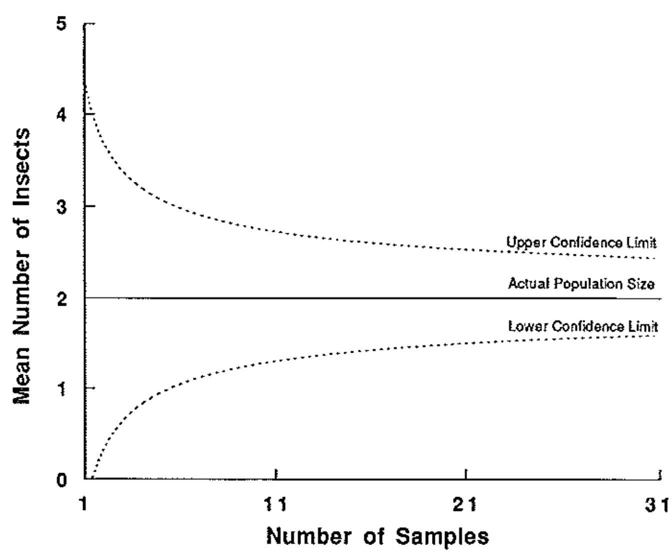

Figure 3. Variation in population estimates in relation to number of samples.

[3] Equipment not commercially available.

[4] Traps available from Trecé Incorporated, P.O. Box 6278, Salinas, California 93912.

Table 1. Probability of detection[a] for insects in stored grain in relation to the number of samples and insect density.

Number of Kg Grain Samples per 1000 Bushels	Mean Number of Insects per Kilogram of Grain					
	0.02	0.06	0.2	0.6	2.0	6.0
1	0.02	0.06	0.19	0.43	0.76	0.95
2	0.04	0.12	0.34	0.67	0.94	1.00
5	0.10	0.28	0.64	0.94	0.99	1.00
10	0.19	0.48	0.87	1.00	1.00	1.00
25	0.42	0.80	0.99	1.00	1.00	1.00
100	0.89	1.00	1.00	1.00	1.00	1.00

[a] Calculated at the 95 percent level.

Table 2. 95 percent confidence intervals for insects in stored grain in relation to the number of samples and insect density.

Number of Kg Grain Samples per 1000 Bushels	Mean Number of Insects per Kilogram of Grain					
	0.02	0.06	0.2	0.6	2.0	6.0
1	±0.07	±0.15	±0.33	±0.67	±1.49	±3.07
2	±0.05	±0.10	±0.23	±0.47	±1.05	±2.17
5	±0.03	+0.07	±0.15	±0.30	±0.66	±1.37
10	±0.02	±0.04	±0.10	±0.21	±0.47	±0.97
25	±0.01	±0.03	±0.07	±0.13	±0.30	±0.61
100	±0.01	±0.01	±0.03	±0.07	±0.15	±0.31

overestimate insect population density and treat the grain unnecessarily. Thus, the confidence intervals for estimates are important in determining whether enough samples have been taken to make a correct management decision.

The number of samples needed to estimate populations within plus or minus the value of the mean decreases from 10 to 1 as the mean insect density increases from 0.02 to 0.6 insects per kilogram of grain (Table 2). Tables 1 and 2 allow us to determine the minimum number of samples needed to detect the lowest density of insects that is of interest, or to estimate densities of insects with the desired accuracy. These tables are generally based on fewer samples being required for uniformly distributed populations than aggregated populations, because the variation among samples decreases as the population becomes more uniform.

The distribution of insects among samples has been shown to be similar for most common species of stored-product insects in a number of diverse situations (Hagstrum et al. 1988). This similarity suggests that these tables may be applicable to many situations. A sufficient number of samples needs to be taken to accurately estimate insect populations at low densities, and thus make correct management decisions. Decisions need to be made while insect densities are low and there is still time to implement management action before damaging levels are reached.

Probe Traps vs. Grain Trier Samples

Probe traps exploit insect behavior to detect insect populations with less effort than grain sampling methods, such as grain triers, that determine the number of insects per volume of grain (Lippert and Hagstrum 1987). However, this exploitation of behavior results in a larger variation in trap catch. Much of this variation in trap catch is attributable to variation in trap efficiency (Hagstrum et al. 1990).

Table 3. Effects of sampling method and duration of trapping on probability of detecting a density of 0.2 rusty grain beetles per kilogram of grain.

Number of Probe Traps	Duration[a] of Trapping	Number of Trier Samples	Probability of Detection
1	1	1	0.19
1	5	5	0.64
2	1	2	0.34
2	5	10	0.87
5	1	5	0.64
5	5	25	0.99

[a]In days.

This variation often is due to environmental factors affecting insect behavior rather than actual changes in population density. Also, probe traps cannot be used when immediate estimates of insect density are required, such as when grain is arriving at an elevator.

Because insects move around in the grain mass, reasing the time that traps are in the grain is equivalent ncreasing the amount of grain that is sampled (Fargo et 1989, Cuperus et al. 1990) (Figure 4). Clearly, traps ɔture rusty grain beetles more readily than lesser grain 'ers. This difference is a result of the greater mobility of rusty grain beetle. Table 3 compares traps and grain rs as insect detection devices. Better estimates of ɜct population size also can be achieved by adjusting capture rate of probe traps for the duration of time the ıs are present in the grain.

Sampling Program

Monitoring insect populations is a fundamental part of managing stored grain. In designing a sampling program, stored-grain managers must consider the number of samples, the choice of sampling device, the locations at which samples will be taken, and the frequency of grain sampling. Decisions about these factors are not independent. If large numbers of samples are taken, managers can sample less frequently and still be confident that insect populations will not grow to unacceptable levels before they sample again.

The number of samples needed is determined largely by the distribution of insects in the grain. When insect densities are high, the sample-to-sample variation is low and fewer samples are needed to obtain the same accuracy (Table 2). However, more than the recommended number of samples may need to be taken to be sure that insects are detected throughout the grain bulk. At least five grain samples or probe traps should be used for sampling 1,000 or less bushels of grain.

For on-farm storage, five grain samples or probe traps may be used in bins of up to 5,000 bushels. With newly harvested grain stored in clean bins, the majority of insects tend to be located in the top 1,000 bushels of grain (Hagstrum 1989). Thus, there is a definite advantage to taking samples in this top three feet of grain.

A typical sampling plan might involve placing one probe trap three inches below the grain surface in the center of the bin, and four other traps equally spaced halfway between the center and the bin wall. Interpretation of trap catch will be more accurate if traps are left in the grain a week or less.

If a grain trier is used instead of traps, samples would be taken at these same locations. Sampling should be repeated at 30-day intervals until grain cools below 20°C in the fall. Pelican samplers generally are more easily used to sample grain arriving at or leaving an elevator. The samples should be evenly spaced through the loading or unloading period.

Role of Sampling in IPM Decisions

The cost-effectiveness of management decisions is directly related to the quality of the sampling program. To minimize the cost of pest management, control decisions

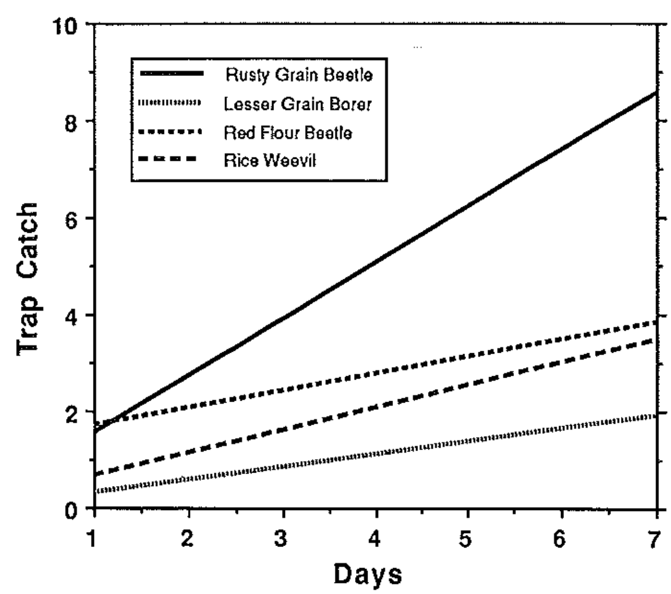

Figure 4. Increase in trap catch in relation to duration of trapping.

must avoid both unnecessary treatments and unacceptable insect population levels. Imprecise estimates of insect density can lead to incorrect management decisions and unnecessary expense. Accurate estimates of insect populations while densities are still low can increase the number of insect control options available.

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12

Stored Grain Management Techniques

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Stored-grain management is the organized, long-term approach to maintaining the post harvest quality of grain, minimizing chemical control inputs, and preserving the integrity of the grain storage system. To implement an effective management program and integrate management practices, operators must understand the ecology of the storage system. Through this understanding, techniques can be integrated into grain storage systems to prevent or minimize losses. These management techniques must focus on factors that regulate storability, including:

1) grain temperature;
2) grain moisture;
3) storage air relative humidity; and
4) storage time.

Grain Temperature—The Management Tool

Grain temperature is the major stored-grain management tool that regulates insects and molds. Harvest temperatures vary widely for grain and seed crops across the U.S. In northern states, grain is generally harvested later and can be stored at higher moisture levels than in southern states (Table 1). For example, corn harvest in the southern U.S. typically occurs from mid-July through September, but in northern states harvest is usually in October and November (Figure 1).

Producers and elevator operators in the north can cool grain much sooner after harvest than elevators in central and southern locations. Most insect and mold activity is greatly reduced at grain temperatures below 15°C (60°F). Planned temperature reductions by controlled aeration can significantly reduce insect populations (Figure 2). Mold populations follow similar temperature control pat-

Table 1. Maximum moisture contents for aerated grain storage.

Grain Type and Storage Time	Maximum Moisture Content for Safe Storage (Percent Wet Basis)		
	South	Central	North
Shelled corn and sorghum			
Sold as #2 grain by spring	14	15	15
Stored 6 to 12 months	13	14	14
Stored more than 1 year	12	13	13
Soybeans sold by spring	13	14	14
Stored 6 to 12 months	12	12	13
Stored more than 1 year	11	11	12
Wheat, oats, barley, rice			
Stored up to 6 months	12	13	14
Stored 6 to 12 months	11	12	13
Stored more than 1 year	10	11	12
Sunflower			
Stored up to 6 months	10	10	10
Stored 6 to 12 months	9	9	9
Stored more than 1 year	8	8	8
Flaxseed			
Stored up to 6 months	9	9	9
Stored more than 6 months	7	7	7
Edible beans			
Stored up to 6 months	14	15	15
Stored 6 to 12 months	12	13	14
Stored more than 1 year	10	11	12

Values for good quality, clean grain and aerated storage.

Note: Reduce one percent for poor quality grain, such as grain damaged by blight, drought, etc. Reduce each entry by two percent for nonaerated storage.

Adapted from MWPS AED-20.

terns. Aeration, the primary tool used to manipulate grain temperatures, is the forced movement of air through grain to lower or equalize grain temperatures. Although ambient airflow rates are generally too low to significantly change grain moistures, excessive aeration can reduce marketable grain weight.

Grain Moisture— The Storability Indicator

Grain moisture is the other critical grain management factor that regulates storability. Higher levels of grain moisture increase the potential for high populations of stored-grain insects and molds. To achieve safe storage moisture contents, forced heated or natural air drying of some crops is necessary, especially for corn harvested in the northern states, and rice in the southern states. At times, soybeans, wheat, and other small grains may also need to be dried during harvest.

Table 1 summarizes safe grain storage moisture levels for southern, central, and northern U.S. storage regions. As shown, grain is at higher risk in southern states than in central and northern states, due to longer periods of warm temperatures and higher relative humidity between harvest and aeration cooling. Thus, lower safe storage moistures are recommended for southern areas.

Because grain moisture and temperature influence mold and insect development, they must be considered in management. Table 2 gives estimates of the maximum expected storage life of corn at selected moisture and temperature levels. Corn stored continuously at these conditions are expected to lose one-half percent dry matter, which may reduce corn by one market grade or more, depending on other grading factors in the sample. **Note:** Table 2 is based on *constant temperature and moisture conditions.* In real life, conditions change over time and new conditions have to be considered with a specific percent of storage life already consumed. To use the table, multiple calculations are needed.

Example: Shelled corn harvested at 25 percent moisture and 60°F grain temperature is held for seven days in a wet holding bin, and then dried to 15 percent moisture and cooled to 40°F. What is the estimated storage time? At the end of seven days, 7/10 of 10 estimated storage days are used up, and 3/10 remain. The estimated storage time at 15 percent and 40°F is 1,398 days, but only 3/10 of that time remains because of the wet holding. Thus, the total estimated storage time of the shelled corn is 419 days (3/10 x 1,398 = 419) before one-half percent dry matter loss is expected to occur.

Stored-grain insect populations and mold growth accelerate rapidly under extended favorable growing conditions. As illustrated in Figure 3, if temperature and grain moisture levels are favorable, stored-grain insects and molds will increase in an exponential (accelerating, nonlinear) fashion. Managers must be aware of the increase

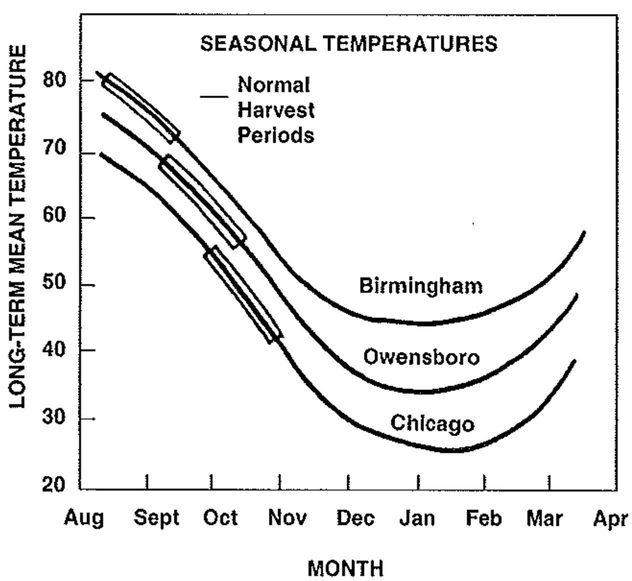


Figure 1. Mean temperatures and harvest dates at three latitudes approximately 250 miles apart.

Table 2. Estimated storage times for shelled corn

Temperature		Moisture Content (%)						
(°F)	(°C)	15	16	17	19	21	23	25
32	0	2,672	1,442	857	377	206	131	92
40	4	1,398	754	448	197	108	68	8
50	10	491	265	155	69	39	26	21
60	16	275	148	85	39	22	16	10
70	21	154	83	49	22	12	8	5
80	27	86	47	28	12	7	4	3
90	32	48	26	15	7	4	2	2
100	38	27	15	9	4	3	1	1

Sources: Data is from proposed ASAE Standard X535 and is calculated from equations presented in various sources including Steele et al. (1969), Thompson (1972), and Friday et al. (1989).

Notes:

1. Continuous aeration is required during the wet holding of shelled corn at and above 18 percent moisture content and with grain and/or air temperatures above 80°F (27°C).
2. Estimated time for corn held at *constant temperature and moisture* during which one-half percent dry matter loss is expected to occur.

in risk, based on the time the product has been stored at grain temperatures and moisture levels suitable for growth.

In Figure 3, the Hagstrum and Flinn (1990) model predicts effects of two grain moisture and two grain temperature levels on insect populations in wheat aerated by a selected target date of October 1. These projections closely model field experience during the past decade in southern high plains wheat storage systems.

Moisture Migration—The Product of Non-Equilibrium Conditions

Grain at suitable uniform moisture and temperature levels can be stored safely. But, maintaining grain storage temperatures within an acceptable range requires close management or thermally insulated storages. When grain is stored at safe moisture levels but is not aerated, moisture

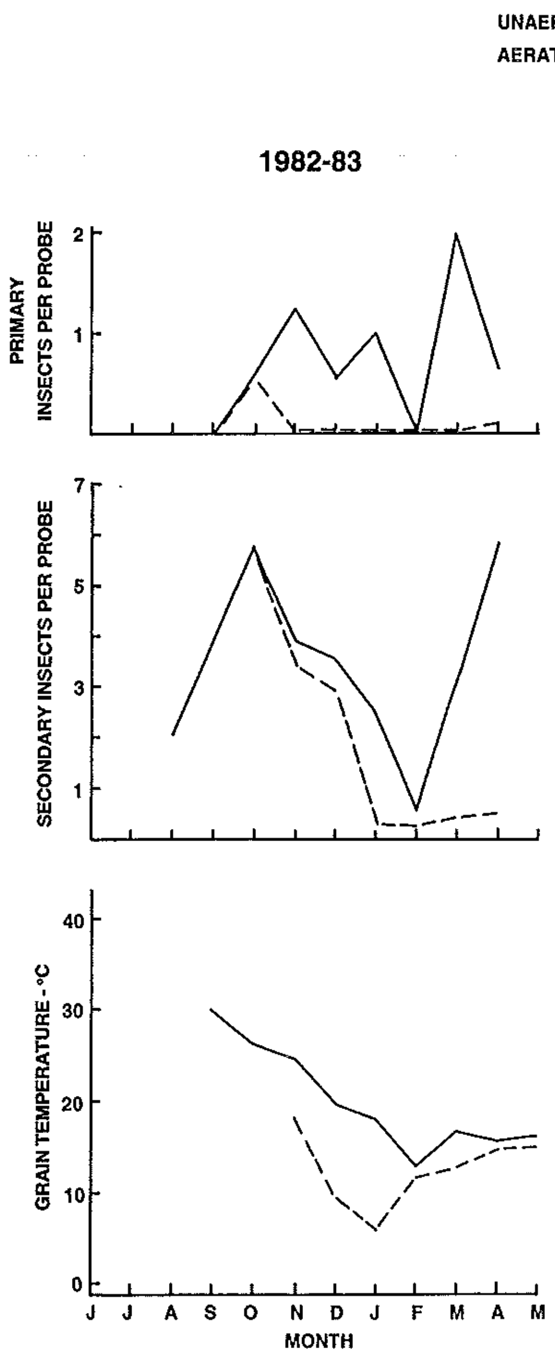


Figure 2. Comparison of aerated to unaerated wheat storage effects on insect populations.

movement, commonly called *moisture migration,* can develop from one part of the storage to another.

Moisture migration is caused by significant temperature differences that develop within a grain mass. Cold weather causes temperatures in the outer two to three feet (top and sides, and bottoms in storages with ducts or plenum floors) of a grain mass to cool significantly faster than the grain closer to the center. This temperature differential results in slow-moving convection air currents (Figure 4). Cold, dense air settles by gravity through the cold, outer grain. The air warms and expands as it moves inward near the bottom of the storage, and then rises in the inner grain mass. As air warms, its relative humidity (R.H.) drops. For each 0°C (20°F) rise in temperature, the percent R.H. is cut in half. Air at 0°C (32°F) at 80 percent R.H. will drop to 40 percent R.H. when warmed to 11°C (52°F).

As grain is dried slowly and/or aerated, its moisture content comes into equilibrium with the surrounding air temperature and relative humidity of the drying or storage environment. Figures 5 through 10 illustrate moisture equilibrium conditions for several common grain types. If temperature increases at a constant R.H., the grain's equilibrium moisture content (EMC) will decrease. If R.H. increases at constant temperature, EMC will increase.

As shown in Figure 5, corn stored at 15 percent m.c., wet basis and 10°C has an equilibrium relative humidity of about 68 percent. Following excessive aeration, if the corn temperature is still 10°C, but the grain intersticial relative humidity is measured at 60 percent, the grain moisture level has reduced to about 13.5 percent. Thus, knowing the relationship between EMC and air conditions is important in properly managing aeration systems to prevent overdrying or condensation.

When cold air moves through warm grain, it warms and absorbs moisture. As this warm, moist air moves up to the grain surface, it cools to "dew" point or saturation. This means the air is at 100 percent R.H., cannot hold more moisture, and begins condensing moisture on colder grain

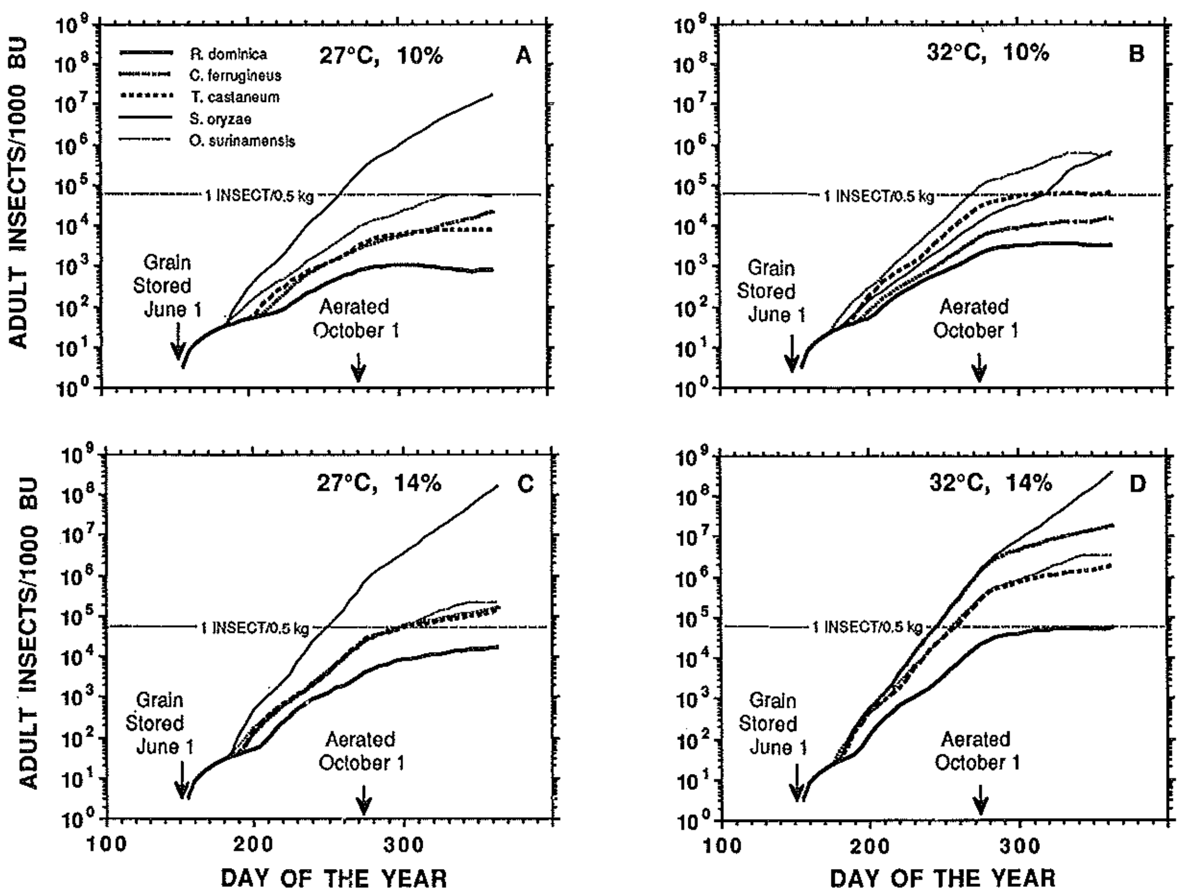


Figure 3. Predicted effects of initial temperatures and percentage of grain moistures of A) 27°C and 10 percent, B) 32°C and 10 percent, C) 27°C and 14 percent, and D) 32°C and 14 percent on the population of growth of five species of stored-grain insects with grain aeration completed on October 1. (Source: Hagstrum and Flinn, 1990.)

near the surface. Warm headspace temperatures activate molds, causing grain to crust and seal over. This process, called *top crusting* (Figure 4), can occur even when grains were initially stored at "safe" grain moistures of 9 to 11 percent, if grain is not properly managed and aerated or turned. Top crusting can also be caused by high humidity headspace conditions, which occur when warm air is exhausted from the grain mass during cold weather.

This situation is typical when corn is transferred hot from a dryer to be cooled in-bin. Significant condensation occurs on the bin walls and roofs, and extended fan operating time is needed to prevent excessive dripping. Increased moisture levels in the top layer of a grain mass are also caused by leaking roofs and hatch covers that allow rain and snow to enter the headspace and condensation from downspouts. If the grain absorbs excessive amounts of moisture, it will begin to mold, spoil, and crust. The development of hot spots in storage is a typical indicator of grain spoiling due to excess moisture.

Management Systems

Specific post-harvest grain management systems require different levels and amounts of management input and time. Elevator operators and producers must develop grain storage management strategies, depending on their location, facility, product, and harvest time (Noyes et al. 1989-A, B 1990; Weinzierl et al. 1990; Steffey et al. 1994).

SLAM

An excellent preventive post-harvest crop management approach is the *sanitize/seal, load, aerate, monitor* (SLAM) concept. Breaking these four key management strategies into working components, these stored-grain management strategies should include the steps listed below.

Sanitize/seal all your facilities and handling equipment. This involves:

- *Housekeeping*—clean bin aeration ducts and unload auger trenches, where insects thrive on grain dust and foreign material.
- *Cleanup*—cleaning out insect harboring locations, such as weeds, trash, and moldy grain in and around storages, and disinfecting and fumigating empty bins pays dividends.
- Empty tank or silo pesticide spray and fumigation is very important if aeration ducts and unload augers are not cleaned and vacuumed.
- Sealing tank, bin, or silo base openings to provide barrier protection against insect entry at all locations below the roof eaves (**Note:** Roof blowers/vents should be left open except when fumigating.

Load storages using cleaning, coring, and leveling.

- *Cleaning* removes grain dust and fines that insects and fungi thrive on and improves aeration.
- *Coring* grain bins and silos involves operating each storage unload conveyor to pull the peak down about half way and remove the central core of fines, trash, and foreign material to make aeration easier and to remove an insect attractant.
- *Spreading/leveling* clean grain makes it much easier to manage.

Aerate grain to safe and equalized temperatures by:

- Managing aeration systems using automatic aeration control;

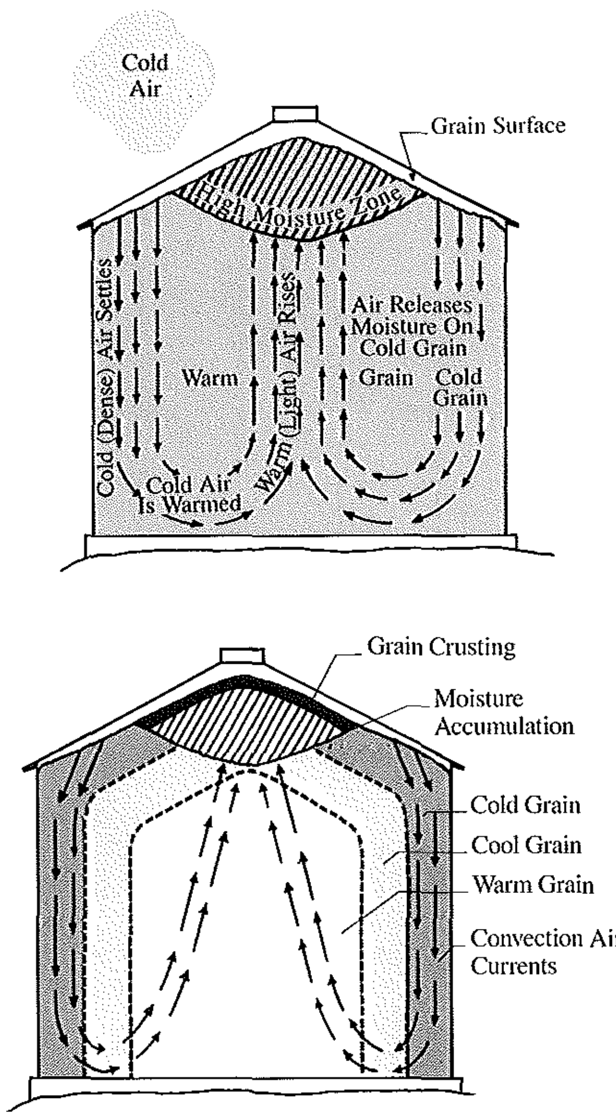


Figure 4. Example of moisture migration in grain stored several months without aeration.

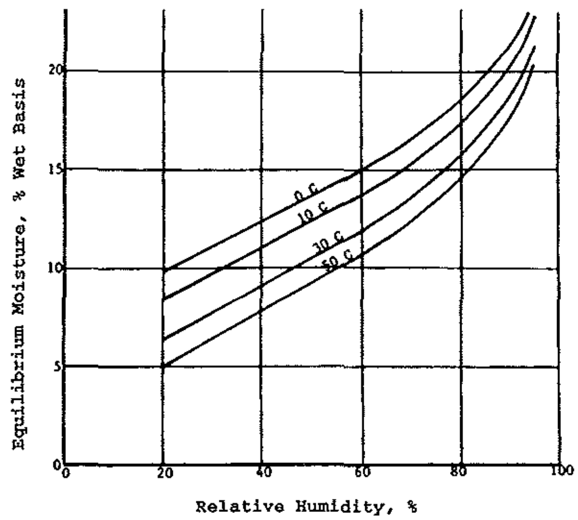


Figure 5. Equilibrium moisture content, yellow dent corn.

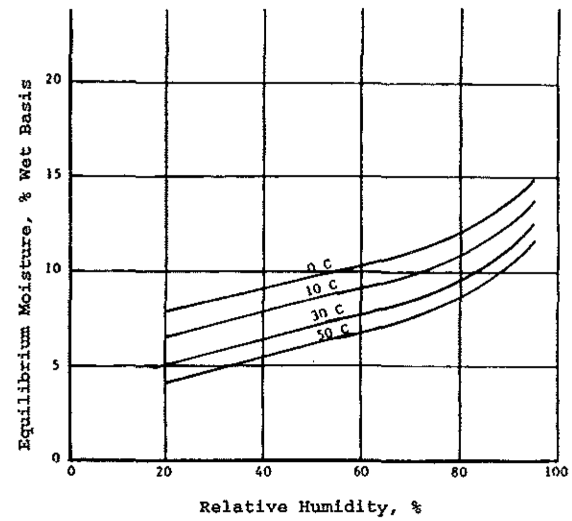


Figure 6. Equilibrium moisture content, peanuts in pods.

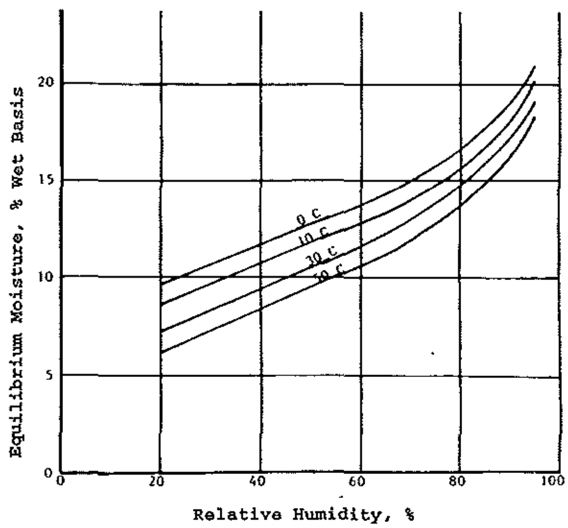


Figure 7. Equilibrium moisture content, rough rice.

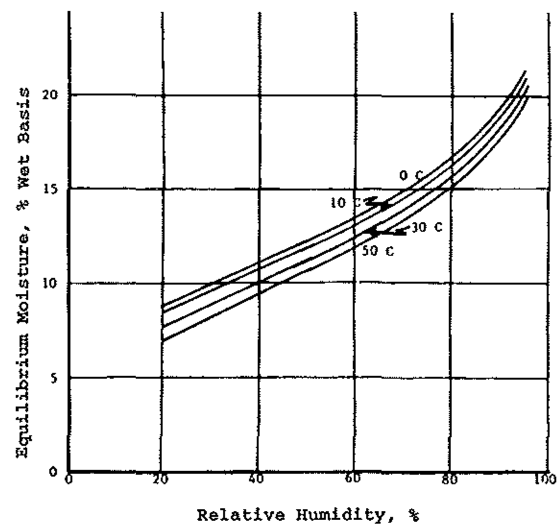


Figure 8. Equilibrium moisture content, sorghum.

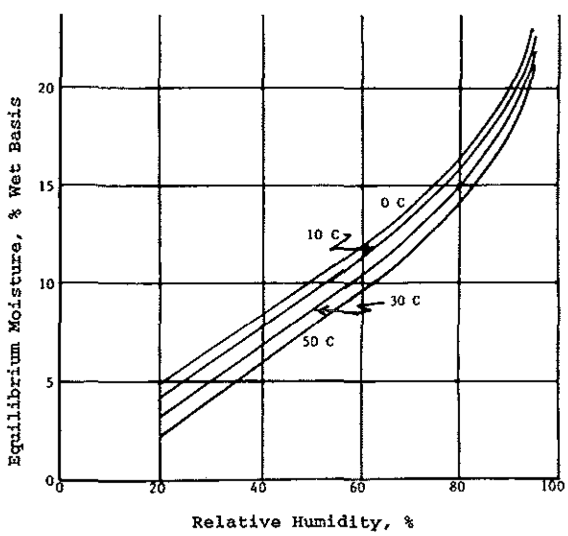


Figure 9. Equilibrium moisture content, soybean.

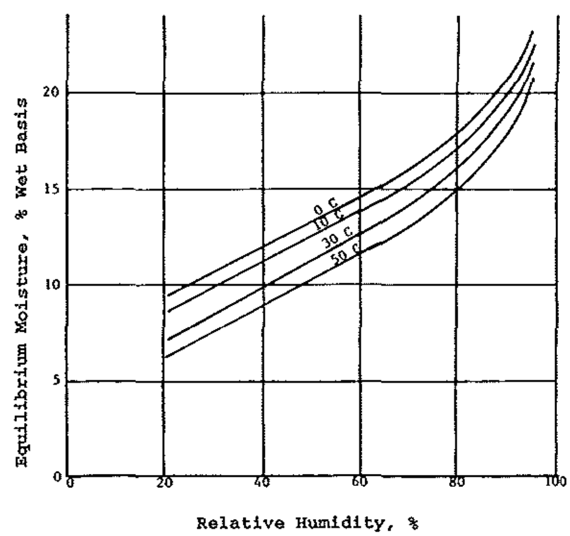


Figure 10. Equilibrium moisture content, hard wheat.

- Maintaining grain temperatures above or below the optimum insect feeding and breeding range of 21 to 32°C (70 to 90°F); and
- Using aeration as part of IPM systems—aeration is a major grain management tool of the future.

Monitor and protect grain in storage using:
- Temperature cable thermocouple readouts;
- Scheduled grain and insect sampling/monitoring;
- Protectant top dressing as needed;
- Fumigation as needed based on economic threshold; and
- Aeration or grain turning when/if hot spots are detected.

When coordinated, SLAM management strategies will help maintain grain quality, minimize marketable moisture weight loss, reduce costs, and preserve product integrity. Key management factors include monitoring grain moisture and temperature, insect and mold populations, checking stored products, and use of aeration.

The bottom line—manage the grain in storage just as intensely as producers manage field production using SLAM stored-grain management principles. If each bin had a bucket with $10,000 hanging from the thermocouple cable, grain managers would check each bin daily. Treat stored grain as a cash asset, and it will be cash in the bank.

The following sections discuss these major SLAM grain management strategy elements in greater detail.

Controlled Aeration—The Insect and Mold Management Tool

Aeration systems are used to manage grain temperature by cooling grain to uniform temperature levels in the fall, winter, and early spring. During aeration, grain moisture content is reduced by about 1/3 to 1/2 percent during one fall aeration cooling cycle, and 1/4 to 1/3 percent during one winter cooling cycle. Insect activity and mold growth can be minimized or controlled by strategic use of aeration to lower and equalize grain temperature. Fall and winter grain cooling is critical in eliminating moisture migration and reducing the risk of insect and mold damage.

Aeration is most effective for the control of insects and molds when grain temperatures can be reduced to an optimum storage level as early as possible following harvest. For wheat in high plains states, this may mean cooling stored wheat to 15 to 17°C (60 to 65°F) between mid-September to mid-October in north Texas, Oklahoma, and Kansas. Grain that is to be stored through the following summer in the central and southern U.S. before it is used should be cooled a second time to -1 to 5°C (30 to 40°F) in December through February to equalize grain temperatures, prevent moisture migration, and provide more cold grain for insect protection during warm summer months.

If grain will be marketed in early spring and average winter temperatures do not drop below -1 to 5°C (30 to 40°F) (as is often the case with hard red winter wheat in Kansas or Oklahoma), one fall aeration may be sufficient to manage insects and molds. By avoiding a second aeration in winter with an added 1/4 to 1/3 percent moisture shrink, about 0.25 to 0.35 percent more weight is available for marketing. On 100,000 bushels of $3 per bushel wheat, savings include $800 to $1,100 in marketable weight plus considerable labor, electrical power, and equipment maintenance costs.

Running a partial cooling cycle in late winter or early spring may be feasible with pressure (up-flow) aeration systems. This may be desirable where grain at the surface and outer walls exposed to the sun has warmed, but most of the grain mass is still cold. Running aeration fans about 15 to 25 percent of the normal aeration time when outside air temperatures are as cold or colder than the center grain will re-cool the surface grain and partially re-cool the sidewall grain with minimal grain moisture loss. This may be desirable when grain will be stored into summer months.

To prevent moisture migration, a second aeration cycle is often necessary in mid-winter in corn, wheat, and soybeans in the north central states, due to greater temperature differentials between center and outer grain. Although past aeration recommendations in the central and northern states have been to aerate whenever average outdoor air temperatures are 5 to 8°C (10 to 15°F) cooler than grain mass temperatures, this is a difficult condition to monitor and achieve.

Table 3. Recommended minimum airflow rates for aeration.

Crop	Moisture Content	Cfm/Bu. Range
Shelled Corn, Sorghum	14 percent and below	1/10 to 1/4
	15 to 16 percent	1/4 to 1/2
	18 percent +	1/2 to 1
Wheat, Oats, Barley, Rice	13 percent and below	1/10 to 1/4
	14 to 16 percent	1/4 to 1/2
	17 percent +	1/2 to 1
Soybeans	10 to 11 percent	1/10 to 1/4
	12 to 13 percent	1/4 to 1/2
	14 percent maximum	1/2 to 1
Sunflowers	8 to 9 percent	1/10 to 1/4
	10 to 11 percent	1/4 to 1/2
	12 to 13 percent	1/2 to 1

Source: Stored Grain Management Handbook, Kansas State University.

Table 4. Approximate aeration fan horsepower per 1,000 bushels - wheat/sorghum.

Grain Depth (Feet)	Cfm/Bu. 1	3/4	1/2	1/4	1/10	1/20
15	1.65	1.11	.47	.11	.040	
20	2.99	1.91	.79	.20	.050	.020
25	6.80	3.33	1.26	.30	.065	.024
30	9.50	5.22	1.92	.45	.080	.029
35	13.88	7.08	2.79	.65	.010	.034
40		9.51	3.68	.87	.14	.040
45			5.16	1.16	.16	.048
50			6.33	1.34	.19	.057
60			9.55	2.06	.28	.076
70				2.82	.39	.096
80				3.64	.50	.13
90				4.95	.66	.17
100					.79	.20
110					1.04	.26
120					1.27	.34

Source: USDA MRR No. 178 and Farmland Industries.

Table 5. Approximate aeration fan horsepower per 1,000 bushels - corn/soybeans.

Grain Depth (Feet)	Cfm/Bu. 1	3/4	1/2	1/4	1/10	1/20
15	0.61	0.31	0.13	.043	.020	
20	1.20	0.57	0.24	.06	.023	
25	2.50	0.95	0.39	.10	.028	.010
30	3.80	1.54	0.58	.14	.033	.011
35	5.50	2.20	0.84	.20	.038	.013
40		3.10	1.11	.25	.043	.015
45			1.55	.32	.052	.017
50			1.90	.41	.064	.018
60			2.86	.61	.097	.023
70				.90	.135	.030
80				1.25	.18	.038
90				1.65	.23	.046
100					.31	.054
110					.40	.096
120					.52	.126

Source: USDA MRR No. 178 and Farmland Industries.

If these guidelines were followed for corn or wheat in Nebraska, where average July air and harvested grain temperatures run about 26 to 29°C (78 to 85°F) and average January temperatures are about -1 to 2°C (28 to 34°F), grain would be aerated three to five times from harvest through mid-winter if aeration cycles were run every 5 to 8°C (10 to 15°F). Market grain weight losses would be 0.85 to 1.5 percent.

Grain managers may be able to reduce shrinkage and spoilage losses by paying closer attention to grain management during periods after the initial cool down. To see if grain in or near the surface is beginning to form a crust layer, grain conditions should be monitored carefully by probing all grain storage units with a rod at two to three week intervals in the winter and spring. If crusting is detected, aeration should be initiated immediately. If a million bushels are involved, $10-15,000 in shrinkage and electrical power may be saved by monitoring grain conditions and eliminating excessive aeration.

Recommended minimum air flow rates by crop for several moisture levels are listed in Table 3. Table 4 lists approximate aeration blower power (KW) per 1,000 bushels at specific airflow rates for a range of storage depths for wheat and sorghum. Table 5 lists similar data for corn and soybeans. Approximate cooling hours required for aeration at specific airflow rates for summer, fall, winter, and spring are listed in Table 6. Throughout the U.S., data indicate that many farm and elevator grain managers do not run blowers the correct number of hours.

Aeration is sometimes used to cool and equalize storage temperatures in the spring for long-term grain storage. In central and northern climates, grain cooled to sub-freezing temperatures is often warmed to temperatures of 2 to 7°C (35 to 45°F) to minimize condensation when grain is unloaded from storage in warm weather.

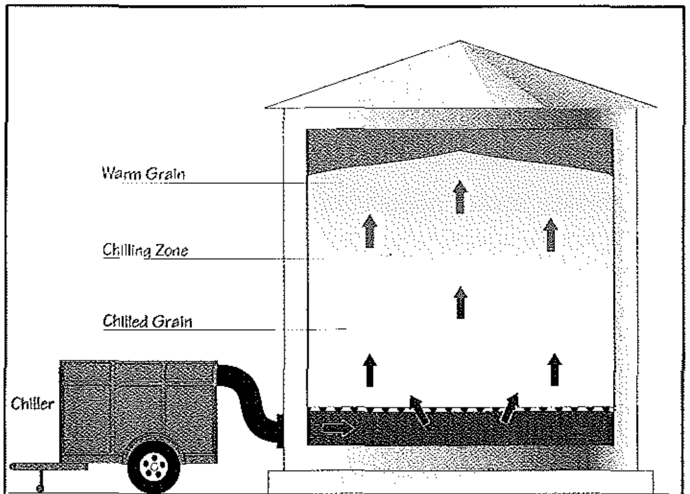
Table 6. Airflow rate, Cfm/bu. vs. cooling time.

	Low Aeration		Medium Aeration				High Aeration		
Cfm/Bu.	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1.0
	Hours*								
Summer	180	90	45	30	24	18	15	12	9
Fall	240	120	60	40	30	25	20	15	12
Winter/ Spring	300	150	75	50	40	30	25	20	15

* Assumes clean grain at safe storage moisture. Grain that is peaked and has foreign material concentrated under the fill point(s), cooling may require 50 percent additional time or more.

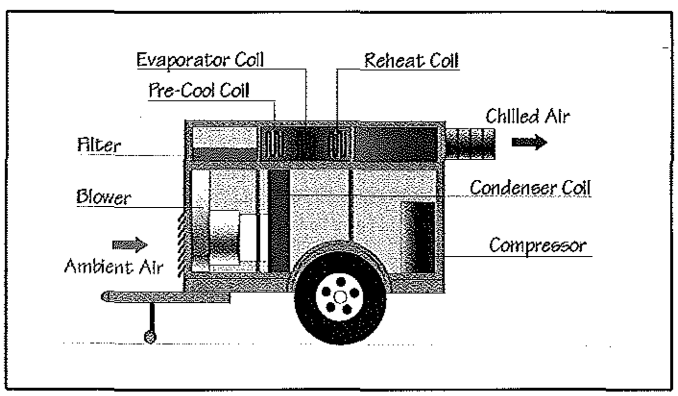
However, grain cooled by mid-winter to -1 to 3°C (30 to 35°F) in the northern and central U.S. generally does not need to be rewarmed in the spring, if it is marketed or fed before summer.

Caution: When grain is being warmed, some moisture absorption may occur. Moisture absorption by grain causes kernel swelling, which could lead to structural failure (bursting) if lateral grain pressures are not relieved by operating the unload conveyor periodically.



Chilled Aeration and Conditioning Process

11a.



11b.

Figure 11. Schematic of the grain chilling process. The binned grain is cooled independent of the minimum ambient temperature by using air conditioned to operator-selected temperature and relative humidity levels.

Aeration Controllers

The use of automatic aeration controllers to optimize aeration time should be a widely adopted stored-grain management technology. Simple aeration controllers with hour meters that operate fans based on a thermostat setpoint will provide precise fan temperature management. Some managers may want to control both high and low temperatures to keep the potential temperature differential to within 15 to 20°F. Humidistat controls add to the cost of controllers and are not necessary for most bulk storage aeration. Humidistats are difficult to maintain, limit the amount of usable cooling time, and generally cause more problems than they solve.

Automatic aeration controllers should control grain temperatures to within 2°C (5°F) of the controller's thermostat set points. Two to three aeration cycles may be needed to accomplish a desired grain temperature reduction using manually operated fans. With suitable cold air ambient temperatures, automatic aeration controllers can reduce grain temperatures by 17 to 22°C (30 to 40°F) in one cycle. *Simple aeration controllers usually pay for themselves in less than one year.*

Chilled Aeration—An Alternative

Conventional aeration systems are able to lower the grain temperature to within a few degrees of minimum ambient temperatures. In contrast, chilled aeration uses a refrigerated air system to cool grain or bulk products independent of minimum ambient temperatures. In a grain chilling system (Figure 11), ambient air is passed through ducts over refrigeration coils to decrease the air temperature. Because dry grain can absorb moisture from the cool moist air, the air is reheated a few degrees to reduce the relative humidity to 60 to 75 percent.

The amount of reheating and the final air temperature are adjusted by the operator for the desired stored grain temperature. Once the grain has been cooled initially, rechilling occasionally for short time periods is required to maintain the storage temperature conditions, due to the insulating properties of the grain. The ability to control the bin inlet air temperature and relative humidity is desirable for selected grain storage, such as cereal processing plants, where product value is relatively high. Grain chilling is currently used for storing wheat, sorghum, corn, popcorn, and rice in several commercial U.S. food processor facilities (Maier 1994).

Potential benefits include:

- reduced liability and improved worker safety due to reduced or eliminated chemical handling,
- less shrinkage,

- less spoilage potential,
- reduced insect damage, and
- lower drying costs.

Direction of Airflow Affects Grain Cooling

Aeration blowers operate effectively in either pressure (up-flow) or suction (down-flow) directions. However, when blowers push air through grain, the energy of compression adds heat to the ambient air. This is called "heat of compression." The amount of heat added depends on the airflow rate, resistance to airflow, grain cleanliness, and depth. An air temperature rise of 4 to 6°C (7 to 10°F) is common in deep steel bins or concrete silos with grain depths of 15 to 35 m (50 to 120 ft.) at airflow rates of 0.1 cfm/bu. in storages of small grains, such as wheat, sorghum, rice, or barley. Temperature rise in coarse grains, such as corn or soybeans, under similar depths, grain quality, and airflow conditions is roughly half that of small grains.

Even in shallow grain depths, a temperature rise of 2 to 3°C (3 to 5°F) from pressure systems can make a measurable difference in final storage temperatures. It is especially important to check the actual temperature of the cooling air at the outlet of pressure blowers on deep storages so that aeration controller thermostat settings can be adjusted to provide desired grain temperatures. Many grain managers are not aware of "heat of compression." Under extreme conditions, temperature increases from compression of 8 to 16°C (15 to 30°F) have been observed at blower static pressures of 15 to 20 inches water column (near blower stall conditions).

Suction (down-flow) systems pull headspace heat down through the grain mass. This is a short-term, periodic problem only when aeration blowers are started during the daytime. Once the blower has been operated long enough to exchange the under-roof airflow, the cooling air is essentially ambient. A problem with suction systems is that the blower will not move as many pounds of air under suction as it will under pressure due to reduced density. Suction systems require about 5 to 10 percent longer cooling times than pressure systems.

Thermocouples

A major tool for good aeration system management is a temperature cable monitoring system in each storage unit. There is no substitute for being able to check periodically on the grain temperature profile throughout each storage. This is analogous to a doctor taking the temperature of each patient as routine monitoring.

Thermocouple systems data is essential for all aspects of aeration management. In addition to vertical temperature profiles of a storage unit, thermocouple data can provide a picture of the lateral temperature profiles. Thus, the rate of grain warming across the grain mass at several levels gives an indication of whether and when a second aeration cycle may be needed.

Monitoring grain temperatures to check for hot spots and determining when cooling zones have moved completely through is essential to good grain management. Winter cooling generally requires 20 to 30 percent longer fan operation than fall cooling (Table 6), so keeping a record of aeration system hours of operation and monitoring the temperatures provides an excellent check on cooling conditions and helps prevent excess cooling.

Aeration Management by Geographic Region

To minimize insect population growth and inhibit mold development, operate aeration systems to cool summer and fall stored grains as soon as weather permits. Seal blowers after each complete aeration cycle to exclude insects, prevent cold air drainage, and reduce convection air currents (up-drafts) from open blowers at the storage base through roof vents.

Northern U.S.—Stored grain should be cooled to 2 to 5°C (35 to 40°F) by late fall or early winter. If grain is to be rewarmed in the spring, warming grain to temperatures of 7 to 10°C (45 to 50°F) by mid-spring should be sufficient to avoid moisture condensation problems in properly dried, good quality grain for storage through the following summer.

Central U.S.—Stored grain should be cooled to 5 to 10°C (40 to 50°F) by late fall or early winter. If grain is to be stored through the following summer, a second partial aeration cycle in late winter to early spring may be needed to stabilize grain temperatures at 7 to 13°C (45 to 55°F). Rewarming, especially in large storages, is generally not recommended if low-moisture grain is stored.

Southern U.S.—Maintain warm temperatures in low-moisture grain until suitable cold weather arrives. Reduce

Table 7. Airflow rates vs. roof vent area for U.S. regions.

	Airflow/Unit of Vent Area (cfm/ft^2)	
Type System	**Southern U.S.**	**Central/Northern U.S.**
Pressure (Up-Flow)	750-1,000	500 - 750
Pressure (w/Roof Fans)	750-1,000	500 - 750
Suction (Down-Flow)	1,000-1,250	750-1,000

grain temperatures from 30 to 35°C (85 to 95°F) to 13 to 19°C (55 to 65°F) or lower as rapidly as possible to inhibit insect population growth for summer harvested crops. One aeration cycle may be adequate to cool the grain by mid-October to mid-November.

Monitor exhaust air (suction cooling) and surface grain (pressure cooling) temperatures to determine when cooling cycles are complete. By late spring, weather conditions will be so warm that the rewarming of the outer 1 m (3 ft.) cannot be avoided. If holding for food or feed processing is planned through summer, recooling in late February and March to 5 to 10°C (40 to 50°F) may be advisable to equalize temperatures throughout the storage.

Roof Ventilation

Make sure roof exhaust or inlet vents, hatches, and roof eaves gap openings are adequate to allow the storage to vent humid air during pressure (up-flow) aeration or provide unrestricted fresh air inlet for suction (down flow) aeration. Push systems need a total roof opening area equivalent to about 0.1 m^2/KW (1 sq. ft. /HP) of fan power as a general design target area for roof vents. Recommendations for suction vs. pressure systems for three regions of the U.S are listed in Table 7.

Pressure systems require more total vent area than suction systems to minimize roof condensation. Pressure systems with roof ventilation fans will exhaust more total airflow than standard pressure systems, so vent cross-section area is based on combined airflow. Larger vents are needed in north central states for suction systems to minimize roof collapse systems caused by snow and ice buildup on vent screens (Noyes, 1991).

Storage Preparation, Housekeeping, and Sanitation

Good grain management starts with housekeeping and sanitation. Spilled grain, debris inside and around storages, tall weeds, and trash are all sources of insect infestation. If not kept clean, these areas serve as an attractant, food supply, and habitat for insects that will infest new grain. Before storing fresh grain each season, storage tanks, silos, bins, and buildings must be thoroughly cleaned inside and out. Follow these key housekeeping management guidelines:

- Vacuum grain/dust from aeration ducts, augers, bin wall supports, sidewalls;
- Spray inside and outside walls with a grain protectant to the point of runoff;
- Keep weeds mowed;
- Clear the ground for at least 6 to 8 m (20-30 ft.) beyond each storage unit;
- Kill all vegetation using a full-coverage herbicide;
- Dispose of all spilled, moldy, or leftover grain.

Seal Storage Base Openings

For best aeration results, seal all round steel tank and concrete silo base openings, including aeration blowers, augers, slide gate push rods, U-trough covers, foundation cracks, missing bolt holes, and sidewall doors. Sealing the base restricts insect access to the top of the structure where it can be more easily monitored. Sealing auger and blower openings prevents cold air from leaking out of the storage and warm convection air currents from moving up through the storage, which gradually reduces grain moisture. Use professional fumigation sealing materials. High-quality sealing tapes, adhesive sprays, foam sealants for roof, doors, eaves, adhesive paste, caulking beads, and plastic sheeting supplies are available from fumigation suppliers or commercial fumigators. Seal for non-leak fumigation; leave base storage openings sealed except when in use or when cleaning. *Note: Do not seal roof aeration exhaust or inlet vents except for fumigation. The storage must have free headspace air movement.*

Empty Bin Fumigation

Empty bin fumigation is an important component of long-term storage (9 + months for northern storage). For crops that are harvested, or that will be stored for more than six to eight weeks in warm weather (average temperature above 21°C or 70°F), fumigate empty storage volumes with chloropicrin (tear gas) or phosphine, especially if augers and aeration tunnels and ducts are not cleaned (Raney et al. 1987). Leave base and sidewall openings sealed year-round, except when using blowers during aeration or venting. After venting the fumigant from the storage, immediately reseal blowers to keep insects from entering the base area.

Conventional Fumigation

Fumigation functions are complemented by using a sealed aeration system management strategy. During fumigation, all base, sidewall, and roof openings must be tightly sealed. Poorly sealed storages cause immediate failure of the fumigation process. The sealed aeration system concept requires that all storage base openings be sealed and left sealed, except when operating blower or conveyor equipment. Fumigants perform better when grain temperatures are above 15.5°C (60°F), so fumigation should take place before fall or winter aeration in southern states, or in rewarmed summer-stored grain in the northern U.S.

Closed Loop Fumigation

Closed loop fumigation (CLF), continuous or intermittent forced recirculation of fumigant gases, started with methyl bromide in the 1920s. In April of 1980, James Cook of Houston, Texas, patented a phosphine gas recirculation CLF system. CLF uses a small volume blower, typically a 0.2 to 0.8 KW (1/4 to 1 1/2 HP) aluminum centrifugal blower, that moves about 8.5 to 25 m^3/min (300 to 900 cfm). CLF systems should be considered in future fumigation system planning for upright silos, steel tanks, and some flat storages, if the structures can be sealed. Chapter 20 provides a detailed discussion of closed loop fumigation.

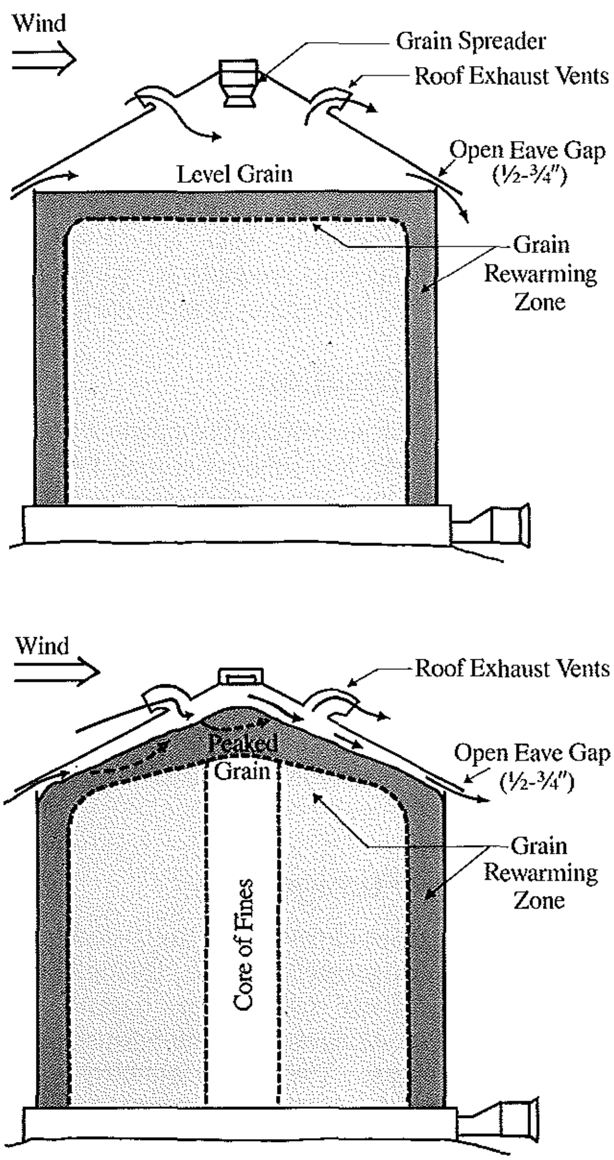


Figure 12. Peaked grain vs. level grain surface in storage bins.

Store Clean Grain

Grain with significant amounts of trash, broken kernels, grain dust, and foreign material increases the potential for insect and mold development due to lack of temperature control. Clean grain is easier to aerate and fumigate, and it carries a much lower management risk than grain with high dockage and foreign material. Cleaning may reduce aeration time by 25 to 50 percent.

Cleaning is most effective before loading dry grain into storage. Although drying efficiency of wet grains can be improved if cleaned before the dryer, the handling and disposal of wet cleanings may be practical only if it can be fed to livestock before spoilage.

Level Grain Surfaces

Storages with peaked grain [Figures 4 and 12 (lower)] are more difficult to manage than those tanks with leveled grain surfaces [Figure 12 (upper)]. Primary problems related to peaked grain surfaces are:

1) Peaked grain temperatures cannot be controlled—peaked grain is very difficult to cool, and after cooling it rewarms rapidly.
2) At least 30 to 50 percent more aeration time is required to cool storages of peaked grain, compared to grain with level or slightly inverted surfaces.
3) Grain protectants deteriorate more rapidly in hot, peaked grain.

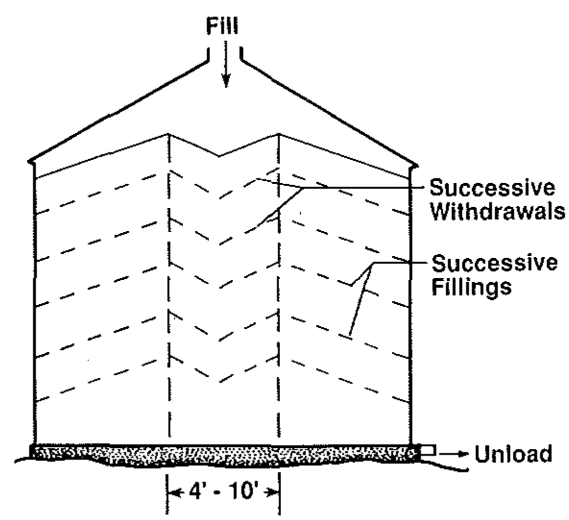


Figure 13. Withdrawals during filling remove most fines from the 4- to 10-foot core.

4) Grain that rewarms in peaks due to warm headspace temperatures provides an environment for insect and mold populations to accelerate.
5) Fumigation of peaked grain is more difficult and generally not as effective.
6) Peaked grain usually has a core of fines and foreign material (FM) down the center of the grain mass. This core of FM is difficult to cool, absorbs moisture more easily, and attracts and harbors insect populations.

Grain levelers or spreaders are used in drying bins and in the central and northern U.S. for corn storage, but they are not used much in wheat, sorghum, and other types of storage throughout the U.S. There a variety of gravity (non-electric powered) spreaders. Some gravity spreaders rotate as they distribute due to the grain volume and velocity. Electric powered units are less dependent on the volume of grain flow and are adjustable for tank diameter. Even simple, inverted cone spreaders help break up the core of fines under the fill point or spout line.

The most effective method for cleaning out concentrations of fines and trash in the center or core of bins with peaked grain is to unload the core from each 0.6 to 1.2 m (two- to four-foot) layer as tanks or silos are being filled or loaded. After the final fill layer, withdraw the peaked grain to form an inverted cone approximately half the bin diameter across the top (Figure 13). Level the grain or leave the depression.

An alternate approach is to fill the tank or silo completely before removing the core. Run the center unload conveyor to remove the peak and form an inverted cone of about half the bin or silo diameter. This process will remove a core of grain about 25 to 50 cm (10 to 20 inches) in diameter from the entire depth (plus the full core in the peak area) that contains a high concentration of grain fines. This will loosen the grain pack density and allow improved air penetration of the center of the grain mass, especially with the peak volume leveled off.

In summer-stored grains, coring should be completed shortly after filling the storages. In fall-stored grains, coring should be completed before aeration, and peaks should be monitored for self-heating. For multiple storages at one site, grain should be drawn from all tanks. If the cored grain cannot be sold or fed immediately and must be recycled into another storage unit, the high FM grain should be cleaned before transferring back into the same or other storage tanks.

To determine when the grain peak has been drawn out, scatter confetti or newspaper shreds on top of the grain peak about half way down the slope. Observing when the first pieces of paper appear will indicate that the peak is starting to come out. When the paper stops coming out, coring is complete. The inverted cone at the grain surface should be about half the storage tank diameter at that time.

Sampling/Monitoring

Monitor grain conditions and sample for insects and mold every three to four weeks and more often throughout the storage period if poor quality grain is stored or found. Fumigate if insects reach economic threshold levels. Economic thresholds are levels of insects that will likely cause significant economic losses if not treated. If a storage has an area of warm grain that's infested, complete fumigation may be required, if grain cannot be cooled to 60°F or turned. Deep cup probes, vacuum samplers, and insect traps can be used to determine the extent of insect infestations. Cylindrical pitfall probe traps (Chapter 11, Figure 1) are the most sensitive tools commonly used to detect insect infestations but are used only in surface grain.

Grain Turning

Grain turning has traditionally been used to manage grain stored in non-aerated silo storages. Turning disrupts insect and mold environments. Grain managers turn stored grain to monitor grain condition and quality, blend grain to meet market order specifications (such as protein content), reduce grain temperature, and manage grain moisture levels.

Grain management functions that may be incorporated during turning are: 1) inspection, 2) blending, 3) cleaning, 4) fumigation, and 5) cooling.

Grain is cleaned and cooled during turning by dropping it in thin streams from overhead bins or spouts to driveway dump pits with strong winds or high volume fans blowing through the grain stream. This allows cheat (chess) and other weed seeds, light chaffy trash and foreign material to be blown out of the grain stream. Besides direct cooling from cold wind, grain cooling is also achieved during direct contact with cold augers, belts, legs, and down spouts. Grain temperature drops of 2 to 5°C (5 to 9°F) per pass are reported during cold weather turning.

Economics of Grain Turning vs. Aeration

Besides significant costs that occur from additional grain damage and extra handling, turning is considerably less efficient and effective than aeration for grain cooling. It is estimated that direct and indirect expense and grain damage caused by "turning" are two to four times the cost of aeration. Turning is more labor-intensive due to the need for continuous monitoring of handling equipment. Grain may need to be turned three to six times to cool as much as it would be in one aeration cycle. Grain economic losses due to handling damage during turning are significant. According to a study at Oklahoma elevators (Noyes and Epperly 1991), the out-of-pocket operating costs are reported to be about 0.1 to 0.2 cents per bushel for wheat aeration, compared to 0.2 to 0.4 cents per bushel for turning.

Summary

Stored-grain management must be considered from a "systems" perspective. The procedures presented in this chapter have only a limited effect if individual steps alone are utilized. The most important factors of stored-grain management are experience, timely interpretation of data from monitoring storage conditions (grain moisture, temperature, dockage, and insect levels), and economic analysis of costs and benefits of specific stored-grain management decisions.

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13

Stored-product Insects and Biological Control Agents

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Insect Biology

Stored grain is subject to insect infestation and deterioration from molds and bacteria. High grain temperatures and moisture, along with dockage and broken kernels, provide conditions that accelerate mold and insect development. Many grain insects are good fliers and move to newly stored grain from fields and from infested grain bins. Insects can reach a high population size in unchecked grain bins, in subfloors or aeration ducts in bins, in equipment used to move grain, or in discarded refuse grain. These areas must be kept free of insects to reduce migration to newly harvested grain.

Grain insects move within the grain mass at a rate that is determined by the season and grain temperature. During the summer and fall, insect infestations are usually on the surface of the grain. In cold weather, insects congregate at the center and lower portions of the grain and may escape detection until high population numbers are reached.

The most favorable grain moisture range for stored-grain insects is from 12 to 18 percent. In many instances, insect infestation amplifies mold problems in grain by exposing otherwise hidden endosperm surfaces to molds, transporting mold spores to new areas in the grain, and encouraging mold germination in microhabitats made moist by insect metabolic activity. Indeed, insect and mold metabolic activity can raise grain temperatures to 110°F (43°C).

It is important to control insect population size before grain is irrevocably damaged by insect boring, feeding, and mold germination. Grain should be inspected every 21 days when grain temperature exceeds 60°F (15°C). Plastic pitfall traps should be checked for the species and numbers of insects, and grain temperatures should be monitored. The number of insects found in a trap should be recorded and charts constructed so that changes in population size can be easily noticed. Increasing numbers of insects indicate that management tactics need to be changed to prevent levels of infestation that damage the grain. Also, grain can be inspected by screening or sieving and searching in the screenings for insects, examining kernels for damage, checking grain for webbing, and investigating off-odors.

Some insects damage grain by developing inside kernels (egg, larvae, pupae), feeding on the inner endosperm, and producing holes in the kernel through which the adult insects exist. The cycle is repeated when the female lays eggs inside the kernels. The maize weevil, rice weevil, granary weevil, lesser grain borer, and Angoumois moth all develop inside the kernels. Other insect species do not develop within the kernels, although they may hide inside cracked grain, making detection very difficult.

Species such as the flat grain beetle, rusty grain beetle, and the foreign grain beetle feed primarily on mold. Other species such as the sawtoothed grain beetle, the red and confused flour beetles, the Indianmeal moth, and the larger black flour beetle feed on damaged grain or fines. Pest species vary in different parts of the U.S., although all stored-grain insects are capable of decreasing grain quality.

Insects damage grain by boring into the kernels and reducing grain quality through weight, nutritional, or quality loss; spreading and encouraging mold germination; adding to the fatty acid content of the grain; and leaving quantities of uric acid that cause grain rancidity. Insects also create fines and broken kernels when feeding that reduce air flow through grain and prevent proper aeration when fans are used. In addition, the presence of insects in a grain sample can cause cash discounts for the grain.

Two insects of any kind in 1,000g of wheat, rye, or triticale cause the grain to be graded as U.S. Sample grade, the lowest possible grade. In corn, soybeans, and sorghum, the tolerances for insect infestation are different. Grain may be designated as Sample grade if two weevils, one weevil and five other live insect harmful to stored grain (OLI), or 10 OLIs are found in 1,000g of corn or sorghum. Insect tolerances in finished commodities such as flour or cornmeal are stricter.

It is important to distinguish between species of stored-grain pests since the insects have different damage potentials, biologies, growing temperatures, moisture requirements, and reproductive potentials. Insect species create different types of damage and have different activity periods.

The following colored drawings are part of the USDA-Federal Grain Inspection Service (FGIS) Interpretative Line Slide Series for insects. Both the slides and caption cards are available through Seedburo Equipment Co., Chicago, Illinois. There are three categories in which an insect can be placed according to the FGIS insect tolerances for a grain:

- **LW** is a weevil or borer;
- **OLI** is an insect injurious to stored grain; and
- **NOLI** indicates that the insect is not counted toward the tolerance.

These pictures and caption cards provide a way of identifying the insect pests and include a description of their basic biology. Identifying insect pests is the first step in understanding and controlling insect problems in grain bins and commodity storage warehouses. Insect traps are useful in either grain storage bins or commodity storage warehouses for collecting insects for proper identification. A knowledge of insect biology and appropriate control strategies is necessary for Integrated Pest Management programs in both grain bins and commodity storage warehouses.

USDA-FGIS Interpretative Line Slides for Insects

Granary Weevil

Category: LW

Minimum Life Cycle: 28 days.

Distribution: Temperate zones; northern distribution; attacks cereal grains.

Biology:

Eggs: Up to 200 per female laid within grains.

Larvae: Within grains; can survive at least 10 weeks at 5°C.

Adults: Flightless; easily overwinter in unheated buildings and bulk grain.

Granary Weevil (*Sitophilus granarius*). The granary, rice, and maize weevils feed on both unbroken and broken grain kernels. The granary weevil is unable to fly. It can be easily separated from the rice and maize weevil in the adult stage by the presence of elongated pits on the surface of the thorax, and by the absence of flight wings and colored markings on the wing covers. It is tolerant of low temperatures and cold climates and is seldom found in semitropical areas. This weevil can subsist in nature on acorns (Figure 1).

(Slide and top caption courtesy of ICI Americas, Inc.)

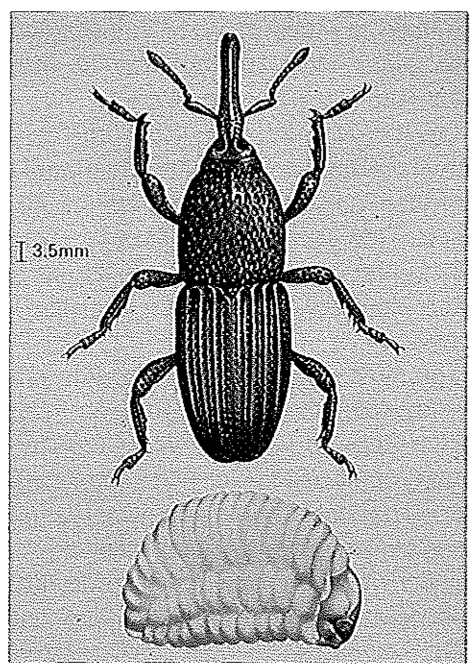

Figure 1. Granary weevil.

Rice Weevil

Category: LW

Minimum Life Cycle: 28 days.

Distribution: Tropical and temperate areas on cereal grains.

Biology:

Eggs: Laid in stored cereal grains and in cereals in the field by flying adults (more prolific than granary weevil).

Larvae: Feed in grain.

Adults: Also feed; cannot normally overwinter in temperate areas unless grain heats.

Rice Weevil (*Sitophilus oryzae*). The rice weevil is able to fly, has small round pits on the surface of the thorax, and red to yellow markings on the forewings. It is less tolerant of low temperatures than the granary weevil. It is widely distributed in both temperate and tropical regions where grain crops are grown and also may be found on acorns (Figure 2).

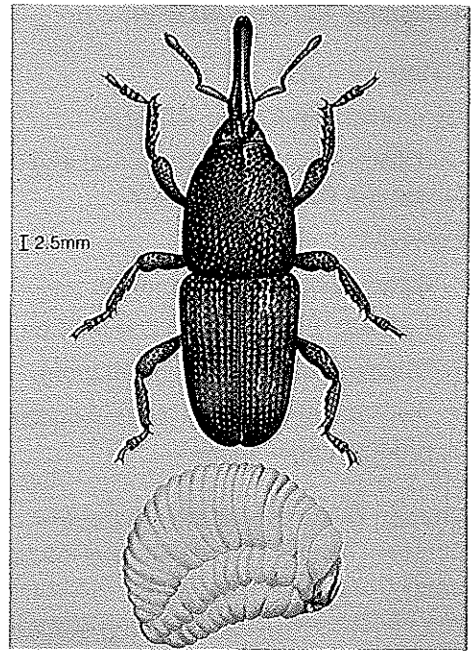

Figure 2. Rice weevil.

(Slide and top caption courtesy of ICI Americas, Inc.)

Maize Weevil
(with yellow blotches on forewings)

Category: LW

Minimum Life Cycle: 28 days.

Distribution: Tropical and temperate areas on cereal grains.

Biology:

Eggs: Laid in stored cereal grains and in cereals in the field by flying adults (more prolific than granary weevil).

Larvae: Feed in grain.

Adults: Also feed; normally cannot overwinter in temperate areas unless grain heats. Good flyer; larger than rice weevil.

Maize Weevil (*Sitophilus zeamais*). The maize weevil is slightly larger than the rice weevil and has more distinct colored spots on the forewings. It is a stronger flier than the rice weevil. The habits and life cycle are similar to the rice weevil (Figure 3).

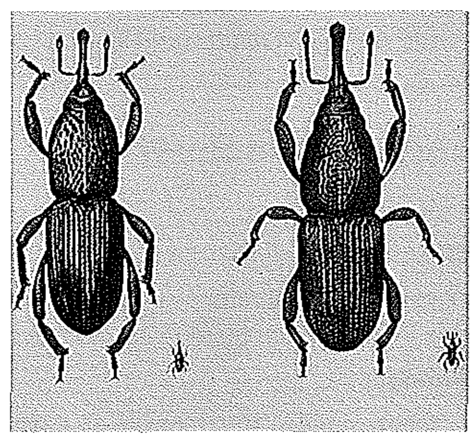

Figure 3. Maize weevil (with yellow blotches on forewings).

(Slide courtesy of Degesch Americas, Inc., and top caption courtesy of ICI Americas, Inc.)

Lesser Grain Borer

Category: LW

Minimum Life Cycle: 25 days.

Distribution: Worldwide; cereal and coarse grains; both adults and larvae are voracious feeders.

Biology:

Eggs: Up to 500 per female.

Larvae: Eat into grain and feed on grain dust.

Pupae: Usually form inside grain.

Adults: Also feed and are long-lived compared to other stored-product beetle pests.

Lesser Grain Borer (*Rhyzopertha dominica*). The lesser grain borer is a small, highly destructive insect that is related to certain wood boring insects. The eggs are laid outside the kernels and young larvae bore inside. Both the larvae and adults are voracious feeders and leave fragmented kernels and powdery residues. The larvae may complete their development in the grain residue. Grain infested with the lesser grain borer has a characteristic sweet and slightly pungent odor. This odor contains the male-produced aggregation pheromone that has been demonstrated to be an effective lure for use in traps. The insect is a strong flier and recently has been discovered in northern areas of the U.S. and in Canada (Figure 4).

(Slide and top caption courtesy of ICI Americas, Inc.)

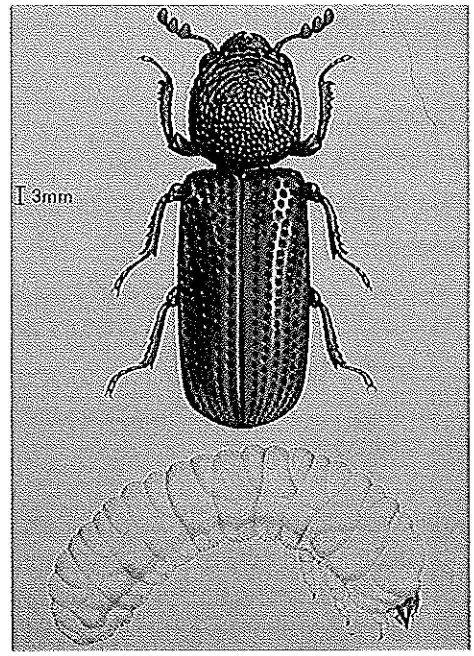

Figure 4. Lesser grain borer.

Larger Grain Borer

Category: LW

Minimum Life Cycle: 25 days.

Distribution: Central America, parts of Africa. Thirty-four percent loss in maize after three to six months storage.

Biology:

Eggs: Laid in stored maize on the cob or bulk maize.

Larvae: Feed on grain.

Adults: Feed on grain.

Larger Grain Borer (*Prostephanus truncatus*). The larger grain borer usually is restricted to corn (maize) and does not commonly occur north of Mexico. In recent years, new infestations have occurred in Africa. The insect is larger and darker in color than the lesser grain borer. It is extremely damaging to maize when dried and stored on the cob (Figure 5).

(Slide and top caption courtesy of GASGA Publication.)

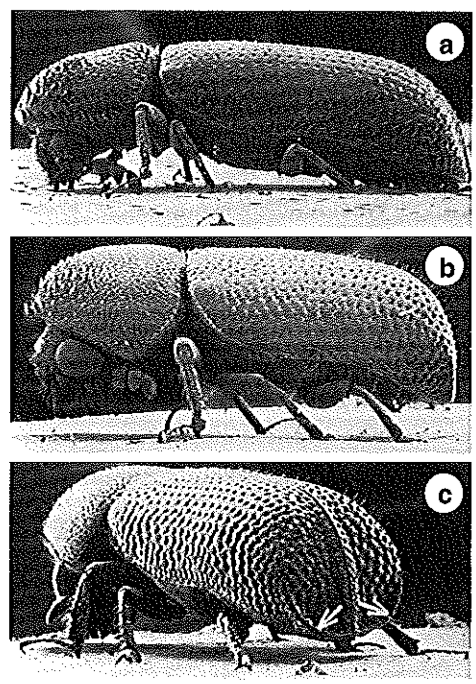

Figure 5. Larger grain borer.
a. Lesser grain borer.
b. Larger grain borer.
c. Larger grain borer (characteristic truncated posterier).

Angoumois Grain Moth

Category: OLI

Minimum Life Cycle: 28 days.

Distribution: Tropical grains (e.g., maize, paddy, sorghum); commonly attacks before harvest.

Biology:

Eggs: 40 to 150 eggs laid on grain surface.

Larvae: Bore into grain, staying until pupation.

Pupae: Form in grain.

Adults: Non-feeding; short-lived.

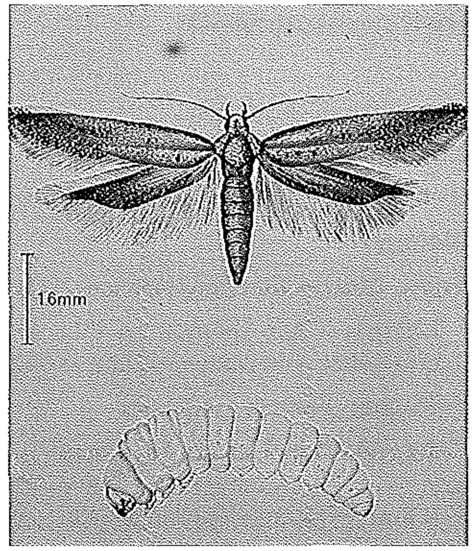

Figure 6. Angoumois grain moth.

Angoumois Grain Moth (*Sitrotroga cerealella*). The Angoumois grain moth is a former pest of crib-stored corn and can infest grain in the field. Modern harvesting and storage procedures have reduced problems with the insect. The moth is sensitive to low temperatures and is not common in the northern section of the United States. The adult moths do not feed (Figure 6).

(Slide and top caption courtesy of ICI Americas, Inc.)

Rice Moth

Category: OLI

Minimum Life Cycle: 42 days.

Distribution: General feeders on rice, cocoa, biscuits, and seeds.

Biology:

Eggs: 100 to 200 eggs laid near produce.

Larvae: Spin threads as they feed forming dense webbing.

Pupae: Found in food.

Adults: Non-feeding; one to two weeks.

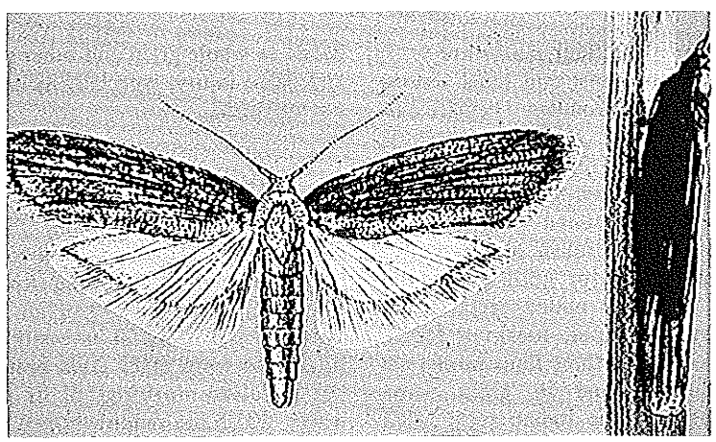

Figure 7. Rice moth.

Rice Moth (*Corcyra cephalonica*). The rice moth is similar in size to the Indianmeal moth, but is much less common. The larvae are general feeders and prefer warm climates (Figure 7).

(Slide and top caption from USDA-ARS Agric. Handbook No. 500.)

Indianmeal Moth

Category: OLI

Minimum Life Cycle: 26 days.

Distribution: Cereals, ground nuts, and dried fruits.

Biology:

Eggs: 100 to 300 eggs laid on or near produce.

Larvae: Spin threads as they feed forming webs; pre-pupal diapause particularly resistant to insecticide treatment.

Pupae: Form in foodstuffs.

Adults: Non-feeding; short-lived.

Indianmeal Moth (*Plodia interpunctella*). This moth is distributed in a wide range of climates, and is found in many types of foods and processing and storage facilities. The larvae are general feeders and the adults do not feed. The larvae produce a dense webbing. The adults have a distinctive forewing pattern with a light-colored base and a distal two-thirds area that may be red to copper colored (Figure 8).

(Slide and top caption courtesy of ICI Americas, Inc.)

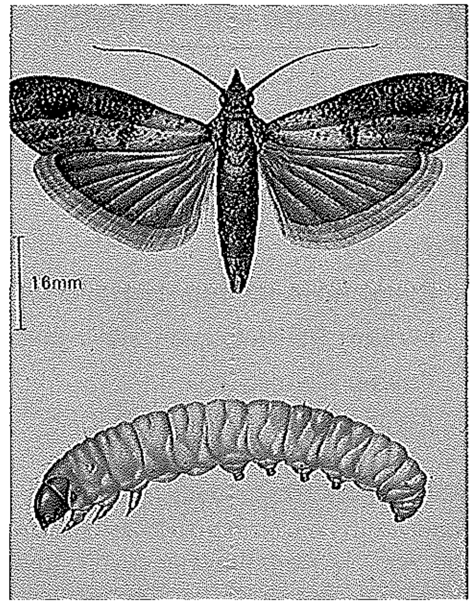

Figure 8. Indianmeal moth.

Mediterranean Flour Moth (Mill Moth)

Category: OLI

Minimum Life Cycle: One to six months.

Distribution: Temperate areas; attacks cereal products particularly flour.

Biology:

Eggs: Up to 300 eggs laid on or near produce.

Larvae: Particularly favor flour dust; webbing from heavy infestations can choke machinery.

Pupae: Form in the produce from overwintered larvae.

Adults: Non-feeding; short-lived.

Mediterranean Flour Moth or Mill Moth (*Ephestia kuehniella*). The Mediterranean flour moth prefers flour and meal, but also will infest grain and other foodstuffs. The larvae produce extensive and characteristic loose webbing. The adults are an off-white or gray color. The moths are widely distributed throughout both temperate and subtropical climates (Figure 9).

(Slide and top caption courtesy of ICI Americas, Inc.)

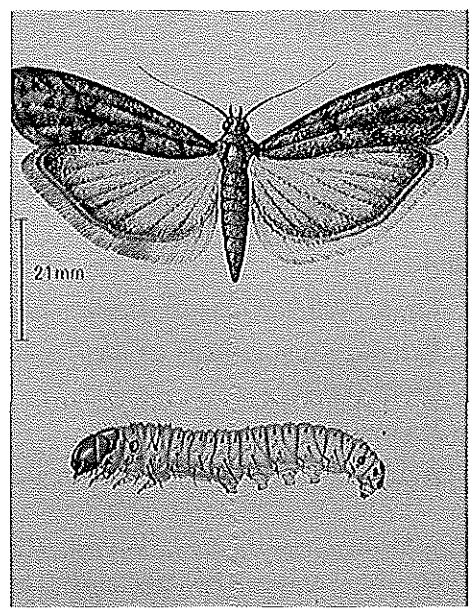

Figure 9. Mediterranean flour moth (mill moth).

Tobacco Moth (Warehouse or Cocoa Moth)

Category: OLI

Minimum Life Cycle: One to six months.

Distribution: Temperate areas; a serious pest, attacking many raw and processed products.

Biology:

Eggs: Up to 270 eggs laid on or near produce.

Larvae: Move to and over produce, feeding and spinning threads that can form webs.

Pupae: Form in cracks nearby.

Adults: Non-feeding; short-lived; fly particularly at dawn and dusk toward top or roof of store.

Tobacco Moth (*Ephestia elutella*). The tobacco moth is smaller, but similar to the Mediterranean flour moth. The forewings are gray with two lighter bands and are bordered by black scales. This moth can infest a wide range of cereal, vegetable, seed, and tobacco products. This insect also produces large amounts of silk webbing (Figure 10).

(Slide and top caption courtesy of ICI Americas, Inc.)

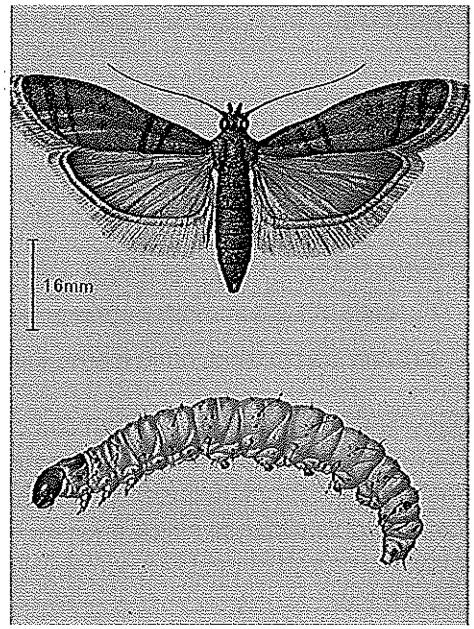

Figure 10. Tobacco moth (warehouse or cocoa moth).

Almond Moth (Tropical Warehouse Moth)

Category: OLI

Minimum Life Cycle: 25 days.

Distribution: Tropical areas; attacks a wide variety of products.

Biology:

Eggs: Up to 300 eggs laid on or near produce.

Larvae: Move to and over produce spinning threads particularly thick just before pupation.

Adults: Non-feeding; short-lived; fly particularly around dawn and dusk.

Almond Moth or Tropical Warehouse Moth (*Ephestia cautella*). The almond moth is more common in tropical areas than the Indianmeal moth, and has an appearance similar to the Mediterranean flour moth. The insect appears to prefer dried fruits, nuts, confectionery, and cereal products, and is often found in concealed locations (Figure 11).

(Slide and top caption courtesy of ICI Americas, Inc.)

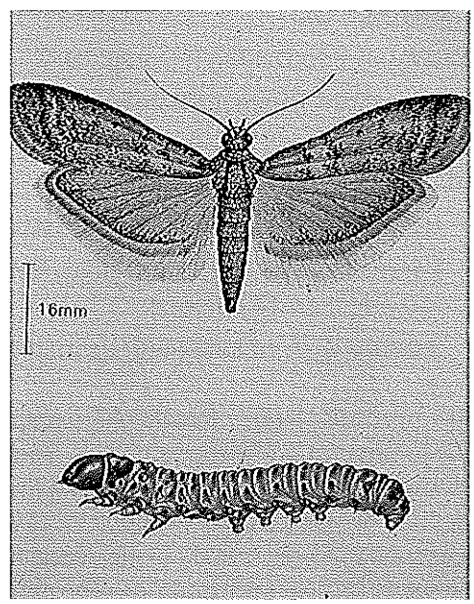

Figure 11. Almond moth (tropical warehouse moth).

Cadelle

Category: OLI

Minimum Life Cycle: 3 to 14 months.

Distribution: Worldwide.

Biology:

Eggs: About 1,000 per female over several months.

Larvae: Found in moth webbing. At pupation, bore into wood.

Adults: Long-lived, often longer than one year.

Cadelle (*Tenebroides mauritanicus*). The cadelle is a beetle that is not common in stored grain. Since the beetle's life cyle extents to nearly a year, it is more common in old grain bins and flour mills where they are destructive to sifting equipment. The larvae and adults are large and can go without food for 52 days (adults) to 120 days (larvae) (Figure 12).

(Slide and top caption courtesy of Degesch America, Inc.)

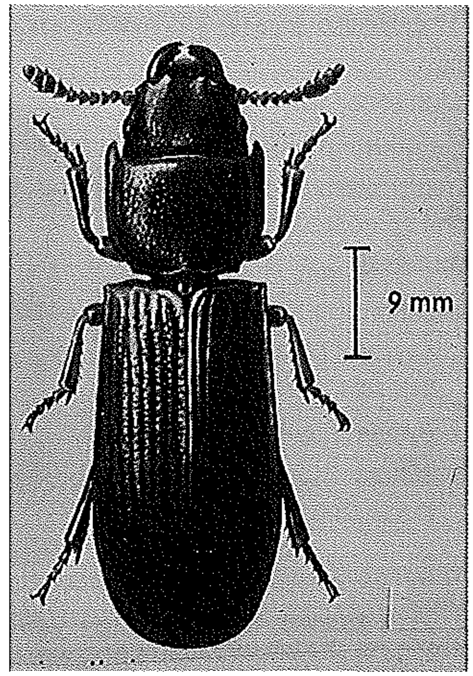

Figure 12. Cadelle.

Sawtoothed Grain Beetle

Category: OLI

Minimum Life Cycle: 20 to 25 days.

Distribution: Cosmopolitan; important pest of many stored products, secondary pest of whole grain.

Biology:

Eggs: Up to 400 per female laid loosely in the grain.

Larvae: Develop rapidly, particularly at high moisture contents (greater than 14 percent).

Adults: Can be long-lived, up to three years.

Sawtoothed Grain Beetle (*Oryzaephilus surinamensis*). The sawtoothed grain beetle is one of most common grain and stored-product insect pests. It is named after the characteristic sawtooth projections on each side of the adult thorax. It feeds on a wide range of foods—especially milled cereals, dried fruits, candies, and nuts. The insect is active and often crawls rapidly in search of food. The sawtoothed grain beetle seems to prefer areas of high temperature and humidity (Figure 13).

(Slide and top caption courtesy of ICI Americas, Inc.)

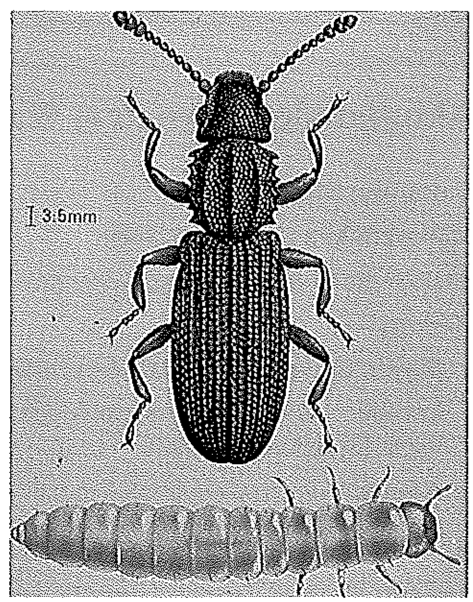

Figure 13. Sawtoothed grain beetle.

Rusty Grain Beetle

Category: OLI

Minimum Life Cycle: 23 days.

Distribution: Worldwide. Normally a secondary pest, but also attack damaged whole grains.

Biology:

Eggs: Up to 400 eggs laid in produce, often in splits or cracks in grain.

Larvae: Prefer to feed on or near endosperm, particularly if grain attacked by fungi.

Adults: Also feed and can live for up to six to nine months.

Rusty Grain Beetle (*Cryptolestes ferrugineus*). The rusty grain beetle is a cosmopolitan pest that is often found in stored grain in the northern United States and Canada. The adults are cold-hardy and fly well in warm temperatures. The insect prefers high moisture grain or moist, decaying food. The insects often occur in large numbers when conditions are ideal. The last larval instar is quite mobile and searches for a pupation site (Figure 14).

(Slide and top caption courtesy of ICI Americas, Inc.)

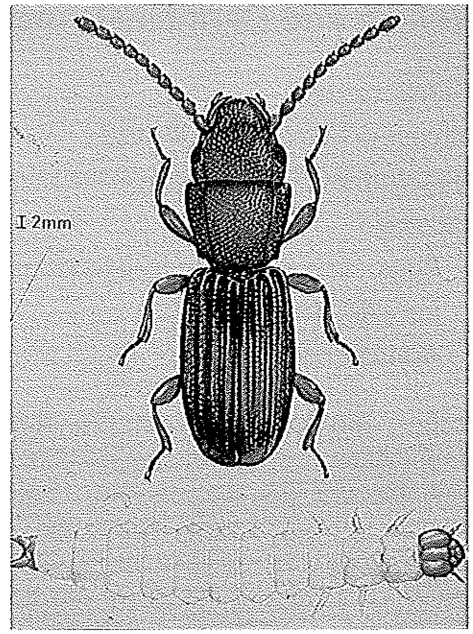

Figure 14. Rusty grain beetle.

Red Flour Beetle and Confused Flour Beetle

Category: OLI

Minimum Life Cycle: 23 days.

Distribution: Worldwide; on many products, secondary on whole grain; red flour beetle more common in tropics than confused flour beetle.

Biology:

Eggs: Up to 450 eggs per female laid on foodstuffs over several months.

Larvae: Prefer cereal embryos.

Adults: Can live for 18 months; many strains of red flour beetle resistant to malathion.

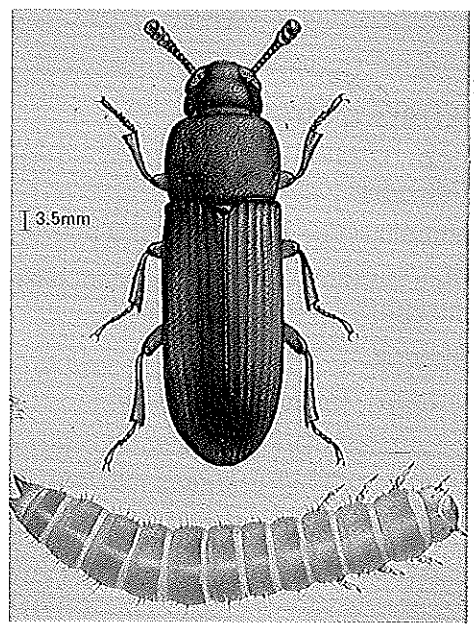

Figure 15. Red flour beetle and confused flour beetle.

Red Flour Beetle and Confused Flour Beetle (*Tribolium castaneum* and *T. confusum*). The red and confused flour beetles are cosmopolitan pests of a wide range of grain, cereal, and other food products, but they prefer milled grain. The antennae of the confused flour beetle gradually expands toward the end, while that of the red flour beetle abruptly expands at the end to form a club of three segments. The red flour beetle will fly under certain conditions; however, the confused flour beetle does not fly. The adults are very active, especially in the evening hours. These insects produce a foul odor and taste in the food products that they infest, which are caused by pheromones and toxic quinone compounds (Figure 15).

(Slide and top caption courtesy of ICI Americas, Inc.)

Yellow and Dark Mealworm Beetle

Category: OLI

Minimum Life Cycle: One year.

Distribution: Cosmopolitan in the United States.

Biology:

- **Eggs:** Laid in grain or food products.
- **Larvae:** Feed in grain.
- **Adults:** Feed in grain.

Yellow and Dark Mealworm (*Tenebrio molitor*). The yellow and dark mealworms are not considered serious pests because of their long life cycle (usually one year). The mealworm larvae and adult beetles both feed on whole grain and grain products. The eggs are sticky and are deposited in the loose food particles. The larvae are active crawlers and the adults are good fliers. The adults have aggregation pheromones and usually prefer dark areas (Figure 16).

(Slide and top caption from USDA-ARS Agric. Handbook No. 500.)

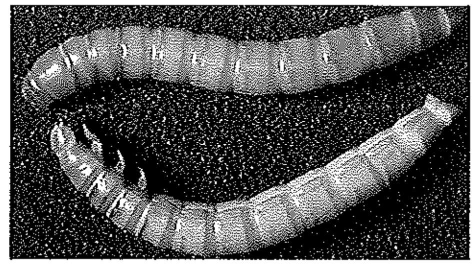

Figure 16. Yellow and dark mealworm beetle.

Khapra Beetle

Category: OLI

Minimum Life Cycle: 25 days to four years in diapause.

Distribution: The most important pest of stored products, attacking principally cereals and oil seeds.

Biology:

- **Eggs:** Up to 80 per female.
- **Larvae:** May enter diapause under favorable conditions when it becomes difficult to control with insecticides.
- **Pupae:** Found in cracks and crevices.
- **Adults:** Short-lived; do not feed or fly.

Khapra Beetle (*Trogoderma granarium*). The khapra beetle is under strict quarantine from the United States. It is a member of the dermestid family and is a voracious feeder of grain products. The insect is capable of hiding in cracks and staying in diapause for years. It is a particularly difficult insect to control with insecticides. Pheromones and traps are used to detect and monitor these insects. The adults of this species do not fly, in contrast to most other dermestids (Figure 17).

(Slide and top caption courtesy of ICI Americas, Inc.)

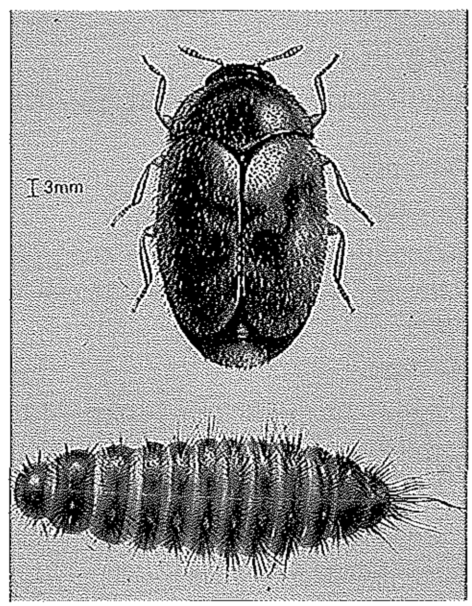

Figure 17. Khapra beetle.

Carpet Beetle

Category: NOLI

Minimum Life Cycle: Six months.

Distribution: Worldwide; not injurious to stored grain or grain products.

Biology:

Eggs: Deposited on animal substances, such as wool or fur.

Larvae: Feed mostly on animal substances.

Adults: Found in warehouses.

Carpet Beetle (*Anthrenus scrophulariae*). The carpet beetle is one of a group of dermestid beetles that are destructive to wool, leather, silk, fur, and other animal products. The adult stage will feed on flower nectar and pollen. There is usually a one-year life cycle. The larvae are active crawlers and the adults fly well. The insect occurs worldwide (Figure 18).

(Slide and top caption courtesy of Degesch America, Inc.)

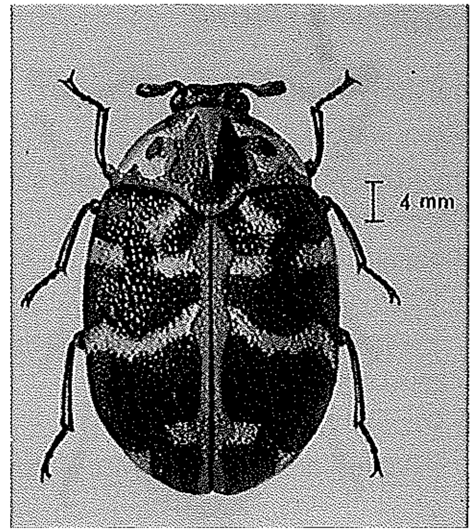

Figure 18. Carpet beetle.

Black Carpet Beetle

Category: NOLI

Minimum Life Cycle: Nine months.

Distribution: Cosmopolitan; not injurious to stored grain products.

Biology:

Larvae: Found in cracks or walls where foodstuffs accumulate.

Adults: Emerge in spring and early summer to lay eggs.

Black Carpet Beetle (*Attagenus megatoma*). The black carpet beetle, a dermestid beetle, includes several similar species that may all be referred to as black carpet beetles. They usually have an annual life cycle. The adults feed only on flower nectar, pollen, and free water, while the larvae usually feed on wool, leather, silk, fur, and other animal products. Several species of these insects are found worldwide, but more commonly in temperate areas. The adult females produce a sex pheromone useful in detecting and monitoring the insect (Figure 19).

(Slide and top caption from USDA-ARS Agric. Handbook No. 500.)

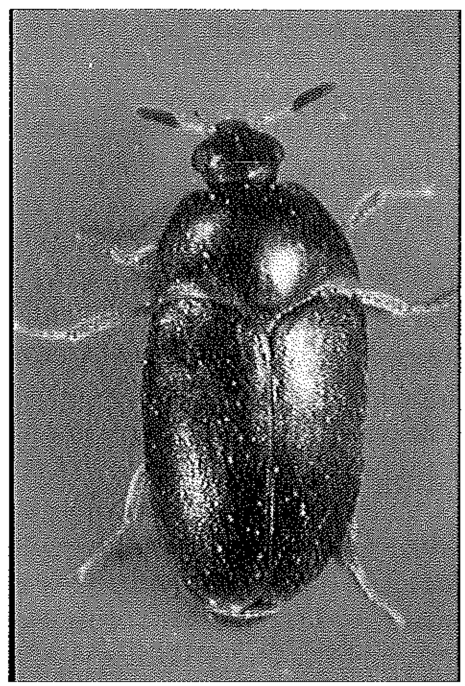

Figure 19. Black carpet beetle.

Cigarette Beetle

Category: OLI

Minimum Life Cycle: 19 days.

Distribution: Worldwide; principally stored tobacco products, can be secondary on other produce.

Biology:

Eggs: About 100 per female laid on produce.

Larvae: Feeding is responsible for damage; developmental period much affected by food source.

Pupae: Form within produce.

Adults: Non-feeding; live two to four weeks.

Cigarette Beetle (*Lasioderma serricorne*). The cigarette beetle, an anobiid beetle, appears to prefer tobacco, but will develop on wheat flower, seeds, and many other dried plant materials. Internal symbionts aid in converting relative non-nutritive materials to suitable food. It has been a serious pest of the tobacco industry, but is now controlled by insect growth regulators (IGRs) and pheromone traps. The insect is found worldwide (Figure 20).

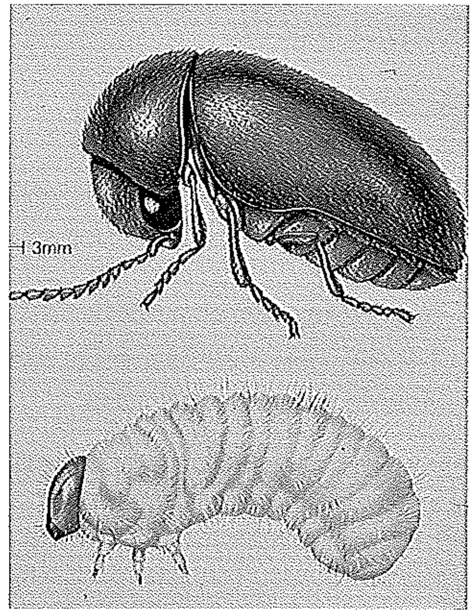

Figure 20. Cigarette beetle.

(Slide and top caption courtesy of ICI Americas, Inc.)

Drugstore Beetle

Category: OLI

Minimum Life Cycle: Eight weeks.

Distribution: Worldwide.

Biology:

Eggs: Female deposits 20 to 100 eggs on suitable nutrients.

Larvae: Feed on most stored commodities, spices, and cereal products.

Adults: Do not fly.

Drugstore Beetle (*Stegobium paniceum*). The drugstore beetle, an Anobiid beetle, is somewhat similar to the cigarette beetle in habits. It has the reputation as a biscuit beetle or bread borer and develops on a wide variety of grain and food products, including spices, dried macaroni, drugs, and paper products. Internal symbionts aid in converting food to more nutritive materials. The sex pheromone is available for detection and monitoring. The insect can be found worldwide (Figure 21).

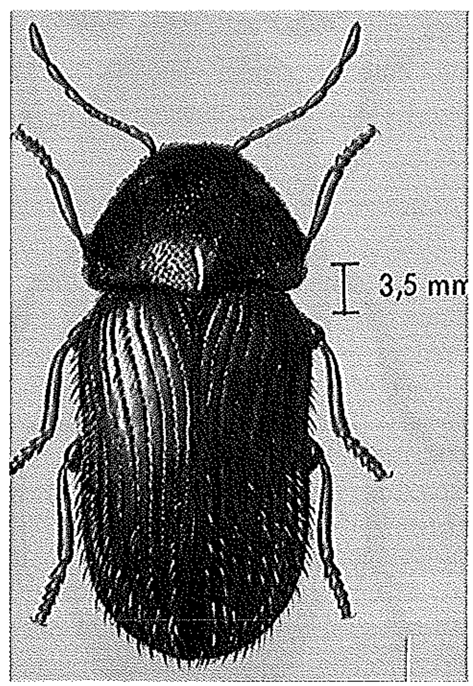

Figure 21. Drugstore beetle.

(Slide and top caption courtesy of Degesch America, Inc.)

Spider Beetle

Category: OLI

Minimum Life Cycle: Two or three generations per year.

Distribution: Worldwide.

Biology:

Larvae: Feed on most stored commodities, spices, and cereal products.

Spider Beetle (*Ptinus* spp.). As the name implies, spider beetles resemble small spiders. These are unusual insects in many ways. The insects are scavengers and indicate poor sanitation or faulty structures, and generally live in accumulated food residues. There are many species that live worldwide. They commonly live in temperate or cold climates and may require cold temperatures to complete their life cycle. They feed on both vegetable and animal material; however, vegetable material appears to be optimum. Spider beetles are often the only insects active in cold buildings (Figure 22).

(Slide and top caption courtesy of Degesch America, Inc.)

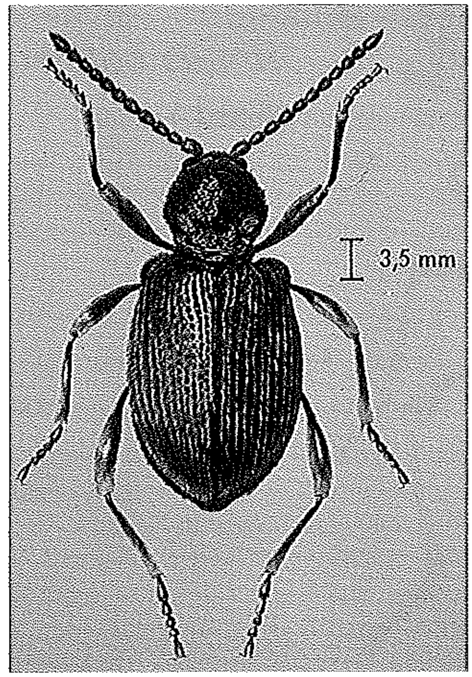

Figure 22. Spider beetle.

Bean Weevil (Dried Bean Beetle)

Category: OLI

Minimum Life Cycle: Three to four months.

Distribution: Worldwide; on pulses both in store and in the field before harvest.

Biology:

Eggs: Laid in pods before harvest or among stored seeds.

Larvae: Enter and feed within one seed.

Pupae: Form in seed which then shows characteristic "window."

Adults: Non-feeding; short-lived.

Bean Weevil or Dried Bean Beetle (*Acanthoscelides obtectus*). Bean weevils, unlike pea weevils, develop on the mature beans in the field and are able to develop in storages. They occur worldwide, but are most common in subtropical areas. They can develop on a range of seeds, from cowpea, broad bean, kidney bean, chick pea, and wild pea. The insect produces a sweet "fruity" pheromone that gives cultures of newly emerged adults a pleasant smell (Figure 23).

(Slide and top caption courtesy of ICI Americas, Inc.)

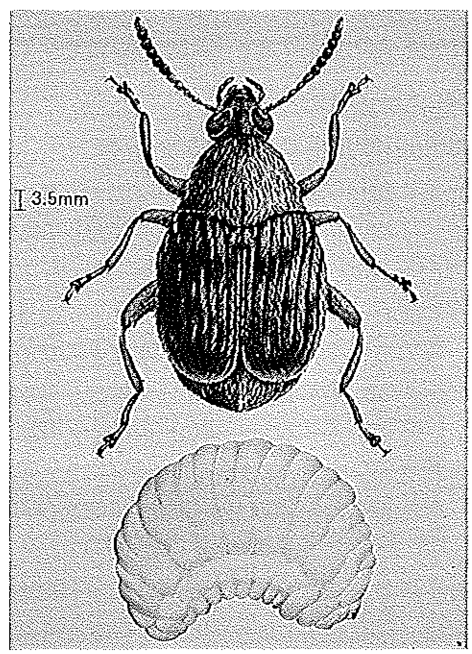

Figure 23. Bean weevil (dried bean beetle).

Vetch Bruchid

Category: NOLI

Minimum Life Cycle: One year.

Distribution: Europe, North Africa, Asia, and the United States where vetch grows. Not injurious to stored grain. Vetch bruchid is black and cowpea weevil is bronze or rusty brown on the back.

Biology:

Eggs: Attached to seed pod of host vetch plant.

Larvae: Feed inside and hollow out inside of vetch seeds.

Adult: Overwinter in vetch fields. Do not reinfest stored products.

Vetch Bruchid (*Bruchus brachialus*). The vetch bruchid is a bruchid seedweevil that attacks the seeds of several species of vetch plants. The weevil is common in Kentucky and the Carolinas where it can infest 90 percent of hairy vetch seeds, although little foliage damage occurs. The adults overwinter in the host fields or in nearby areas where vetch is used for cover crop. After harvest, wheat can be planted. The vetch bruchid can be found in wheat harvested from these fields. The insect has only one generation per year, cannot survive in storage, and is not a pest of wheat or stored products (Figure 24).

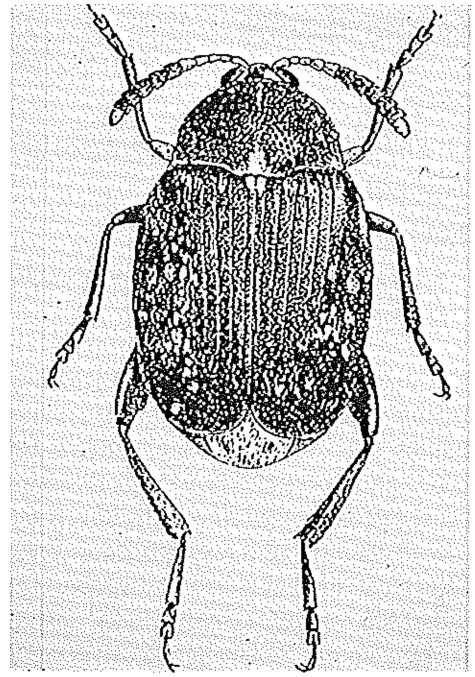

Figure 24. Vetch bruchid.

(Slide and top caption courtesy of USDA.)

Red and Gray Sunflower Weevil

Category: NOLI

Minimum Life Cycle: One year.

Distribution: Areas with sunflower farming, especially the Dakotas. Not injurious to stored grain. Two species: red and gray sunflower weevil.

Biology:

Eggs: Deposited in immature sunflower seeds in late summer.

Larvae: Develop inside sunflower seeds. Infested seeds are often harvested. Larvae drop from the infested heads and pupate in the soil.

Adults: Emerge the next summer and feed on foliage and pollen. Do not reinfest stored products.

Figure 25. Red and gray sunflower weevil.

Red and Gray Sunflower Weevil (*Smicronyx fulus* and *S. Sordiadus*). The red sunflower seed weevil adults are reddish-brown, and the gray sunflower seed weevil are slightly larger and gray in color. The larvae of both species are small, cream colored, legless, and C-shaped in appearance. Seed weevil adults emerge in mid-summer and feed on sunflower buds. As the sunflower matures, the adults feed on pollen, and, as the seeds mature, eggs are deposited within the seed. After developing in the seed, the larvae drop to the ground, overwintering in the soil. The insect is univoltine in North Dakota, cannot survive in storage, and is not a stored-product pest (Figure 25).

(Slide courtesy of D. K. McBride, and top caption courtesy North Dakota Coop. Ext. Service.)

Psocids

Category: NOLI

Minimum Life Cycle: 21 days.

Distribution: North America and Europe. Not injurious to stored grain.

Biology:

Eggs: Up to 100 eggs per female laid on commodities and bags.

Larvae: No larval stage; young resemble adults, but smaller in size and paler in color.

Adults: Some species are winged and other wingless. Feed on a variety of organic matter of plant and animal origin; troublesome due to presence alone and not actual damage.

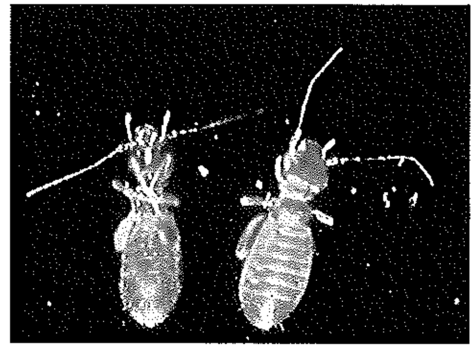

Figure 26. Psocids.

Psocids (*Liposcelis* spp.). These soft-bodied insects have no larval state. The young resemble the adults and are smaller and paler in color. Psocids feed on a wide variety of organic matter, both of animal and plant origin. They do not actually damage grain, but are troublesome due to their presence. Eggs are laid on bags and on commodities (Figure 26).

(Slide courtesy of AOM.)

Grain Mite (Cheese or Flour Mite)

Category: OLI

Minimum Life Cycle: 17 days.

Distribution: Worldwide; attacks many types of produce particularly if moisture is high or after fungal attack.

Biology:

Eggs: At least 100 per female; egg stage can tolerate several months at 0°C.

Immature stages and adults: Attack cereal embryos, dormant stage resists starvation, desiccation, and chemical treatments.

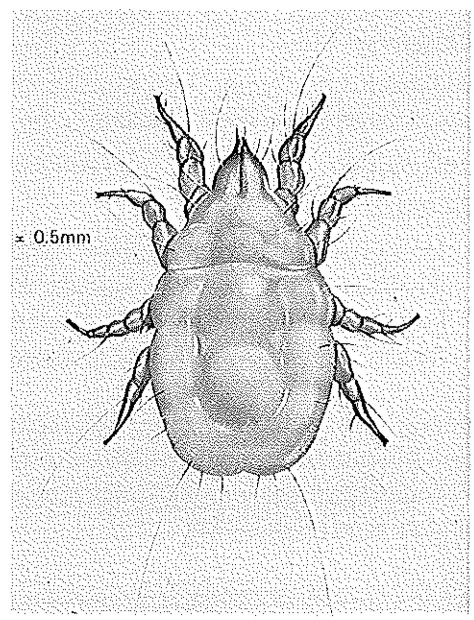

Figure 27. Grain mite (cheese or flour mite).

Grain Mite, Cheese Mite, or Flour Mite (*Acarus silo*). The body of the grain mite is a white oval with reddish-brown mouth parts and legs. It is widely distributed and endures low temperatures. The grain mite will live in fields, barns, loading areas, and grain elevators, as well as in grain, flour, or other food products that contain sufficient moisture. The mite develops quickly and will cause damage to the grain embryo. The mite leaves a characteristic and mildly pungent odor. Development usually takes place only in grain with a high moisture content (Figure 27).

(Slide and top caption courtesy of ICI Americas, Inc.)

Bracon hebetor

Category: NOLI

Minimum Life Cycle: Egg to adult 9 to 10 days (30°C). Adult female longevity about 23 days. Fecundity: approximately 100 eggs.

Distribution: Cosmopolitan associated with stored-product moths. Not injurious to stored grain.

Biology:

Adults: Females paralyze and lay eggs in late instar moth larvae. Each female produces about 100 eggs. On the average, eight larvae develop in one host. (Host: Indianmeal moth and almond moth external to grain.)

***Bracon hebetor,* a Parasitoid.** *Bracon hebetor* parasitizes several of the common grain moths such as the Indianmeal moth in the late larval stage. According to the results of laboratory tests, it promises to be a useful biological control agent (Figure 28).

(Slide courtesy of USDA, J. Brower.)

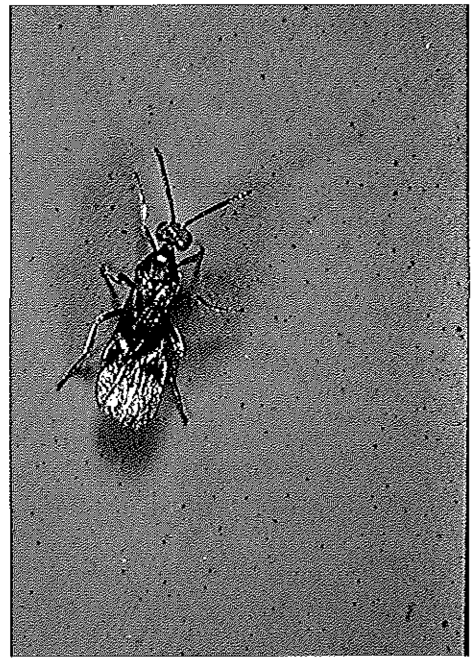

Figure 28. *Bracon hebetor* (Parasitoid).

Ansiopteromalus calandrae

Category: NOLI

Minimum Life Cycle: Egg to adult 12 days (30°C). Adult female longevity about 70 days. Fecundity: approximately 280 eggs.

Distribution: Worldwide. Not injurious to stored grain.

Biology:

Most important natural enemy of *Sitophilus* weevils. Female adults locate weevils inside grain kernels. Female lays eggs inside grain kernel on weevil larvae. Can also attack larvae external to grain. (Host: *Sitophilus* weevils, bruchid bean weevil, cigarette beetle.)

***Anisopteromalus calandrae,* a Parasitoid.** This parasitoid has been demonstrated to reduce populations of the maize weevil in stored corn. This small pteromalid wasp is now produced commercially for release in grain bins (Figure 29).

(Slide courtesy of USDA, J. Brower.)

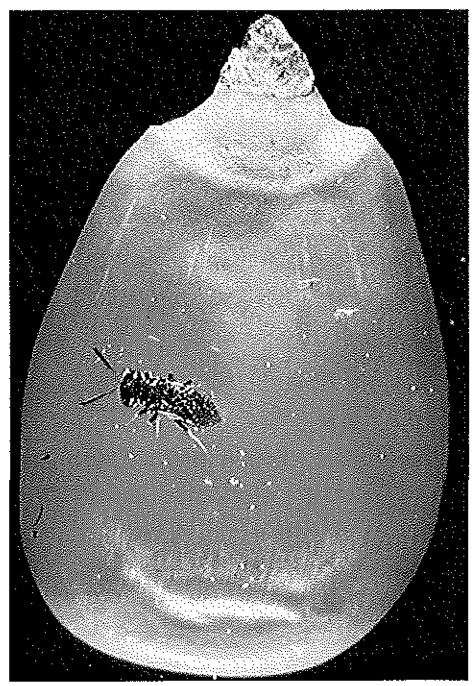

Figure 29. *Ansiopteromalus calandrae.*

Warehouse Pirate Bug

Category: NOLI

Minimum Life Cycle: Egg to adult 16 days (30°C). Adult female longevity is five to six weeks. Fecundity: approximately 150 eggs.

Distribution: Widespread and common in grain storage. Not injurious to stored grain.

Biology:

Most important predatory insect in grain storage. Nymphs and adults prey on eggs, larvae, and pupae of many species of grain insects.

Warehouse Pirate Bug (*Xylocoris flavipes*). This predator is an anthocorid bug that is commonly found in storages. This insect shows considerable promise as a biological control agent since it preys on moths as well as several important beetle species, such as red and confused flour beetles and sawtoothed grain beetles. This predator also is produced commercially for release in grain bins (Figure 30).

(Slide courtesy of USDA, J. Brower.)

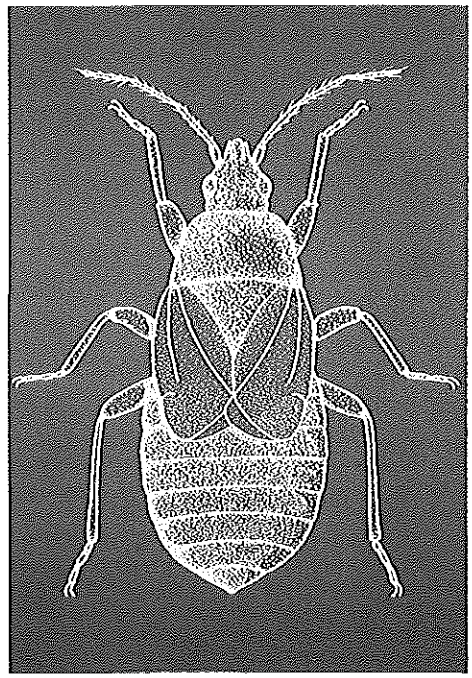

Figure 30. Warehouse pirate bug (Predator).

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14

Occurrence of Insects in Stored Corn

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Introduction

Post-harvest insect pests cause some of the most severe crop production losses in the United States. These losses, both direct and indirect, occur while the commodities are stored on- or off-farm and in grain export shipments. Despite knowledge and utilization of proper grain storage methods, many bulk grain stores still may be infested with many storage insects.

Insects Associated with Stored Grains

Nationwide, stored grains are infested by roughly 50 species of insects. These species primarily are in the orders Coleoptera (beetles) and Lepidoptera (butterflies and moths). The USDA-ARS (1986) has placed the more common of these insects in 11 general categories based on their feeding preferences and other life history phenomena (Table 1). According to Wilbur and Mills (1986), the species footnoted with an asterisk are major pests of stored grains, while those not so designated are minor stored-grain pests. Double asterisks denote beneficial insects. Because a previous publication has dealt thoroughly with stored-wheat insects (Cuperus 1990), this chapter will primarily deal with stored-corn insects.

Insects Associated with Stored Corn

Primary Pests

The granary weevil, maize weevil, rice weevil, lesser grain borer, and Angoumois grain moth are primary pests of stored grains, causing most of the insect damage to stored corn (Figure 1). These insects are called primary insect pests because the adults attack whole kernels—larvae feed and develop entirely within the kernels (Storey 1987).

Weevils are easily recognized by the long head and snout. Subtle differences in markings on the pronotum (i.e., dorsal surface of the first thoracic segment) enable differentiation between the three species. The maize weevil's pronotum is uniformly covered with round punctures, while the rice weevil has a narrow, shiny band with no punctures running the length of the pronotum. The granary weevil has oval-shaped punctures uniformly covering the pronotum. Maize and rice weevils can fly, whereas the granary weevil cannot. This means that these insects have very different abilities to infest new grain stores. Infestations by the granary weevil occur primarily by placing new grain atop previously infested grain, or vice versa.

The lesser grain borer is one of the smallest beetles injurious to stored corn. This pest is easily identified by its somewhat slender cylindrical shape, small size, dark brown to black color, and body that appears to have many

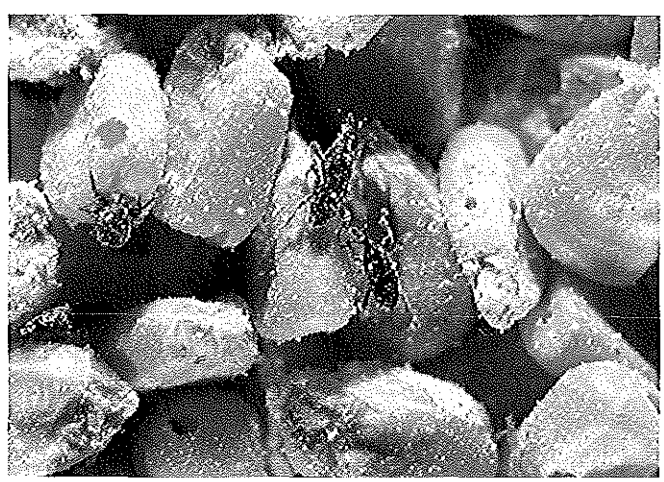

Figure 1. Maize weevil, *Sitophilus zeamais,* amidst corn kernels extensively damaged by feeding.

Table 1. Categories and their members of stored grain insects.

General Category	Common Name	Scientific Name	Family
Grain Weevils	Granary weevil*	*Sitophilus granarius* (L.)	Curculiondae
	Rice weevil*	*Sitophilus oryzae* (L.)	Curculiondae
	Maize weevil*	*Sitophilus zeamais* Motschulsky	Curculiondae
Grain Borers	Lesser grain borer*	*Rhizopertha dominica* (F.)	Bostrichidae
	Larger grain borer*	*Prostephanus truncatus* (Horn)	Bostrichidae
Flour Moths	Indianmeal moth*	*Plodia interpunctella* (Hubner)	Pyralidae
	Mediterranean flour moth*	*Anagasta kuehniella* (Zeller)	Pyralidae
	Meal moth	*Pyralis farinalis* L.	Pyralidae
Grain Moths	Angoumois grain moth*	*Sitotroga cerealella* (Olivier)	Gelechiidae
	Rice moth	*Corcyra cephalonica* (Stainton)	Pyralidae
Grain and Flour Beetles	Cadelle*	*Tenebroides mauritanicus* (L.)	Trogositidae
	Sawtoothed grain beetle*	*Oryzaephilus surinamensis* (L.)	Cucujidae
	Squarenecked grain beetle	*Cathartus quadricollis* (Guerin-Meneville)	Cucujidae
	Foreign grain beetle	*Ahasverus advena* (Waltl)	Cucujidae
	Flat grain beetle*	*Cryptolestes pusillus* (Schoenherr)	Cucujidae
	Rusty grain beetle*	*Cryptolestes ferrugineus* (Stephens)	Cucujidae
	Confused flour beetle*	*Tribolium confusum* (Jacquelin du Val)	Tenebrionidae
	Red flour beetle*	*Tribolium castaneum* (Herbst)	Tenebrionidae
	Longheaded flour beetle	*Latheticus oryzae* Waterhouse	Tenebrionidae
	Broadhorned flour beetle	*Gnatocerus cornutus* (F.)	Tenebrionidae
	Slenderhorned flour beetle	*Gnatocerus maxillosus* (F.)	Tenebrionidae
	Smalleyed flour beetle	*Palorus ratzeburgi* (Wissmann)	Tenebrionidae
	Depressed flour beetle	*Palorus subdepressus* (Wollaston)	Tenebrionidae
	Larger black flour beetle	*Cynaeus angustus* (Le Conte)	Tenebrionidae
Mealworms	Yellow mealworm	*Tenebrio molitor* L.	Tenebrionidae
	Dark mealworm	*Tenebrio obscurus* F.	Tenebrionidae
Dermestid Beetles	Black carpet beetle	*Attagenus unicolor* (Brahm)	Dermestidae
	Trogoderma beetle*	*Trogoderma granarium* Everts	Dermestidae

*denotes that this is a major pest of stored grains.

puncture holes in it. The head is oriented downward and is covered by the pronotum. Adults have funtional wings enabling them to fly, thereby spreading infestations more rapidly. This insect can tolerate low grain moisture content and high grain temperatures, enabling it to be a serious pest of stored grains.

The Angoumois grain moth is a small, beige to yellow-brown moth having a wing span of a half inch. Wing fringes are long and both pairs of wings are narrow and sharply pointed. This insect is commonly found in stored corn, but it may be found in all cereal grains. Infestations may begin in the field and be conveyed to stores, or adults may attack grain already in storage.

These insects have a worldwide distribution. The maize weevil and Angoumois moth primarily are problems in the southern United States. The lesser grain borer is found primarily in the central and southern plains region and is more a pest of wheat.

Table 1. (Continued)

General Category	Common Name	Scientific Name	Family
Spider Beetles	Hairy spider beetle	*Ptinus villiger* (Reitter)	Ptinidae
	Whitemarked spider beetle	*Ptinus fur* (L.)	Ptinidae
	Brown spider beetle	*Ptinus clavipes* Panzer	Ptinidae
	Australian spider beetle	*Ptinus ocellus* Brown	Ptinidae
Miscellaneous Beetles	Hairy fungus beetle	*Typhaea stercorea* (L.)	Mycetophagidae
	Corn sap beetle	*Carpophilus dimidiatus* (F.)	Nitidulidae
	Cigarette beetle	*Lasioderma serricorne* (F.)	Anobiidae
	Drugstore beetle	*Stegobium paniceum* (L.)	Anobiidae
Psocids	Booklice	*Liposcelis* spp.	Liposcelidae
Other Arthropods	Grain and flour mites	*Acarus* and *Tyrophagus* spp.	Acaridae
Beneficial Insects			
Wasp Parasitoids		*Anisopteromalus calandrae* (Howard)**	Pteromalidae
		Choetospila elegans Westwood**	Pteromalidae
		Habrocytus cerealellae (Ashmead)**	Pteromalidae
		Lariophagus sp.**	Pteromalidae
		Dibrachys sp.**	Pteromalidae
		Pteromalus sp.**	Pteromalidae
		Cephalonomia tarsalis (Ashmead)**	Bethylidae
		Holepyris sp.**	Bethylidae
		Laelius sp.**	Bethylidae
		Bracon hebetor Say**	Braconidae
		Venturia canescens (Gravenhost)**	Ichneumonidae
		Mesostenus sp.**	Ichneumonidae
		Trichogramma pretiosum (Riley)**	Trichogrammatidae
		Trichogramma evanescens Westwood**	Trichogrammatidae
Predators	Windowpane flies	*Scenopinus fenestralis* (L.)**	Scenopinidae
		Scenopinus glabrifrons Meigen**	Scenopinidae
	Warehouse pirate bug	*Xylocoris flavipes* (Reuter)**	Anthocoridae
		Lyctocoris sp.**	Anthocoridae
		Dufouriellus sp.**	Anthocoridae

** denotes that this is a beneficial insect.

Secondary Pests

External, or secondary, insect pests are capable of causing much damage to stored corn if storage conditions favor their development. Population increases of secondary pests are favored by grain dust or broken kernels produced by mechanical damage during harvesting and/or binning procedures, or by the feeding activity of primary insect pests. They are also associated with microbial activity in the grain. In general, these individuals are associated with corn and other grains that are in poor condition (Christensen and Meronuck 1986).

Flat and rusty grain beetles, confused and red flour beetles, sawtoothed grain beetle, Indianmeal moth, and almond moth are externally developing insects that feed primarily on damaged corn (i.e., broken kernels, germ, grain dust) or other cereal products (Storey 1987).

The other group of externally developing insects are those that are associated with high-moisture grain and which feed on mold, but may also damage kernels. These include the foreign grain beetle, hairy fungus beetle, larger black flour beetle, and booklice (Storey 1987).

Although high numbers of fungus-feeding insects may be present, they seldom cause damage to the grain itself. Their mere presence, however, may devalue the grain at the time of sale. They, along with other secondary pests, are ubiquitous where grains are stored.

Incidental Pests

These insects rarely damage grain except by contamination resulting from their presence (e.g., odors from metabolic wastes and contamination by body parts or fragments). According to Wilbur and Mills (1986) and the USDA-ARS (1986), roaches, several types of mealworms, some types of fungus beetles, and silverfish are among insects that are incidental pests. Some of these species feed on the fungi and other microbes present, and thus serve as indicators of grain that is in poor condition.

In addition, living and dead grasshoppers, stinkbugs, wasps, hornets, flies, lady beetles, and blister beetles have been observed in grain storage facilities. These insects do not feed on the grain, but are trapped in the grain flow during harvest and binning, or they simply fly or crawl into the bins and get trapped.

Parasitoids and Predators

These insects may be found in bulk grain or in flour mills, but they are not harmful to grain. In fact, many are beneficial because they attack and reduce populations of harmful insects that infest corn and other grains.

The approximate number, identity, and impact of insects that parasitize and prey upon primary and secondary insect pests of grain is unknown. However, some species of parasitic wasps, predaceous flies, and true bugs have been found to reduce populations of some stored-grain insect pests (Table 1) (Borror et al. 1976, Brower 1983, USDA-ARS 1986, Brower and Press 1988, Federal Register 1991).

Factors Affecting Distribution and Abundance of Insects

The number and variety of insects present in a given grain mass depends on many factors. These factors can be broken down into three major categories—abiotic, biotic, and historical. In addition to these factors, randomness may play a significant role in infestations.

Abiotic Factors

The abiotic factors of greatest importance are grain temperature and moisture content. Grain temperature influences the activity level of insects, and temperature extremes may kill insects. Sampling a grain bin in July and December will likely yield very different estimates of the insect fauna. Fargo et al. (1989) showed that the number of insects caught in probe traps decreased steadily with grain temperature. Even sampling methods that are independent of insect activity, such as trier samples, yield lower estimates of insect numbers in cool grain as opposed to warm grain (Barak and Harein 1981). When sampled in May and June, corn stored in northern and eastern counties of western Kentucky yielded no maize weevils. When sampled in July and August the following year, abundant weevils were found (unpublished data).

The geographical range of insect pests is undoubtedly influenced by temperature. Differences in optimum, maximum, and minimum temperatures may result in one insect being abundant in one region and rare in another. For example, the most abundant pest of stored corn in South Carolina (Horton 1982) and Kentucky (unpublished data) is maize weevil. In contrast, *Cryptolestes* spp. is the most numerous pest of stored corn in Minnesota (Barak and Harein 1981). Although temperature no doubt plays a major role in these distribution patterns, other factors may contribute. For example, maize weevil has recently been discovered in corn in Wisconsin (Burkholder, personal communication). This apparent expansion in range is presumably the result of transportation of insects in infested grain, but it is not clear whether the insect will become widely established in this region, which is thought to be outside its inhabitable range.

Moisture content is arguably the most important factor in determining how long grain can be stored without infestation by insects. The critical range of moisture content for infestation is from 9 to 16 percent. Insect survival is essentially zero on grain with less than 9 percent moisture, whereas grain with a moisture content of 16 percent or more will undoubtedly become heavily infected with fungi, making insect infestation secondary in importance.

The most pronounced effect of moisture content is on the abundance of fungus-feeding insects. These insects are unlikely to be found at the lower end of the 9 to 16 percent range, but they are quite likely to be found at the upper end. Even minor variation in moisture content can result in very large differences in insects present. Storey et al. (1983) found the moisture content of corn containing nine species of insects known to prefer high moisture or feed on fungi to be 12.5 percent, whereas corn uninfested with these species (but infested with others) averaged 12.0 percent moisture. Completely uninfested grain averaged 11.5 percent moisture. It is unclear whether these differences in infestation were responses to moisture content *per se* or to increased fungal infestation. In any event, the influence of moisture content on insect infestations in stored corn cannot be overemphasized.

Biotic Factors

The major biotic factors influencing insect abundance are the presence of primary insect colonizers, the presence of fungi, and the biochemical state of the grain. Secondary colonizers are rare in corn undamaged by grain-handling equipment, but increase markedly with prior infestation by primary pests. For example, Arbogast and Mullen (1988) found the Angoumois grain moth, a primary colonizer, to be the most abundant insect in a storage facility at the time of binning. After one year, the most numerous insect was the sawtoothed grain beetle, a secondary colonizer. Over the following seven years, a variety of insects, both primary and secondary pests, assumed dominance. Thus, it may be difficult to predict the most abundant insects in a grain storage, even with knowledge of insect inhabitants the previous year. However, limiting the establishment of primary colonizers will no doubt curb the establishment of secondary colonizers (provided that moisture content is kept low).

Fungi may also influence the composition of insect populations infesting stored corn. It is not clear to what extent fungi influence movement of fungus feeders into grain stores, but a number of stored-product insects are known to orient toward volatiles of storage fungi (Starratt and Loschiavo 1971, 1972). Even if fungi have little effect on movement of insects in grain storages, some can increase the fitness of fungus feeders that end up there (Sinha 1971).

The biochemical state of stored corn can also influence insect abundance. Lipids in corn kernels become oxidized over time, liberating volatiles that may influence the movement behavior of stored-product insects toward or away from the grain (Cohen et al. 1974, White et al. 1989, Pierce et al. 1990). Production of these compounds increases upon contact of corn tissue with air, and so may be elevated in corn damaged by grain-handling equipment or primary insect colonizers. The levels of these compounds increase steadily as the grain ages.

Historical Factors

The integrity of the storage structure and its immediate environment also influence the number and type of insects present in a grain mass. Rain leaking through roofs or sides of bins causes localized areas of elevated grain moisture, increasing the likelihood of insect and fungal infestations. Gaps at the base of a grain bin similarly increase the likelihood of infestation by insects, particularly if poor sanitation practices are used. Piles of grain near a grain bin are potential sources of insect colonizers. Infested bins nearby also are likely sources of colonizers. Of course, placing new grain on top of old, infested grain, or vice versa, will guarantee infestation of the new grain. Another source of insects is the fines accumulated under the false floor of grain bins—secondary pests thrive on this material. The insect fauna of a storage structure are largely influenced by the sanitation and previous management practices at a given site.

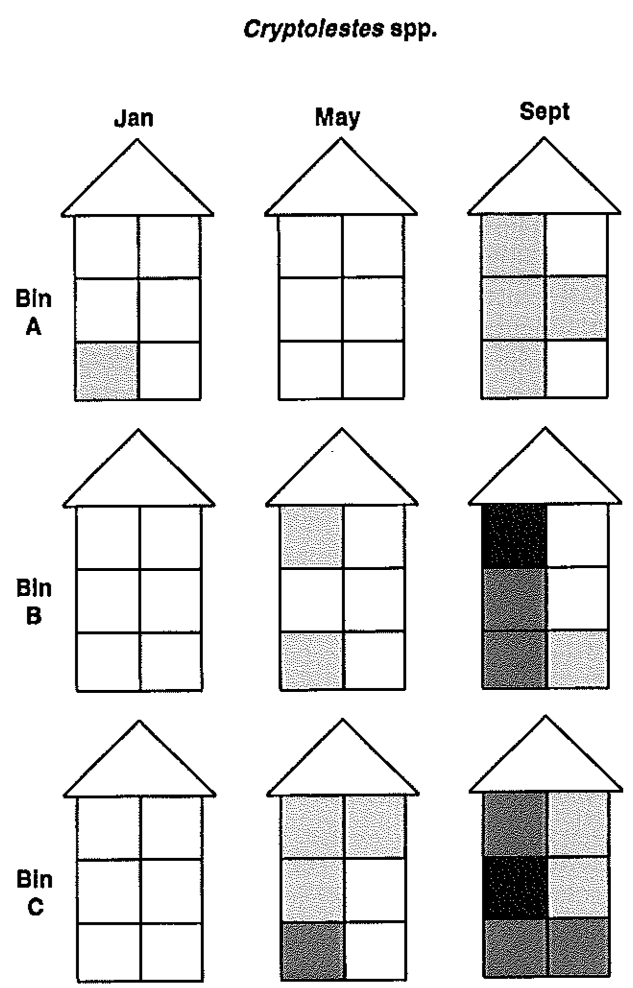

Figure 2. Graphical representation of *Cryptolestes* spp. infestation of corn stored in three identical bins at the same time as measured by probe traps. The boxes represent three sampling depths on the north and south sides of the bins. White boxes indicate minimal numbers of insects caught, light gray indicates 10-fold higher trap catches, medium gray boxes are 10-fold higher than light gray, and black boxes are 10-fold higher than medium gray.

The duration of storage also influences the number and type of insects present. As mentioned earlier, several factors change the susceptibility of grain to various insects over time. These factors include presence of primary colonizers, fungi, and lipid oxidation products. Thus, duration of storage is another management variable that deserves the attention of grain managers.

Random Effects

In spite of these identifiable sources of variability in insect infestation, the role of randomness should not be underestimated. We have found great variability in the insect fauna of corn harvested at the same time and held in identical grain bins within several feet of each other. The bins had been cleaned and treated with recommended amounts of insecticide prior to binning. Thus, the major source of secondary colonizers was from outside the bins, and presumably the same for each. Nonetheless, the distribution and abundance of secondary pests present in various bins of corn treated the same were quite different (Figure 2). Another source of randomness is time—the longer grain is held in storage, the greater the probability of chance encounter by insects.

Insect Movement

Little is known about long-range orientation of stored-product pests to grain in storage. It is likely that flying insects orient to plumes of odors emanating from grain storage structures, but the existence of such behavioral responses and the range over which they might operate is unknown. It is also likely that stored-product insects orient to pheromones emitted by conspecifics in grain storages—particularly male lepidopteran species in response to female-produced sex pheromones—but again, the extent to which such responses occur is undocumented. Because insects typically respond to pheromones at much lower doses than to food odors, one would expect pheromones to exert their influence at a greater distance than grain volatiles. Thus, keeping grain as free as possible from insects will reduce not only the direct damage caused by colonizers and their progeny, but also the probability of further infestation by other members of the invading species.

On-farm Infestations: Perceptions by Farmers

A survey conducted by Barney et al. (1989) provides insight into some avoidable causes of infestations in stored corn. Kentucky farmers have stored corn on-farm up to four years and usually do not follow a bin filling strategy. Further, many of them never use standard IPM techniques of aeration, sanitation, or insecticide treatments to control potential insect problems in their storage facilities. The lack of IPM practices to manage stored grains is not limited to Kentucky. Similar reports have been made in Kansas (Storey et al. 1984), Minnesota (Harein et al. 1985), and, to a lesser degree, Oklahoma (Cuperus et al. 1990).

More than a third of Kentucky farmers storing corn six to 12 months were not sure if they had storage pests in their bins, and 40 percent were sure they did not. Around 45 percent of the farmers storing corn up to 36 months said they did not have any pests in their storage facilities, which is extremely unlikely. We believe many farmers are aware of insects in their bins, but they misidentify them. The maize weevil is one such example. Maize weevils were detected in slightly more than 38 percent of bins sampled, yet more than 66 percent of the farmers who store corn on-farm thought they had a weevil problem (Barney et al. 1989). It is believed that farmers identify all beetles (and in some cases, all insects) as weevils. Farmers also commented on the "weevils" when a swarm of Angoumois grain moths would emerge from a bin as the side hatch was opened. Only 16 percent of the farmers thought Angoumois grain moth was a problem in their bins, when in fact it was found in more than 35 percent of the bins sampled. Cuperus et al. (1990) observed in Oklahoma that producers and commodity managers do not recognize differences between insect species. Therefore, it is obvious that incorrect pest diagnoses are occurring, which may affect pest management decisions or options selected.

Conclusion

Losses of stored corn may be considerable if storage periods are long and sound management practices are not followed. It is important for managers of stored grain to know what pests are likely to be a problem in their area, to correctly identify insects present, to understand what factors influence insect infestation, and to implement sound management practices. Additional education through county Extension offices is probably the most effective means of achieving the goal of producing high-quality grain.

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15

Mycotoxins

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Mycotoxins are toxic substances that are produced by fungi growing under suitable conditions in the field, in storage, and transport. The three major mycotoxin-producing fungi are *Aspergillus*, *Fusarium* and *Penicillium*. Certain strains of these fungi will produce these toxic metabolites when growing on a suitable substrate which has the required moisture, temperature, and certain other factors, such as pH and plant stress.

Although it has been known for about 100 years that some kinds of moldy grain, when eaten, could cause illness, intensive study of mycotoxins and mycotoxicoses only dates from the 1960s, when a toxic compound was extracted from cultures of the fungus *Aspergillus flavus* isolated from a batch of toxic peanut meal. The toxin was soon purified, chemically characterized, and named aflatoxin. It caused toxicoses in animals when their feed contained only a few parts per billion (ppb). The work on aflatoxin led to work on other serious livestock health and production problems.

Animals exposed to toxic levels of mycotoxins can produce a wide range of symptoms. Low concentrations of several mycotoxins have been shown to reduce weight gain, reduce litter sizes, deform offspring, reduce egg production, and reduce milk production. The fact that mycotoxins may be contributing to the problem often goes undetected, because the mycotoxin is not being recognized as the cause. Cases are now more often recognized as more information on mycotoxicoses is discovered and more information is reaching the producer and the veterinary practitioner. Acute cases often seriously reduce productivity; increase disease due to immune suppression; damage vital organs; and cause hemorrhage, false heat, nervous system dysfunction, cancer, and death.

Economic losses due to mycotoxicoses are derived directly from livestock losses and the regulatory programs designed to reduce animal exposure. However, no reliable data are available on the total impact of mycotoxins on world or U.S. production. Years of extreme drought or extreme cool, and wet conditions during harvest can predispose corn to infection by mycotoxin-producing fungi and mycotoxin formation. Annually, only about two percent of the U.S. corn crop is affected economically, yet losses for individual producers can be significant when local environmental conditions favor the significant accumulation of mycotoxins in feed grains (CAST 1989).

There have been a number of toxic compounds produced by a variety of fungi. New ones are being discovered, some of which have been found to be connected to significant animal disease problems. For the purpose of this article, only a few mycotoxins routinely or newly recognized to cause feeding problems will be discussed.

Aflatoxins

The aflatoxins are a group of toxic metabolites produced by *Aspergillus flavus* and *A. parasiticus,* and they have a high potential to contaminate feeds that have a suitable environment for the growth of the fungi. Contamination of corn and other commodities with significant levels of aflatoxin has been and continues to be a major problem in many parts of the world.

The two species of *Aspergillus* mentioned above are the only fungi known to produce the toxin (Davis and Diener 1983). Toxigenic *A. flavus* isolates generally produce only aflatoxin B_1, and B_2, whereas *A. parasiticus* isolates generally produce aflatoxins B_1, B_2, G_1, and G_2 *A. flavus* is the predominant fungus in contaminated corn and cottonseed meal. *A. parasiticus* is more common is peanuts.

A. flavus and *A. parasiticus* are considered to be temperature-tolerant fungi (Davis and Diener 1983). The limiting temperatures for the production of aflatoxin are reported as 12° to 41°C (54-106°F), with optimum production occurring between 25° and 32°C (77-90°F) (Lillehoj 1983). Growth of *A. flavus* will occur rapidly at 86 to 87 percent relative humidity (RH) within 48 hours (Davis and Diener 1983).

Aflatoxin has been found in bins of heating and discolored corn (Lillehoj and Fennell 1975, Shotwell et al. 1975). It has also been found in the field and in heating ensiled, high-moisture corn. In the fall of 1988, a drought year in Minnesota, 34 out of 631 corn samples tested had more than 20 ppb of aflatoxin. The range of concentrations was 20 to 423 ppb. Concentrations of 80 to 100 ppb were found in ensiled, high-moisture corn stored in stave silos.

Field infection of corn (Wiklow 1983) is more common when high temperatures and RH along with plant stresses occur, such as drought and insect damage (Payne 1983). There also is evidence to indicate that preharvest corn infection can occur through the corn silk (Marsh and Payne 1984).

Toxic effects on livestock can vary significantly and often go undetected. Aflatoxin in rations can lower resistance to disease and interfere with vaccination and acquired immunity. Immunosuppression caused by aflatoxin B_1 has been demonstrated in turkeys, chickens, and pigs and also in mice, guinea pigs, and rabbits (Sharma 1993). Acute signs, when observed, might include anorexia, depression, ataxia, and epistases. Signs due to chronic exposure of aflatoxin include reduced feed efficiency, reduced milk production, icterus, and decreased appetite (Nibbelink 1986). If these signs are observed and feed analysis reveals the presence of aflatoxin, the feed should immediately be withdrawn and a low-fat, high-quality protein ration should replace the suspect ration. Any environmental stress should also be minimized (Nibbelink 1986).

Indirect exposure of humans to aflatoxins can occur by consumption of foods derived from animals that consume contaminated feeds. Studies with aflatoxin transfers from dairy rations to milk have shown that lactating dairy cattle secrete 1.7 percent of their total aflatoxin B_1 intake as aflatoxin M_1 in milk (Frobish et al. 1986). The authors conclude a B_1/M_1 ratio of 66:1, and suggest that the present action level of 20 ppb of aflatoxin B_1 in the complete feed of lactating dairy cattle is appropriate for reducing the risk of incurring M_1 levels in milk greater than the action level of 0.5 µg/L.

Table 1. FGIS approved aflatoxin test kits.

Quantitative Test Kits ***(those that provide an actual aflatoxin concentration):***		
VERATOX - AST	Neogen Corporation 620 Lesher Place Lansing, Michigan 48912 Attn: Chuck Bird	800-234-5333
Aflatest-P	VICAM, L.P. 313 Pleasant Street Watertown, Massachusetts 02172 Attn: Thomsen Hansen	800-338-4381
Qualitative Test Kits ***(those that provide a yes or no answer at 20 parts per billion total aflatoxin content):***		
EZ-Screen	EDITEK 1238 Anthony Road Burlington, North Carolina 27215 Attn: MelRee Krivanic	800-334-1116
CITE Probe	IDEXX Laboratories, Inc. 1 IDEXX Drive Westbrook, Maine 04092 Attn: Bill Thomas	207-856-0300
Afla-Cup-20	International Diagnostic Systems Corporation P.O. Box 799 St. Joseph, Michigan 49085 Attn: E. Lewis	616-983-3122
Agriscreen	Neogen Corporation 620 Lesher Place Lansing, Michigan 48912 Attn: Chuck Bird	800-234-5333

Presently, the Food and Drug Administration will commence enforcement actions if aflatoxin levels in corn exceed the following limits—20 ppb when intended for human use, dairy feed, or feed for immature animals; 100 ppb when destined for breeding cattle, breeding swine, or mature poultry; 200 ppb when destined for finishing swine (i.e., more than 1,200 lb. body weight); and 300 ppb when destined for feedlot cattle. Corn having an unknown destination or use is subject to seizure if it exceeds 20 ppb aflatoxin. In May 1992, the FDA reminded grain elevators that the blending of aflatoxin-contaminated grain with uncontaminated grain is illegal and subject to legal action.

The analysis of a sample to determine the concentration of aflatoxin involves extraction, purification of the extract, and measurement of the toxin concentration using thin layer chromatography plates (TLC plates), high-pressure liquid chromatography, or the new enzyme-linked immunosorbent assays (ELISA). Several of these ELISA tests are approved for use by the FGIS (Table 1).

Zearalenone

Zearalenone is best known for its role in the estrogenic syndrome in swine and has been reported from many areas of the world. In the U.S., it is common throughout the Corn Belt, where scattered cases occur every year. Although it has been reported in the southern states, it is much more common in the north.

Fusarium graminearum is the major zearalenone-producing fungus of the *Fusarium* species that cause corn ear and stalk rots. Other *Fusarium* species may produce some zearalenone, as will as other toxins that complicate estrogenic syndrome diagnosis in swine (Christensen et al. 1988).

Corn is the major source of zearalenone, although it has been found occasionally in smaller amounts in wheat, barley, oats, sorghum, sesame seed, hay, and silage.

The combination of conditions necessary for zearalenone production in corn include at least a moderate prevalence of *F. graminearum* ear rot in corn in the field before harvest, exposure to conditions which retain moisture contents of 22 to 25 percent so that the fungus continues to grow, and a period of several weeks of fluctuating temperatures during crib storage or delayed harvest which would stimulate the growth of the fungus and the production of zearalenone.

There is no evidence to suggest that zearalenone present in corn at harvest will continue to develop in stored shelled corn. *F. graminearum* requires a minimum of 22 to 25 percent moisture to grow, and if shelled corn is stored at that moisture content it is likely to be invaded by a mixture of other yeasts and bacteria with which *F. graminearum* cannot compete.

Zearalenone can invade corn after hail damage. Hail damage to the husks and immature kernels appears to predispose the affected areas to infection.

Swine are the most susceptible to the effects of zearalenone. When consumed by swine, it chiefly affects the genital system. In the prepuberal gilt, the vulva becomes swollen, and this may progress to vaginal or rectal prolapse. These outward changes are accompanied by an enlarged, swollen, and twisted uterus and shrunken ovaries. In young males, testes atrophy and mammary glands enlarge. Litter size also may be reduced.

Dairy cattle consuming zearalenone-infected rations have decreased fertility, prolonged estrus, and swelling of the vulva. Animals vary as to their response, but some will show standing estrus during mid-cycle.

Broiler chicks and laying hens are not greatly affected by zearalenone, even when they eat large amounts of the compound. Turkeys, on the other hand, when eating feed containing 300 ppm, develop greatly enlarged vents within four days. No other gross effects were noted (Christensen et al. 1988).

Deoxynivalenol

Deoxynivalenol (DON) is usually associated with the refusal syndrome in swine. It has been found worldwide, especially in the temperate zones.

Most of the reports in the literature implicate *F. graminearum* as the major producer of DON (Marasas et al. 1984). Wet or rainy, or warm and humid weather from flowering time on promotes infection of corn and the small grains by *Fusarium*, resulting in ear rot in corn and in scab or head blight in barley, wheat, oats, and rye. An analysis of weather data in Indiana revealed that optimal conditions for infection were at least nine days of rain and a mean temperature below 21°C (51°F) during silking (Tuite et al. 1974).

DON already present in corn at harvest may increase in ear corn stored in cribs. It is not known to increase in stored shelled corn or in small grains that come contaminated from the field, nor would it be expected, as *Fusarium* growth requires a minimum moisture content of 22 to 25 percent.

Feeds containing more than 1 ppm of DON may result in significant reductions in feed intake by swine, resulting in lower than normal weight gain. Vomiting also has been reported in other cases as well, thus the term vomitoxin was coined as another name for DON. Pure DON fed in swine rations decreases feed intake, with decreased intake inversely proportional to the concentration added (Marasas et al. 1984). It should be pointed out, however, that other mycotoxins have been found with DON in cases where feed was refused. In these cases, the clinical signs and lesions were greater than that reported to be contributed by DON alone.

Dairy cattle seem to be less susceptible to DON. However, there are cases when the compound was present in rations fed to poor-producing herds. Again, other mycotoxins along with DON could be the cause of these conditions. More research needs to be done on the effect of *Fusarium* mycotoxins on dairy animals.

Chickens suffered no detectable ill effects from rations containing up to 18 ppm of DON. When chickens ate a ration containing 9.18 ppm of DON, none was detected in the flesh or eggs. No ill effects were detected in turkey poults given a ration containing 5 ppm of DON (Christensen et al. 1988).

Significant losses in wheat and other small grain have been reported in the wheat growing areas in the north central states and Canada. Wheat scab caused by *Fusarium graminearum* is most serious when warm, wet weather is present during anthesis. Changes in crop rotation and tillage practices are blamed for the increase in inoculum. Corn/wheat rotations increase inoculum as it survives on both corn and wheat residue. Minimum or no tillage production practices, which are popular today, tend to enhance the survival and spread of the pathogen. The presence of DON in the small grain crop has made marketing quite difficult. Guidelines have been provided by FDA to help with the marketing and utilization of the infested lots. The FDA advisory levels for DON are as follows:

1) One ppm on finished wheat products (e.g., flower, bran, and germ) that may potentially be consumed by humans. The FDA is not stating an advisory level for wheat intended for milling because normal manufacturing practices and additional technology available to millers can substantially reduce DON levels in the finished wheat product from those found in the original raw wheat. Because there is significant variability in manufacturing processes, an advisory level for raw wheat is not practical.

2) Ten ppm DON on grains and grain by-products destined for ruminating beef and feedlot cattle older than four months and for chickens, with the added recommendation that these ingredients not exceed 20 percent of their diet.

3) Five ppm DON on grains and grain by-products destined for swine, with the added recommendation that these ingredients not exceed 20 percent of their diet.

4) Five ppm on grains and grain by-products destined for all other animals, with the added recommendation that these ingredients not exceed 40 percent of their diet.

T-2 and Diacetoxyscirpenol

Along with DON, T-2 and diacetoxyscirpenol (DAS) are members of a group of compounds called trichothecenes. Routine analysis is preformed for only a few of these compounds, and few additive of synergistic effects of combinations of these toxins is known. Nevertheless, the toxic effects from consumption of toxin-contaminated feeds have been reported throughout the temperate zones of the world. The most common of these have involved a sudden and drastic drop in egg production in laying hens, and an outbreak in beef or swine herds of hemorrhagic bowel syndrome, resulting in the death of some animals.

Fusarium sporotrichioides has been shown to be a major producer of these toxins, but other species of *Fusarium* have been shown to produce it as well (Marasas et al. 1984). T-2 and DAS have been found in barley, wheat, millet, safflower seed, field corn, sweet corn, and in mixed feeds.

Any conditions that favor the growth of *Fusarium* species will increase the chances that these mycotoxins will be produced. Fluctuating moderate and low temperatures during a delayed harvest or crib storage will increase the chances for toxin production if accompanied by adequate *Fusarium* infection.

Unthriftiness, decreased feed consumption, slow growth, lowered milk production, sterility, gastrointestinal hemorrhaging, and death can occur when cattle consume rations containing these toxins. Effects of T-2 on swine include infertility, with some lesions in the uteri and ovaries. Drastic and sudden decreases in egg production in laying hens have been shown to be caused by T-2 toxin in the parts per million range. Other effects include reduced egg production, eggs with thin shells, abnormal feathering, and slow growth in chickens. Turkeys fed T-2 experienced reduced growth, beak lesions, and less immunity to infection (Christensen et al. 1988). Trichothecenes are potent immunosuppressive agents that affect immune cells and modify immune responses as a consequence of other tissue damage (Sharma 1993).

Fusarochromanone

This mycotoxin is produced by *Fusarium equiseti.* When grown on autoclaved moist corn and fed to chicks as three percent of their ration, this fungus produced a high percentage of leg lesions typical of tibial dyschondroplasia (TDP). The lesions show up in a cone of cartilage extending distally from the proximal tibiotarsal physics. (Walser et al. 1982). When added at 75 ppm to broiler check rations, fusarochromanone resulted in TDP in 100 percent of the chicks, and killed chick embryos in fertilized eggs (Lee et al. 1985).

Fumonisin

This mycotoxin is produced by certain strains of *Fusarium moniliforme*, a fungus that is commonly found in corn. This fungus has long been associated with occasional outbreaks of blind staggers (equine leucoencephalomalacia) in horses (Wilson et al. 1985). This toxin has also been shown to be carcinogen in laboratory tests using rats, and has been reported to be associated with pulmonary edema in swine (Gelderblom et al. 1988, Ross et al. 1990). A recent review by Nelson et al. discusses these animal diseases caused by fumonisins. These include equine leukoencephalomalacia, porcine pulmonary edema, and experimental liver cancer (Nelson et al. 1993).

Day-old chicks fed diets containing 450 and 525 ppm of fumonisin for 21 days had lower feed intakes and body weight gains. Levels as low as 75 ppm increased the free sphingosine levels (a principal long-chain base found in sphingolipids that are associated with nerve tissue). Inhibition of sphingolipid formation is thought to be the mechanism of action of fumonisin B_1. This may suggest that feed containing 75 ppm of this compound is toxic to young broiler chicks (Weibking et al. 1993). In another study, Weibking found that day-old poults fed rations containing 199 and 200 ppm of fumonisin B_1 for 21 days had lower body weight gains and feed efficiency when compared to the controls. There were also differences in organ weights and blood parameters. He concluded that *Fusarium moniliforme* culture material containing fumonisin, is toxic to young turkey poults and that the poult appears to be more sensitive to the toxin than the broiler chick (Weibking et al. 1993).

Steers fed diets containing fumonisins at 15, 31, or 148 ppm (mg/g) for 31 days had no treatment-related effect on feed intake or weight gain, but it appeared that the feed containing 148 ppm was less palatable. Mild liver lesions were found in two calves fed the highest level of fumonisin. Lymphocyte blastogenesis was significantly impaired at the end of the feeding period in the group having the highest dose. Fumonisins can cause changes in liver function and have some effect on the immune function. Cattle, however, seem to be less susceptible to fumonisins found naturally in grains than either swine or horses (Osweiler et al. 1993).

Murphy et al. analyzed fumonisin B_1, B_2, and B_3 contents of corn from the 1988 to 1991 Iowa corn crop. Fumonisin B_1 concentrations ranged from 0 to 14.9, from 0 to 37.9, and from 0 to 15.8 ppm in corn collected and analyzed in 1988, 1989, 1990, and 1991, respectively. They found that corn screenings had about 10 times the fumonisin content than intact corn (Murphy et al. 1993).

Fusarium moniliforme contaminated corn consumed by humans in certain areas of the world is associated with higher incidence of esophageal cancer, and the fumonisins may be responsible. These compounds are structurally similar to sphingosine, and they exert their biological activity through blocking sphingolipid biosynthesis (Norred 1993).

Mycotoxin Control and Management

Mycotoxin production in the field is hard to control. Know and follow practices that minimize mycotoxin production during production and harvesting. When weather conditions or hail predispose grain to infection by toxic fungi, it is best to treat this grain with extreme caution. Testing each suspect lot of corn would help in making decisions about feeding. Be aware of the presence of mold on ripening grain and the possible feeding significance. If feeding problems occur, work closely with a veterinarian to determine the possible presence of mycotoxins.

Storage of grain and feed at low moisture and temperatures will help prevent fungus growth. *Fusarium* species, for example, will not grow in starchy seeds unless the moisture content is higher than 22 to 24 percent. Always follow the recommended removal rates in stave silos to prevent surface growth of potentially toxic fungi. Apply chemical preservatives correctly to ensure complete coverage. Monitor and aerate treated grain as you would dry grain.

In the U.S., aflatoxins are the only mycotoxins that are formally and specifically regulated. Be aware of the action levels when feeding livestock.

Feed preservatives, such as propionic acid, may decrease the chances of mycotoxin production (Smith et al. 1982, Tabib et al. 1987). Hydrated sodium calcium aluminosilicate (HSCA), when used as a feed anti-caking agent, has been shown to bind aflatoxin and to diminish the adverse effects of feeding harmful levels of aflatoxin to broiler chicks (Phillips et al. 1987).

Improvements in growth rate for crossbred pigs (41-day trial) occurred when HSCA at a rate of a half of a percent was added to a ration that contained 840 ppb of aflatoxin. In another trial of 42 days, HSCA improved average daily gain and all clinical chemistry indicators that had been negatively affected by the diets containing 800 ppb of aflatoxin. Two sodium bentonites tested had the same effect as HSCA. There was no apparent benefit to adding more than one-half percent sodium bentonite for maximum effect (Lihdemann et al. 1993).

The addition of HSCA at one-half or one percent of the ration did not influence average daily gain of piglets in a series of trials conducted with corn naturally contaminated with deoxynivalenol at 15 mg DON/kg. Piglets fed this corn at 72, 50, and 25 percent of their diet suffered a severe reduction in growth rate. Feed intake and gain-to-feed ratio were not reliable criteria due to excessive feed wastage by the pigs fed (Patterson et al. 1993).

Scheidler tested the efficacy of four HSCA brands and found Novasil and Zeobrite to have the highest rates of sorption when tested in a methanol solution (Scheideler et al. 1993).

Kubena et al. fed day-old broiler chicks rations containing 3.5 ppm aflatoxin (AF) and 5 ppm diacetoxyscirpenol (DAS) singly and in combination. Body weight gains were depressed by AF and DAS, and a synergistic interaction occurred between AF and DAS for a further depression of weight gains. Adding hydrated sodium calcium aluminosilicate resulted in almost total protection against the effects caused by AF alone. There was limited protection against the combination and no protection against the DAS alone. These findings suggest that HSCAS can diminish the adverse effects of AF, but not of DAS (Kubena et al. 1993).

Cleanliness in the feed houses should be promoted whenever possible. Remove caked and obviously molded grain from transport trucks, storage bins, conveyors, and feeding troughs. A North Carolina field trial showed that removal of moldy, caked feed from the above equipment by scrubbing and disinfection resulted in improved body weight, pigmentation, and carcass grade of broiler chicks (Hamilton 1975).

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16

EPA Regulations for Stored Grain

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Introduction

Pesticides are products that are used to kill various pests. Classification for pesticides include herbicides, insecticides, fungicides, and others. In grain storage, the primary pesticides utilized are insecticides, including grain protectants, residual sprays, and fumigants.

Pesticide Laws

There are several federal and state laws that regulate the use of pesticides. If a pesticide is used in a manner not allowed by law, the applicator can be fined or even imprisoned. Every applicator is responsible for knowing the specific requirements for proper application.

FIFRA

For pesticide applicators, one of the most important laws to become familiar with is the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). This law regulates the use of pesticides and requires that certain pesticide applicators be certified. These regulations include:

- **Classification of pesticides.** All pesticide must be classified as either general or restricted use. Manufacturers must register all pesticides with the Environmental Protection Agency (EPA). When the pesticide is registered, each use of the pesticide is classified. There are two classifications:
  a. **General Use Pesticides (GUP)** are pesticides that present little or no potential danger to persons or the environment when applied according to uses specified on the label. These include grain protectants and residual sprays.
  b. **Restricted Use Pesticides (RUP)** are pesticides that may have adverse effects on humans and/or the environment even when used according to the label. They are called "restricted use" because there are specific regulations governing their use. Included in these are all the fumigants.
- **Certification of pesticide applicators.** Private pesticide applicators using restricted use pesticides must be certified. All commercial applicators must also be certified. In many cases, in order to purchase or use pesticides, an applicator must be certified, depending on which category the applicator belongs. It is strongly recommended that everyone who supervises, handles, or applies any pesticide be certified, even if they are not required to do so by law.

The EPA has set minimum national standards of competency for the various categories of pesticide applicators. These laws are regulated and enforced at the national level by the EPA. They are enforced at the state level by the state lead agency for pesticides (Department of Agriculture, Natural Resources).

If an applicator violates FIFRA, he/she is subject to civil and possible criminal penalties. Civil penalties can be as much as $5,000 for each offense. Before the EPA or the state can fine an applicator, he/she has the right to ask for a hearing in their own city or county. Criminal penalties can be as much as $25,000, one year in prison, or both.

Other Laws

In addition to FIFRA, there are other federal and state laws governing pesticides. Listed in this chapter are the main activities involving pesticides that are regulated by these laws.

Other aspects of pesticide use that are regulated by laws include shipment of pesticides (land and water), safety of pesticide workers, pesticide residues in or on farm products, disposal of pesticide waste products, pesticide spills, and pesticides in aquatic environments.

Worker Safety (OSHA)

An employer with 11 or more workers is required to keep records and make reports to the Occupational Safety and Health Administration (OSHA) in the U. S. Department of Labor. The records must include all work-related deaths, injuries, and illnesses. You do not have to record minor injuries needing only first aid treatment. But a record must be made if the injury involves:

- medical treatment,
- loss of consciousness,
- restriction of work or motion, and
- transfer to another job.

Pesticide workers are also protected by EPA rules regarding when they may safely enter a treated area. Re-entry intervals are stated on the pesticide label.

Residues (EPA)

Any pesticide that stays in or on raw farm products or processed food is called a residue. The amount of residue allowed on these products is determined by the EPA under regulations authorized by the Federal Food, Drug, and Cosmetic Act.

The EPA sets residue tolerances. A tolerance is the concentration of a pesticide judged safe for human use. Tolerances are expressed in "parts per million" (ppm). One ppm equals one part (by weight) of pesticide for each million parts (by weight) of farm or food products. For example, using pounds as a measure, 50 ppm would be 50 pounds of pesticide in a million pounds of the product. A pesticide may have different tolerances on different products. For example, the tolerance might be 5 ppm on wheat and 2 ppm in flour. If too much residue is found on a farm or food product, the product may be seized or condemned. The Food and Drug Agency (FDA) inspects food and feed for pesticide residues, while the U.S. Department of Agriculture (USDA) inspects meat and meat by-products for pesticide residues.

Pesticide Label

Label information is the result of years of research and testing for each pesticide put on the market. These tests include:

- toxicological tests—to determine possible health hazards to humans and animals;
- metabolism studies—to see how long it takes a compound to break down into simple, less toxic materials;
- residue tests—to determine how much of the pesticide or its breakdown products remain on farm products, including crops, meat, milk, and eggs;
- soil movement tests—to determine how long a pesticide remains in the soil, and how it moves in the soil and to ground water;
- wildlife tests—to determine the immediate and long-range effects on wildlife; and
- performance tests—to prove that the pesticide controls the pest and improves the quality and quantity of the crop.

The EPA reviews these test results and determines whether to approve the pesticide. Once it is approved, the pesticide is registered. Information on the label and all supplemental labeling must not differ from the information given to the EPA when the product was registered. The label is the information printed on or attached to the pesticide container or wrapper. Labeling refers to the label plus all additional product information, such as brochures and flyers provided by the manufacturer or dealer. Both the label and supplementary labeling are legally binding documents and must be followed.

State labels—that is, special local needs (24c) and emergency labels (Section 18)—need to be in the hands of the applicator at the time of the pesticide application.

Applicator Safety and Protective Clothing

The best protection when working with pesticides is to avoid all direct contact with the pesticide. To do this, special clothing and protective devices should be worn. Contaminated clothing and equipment also require careful handling. Many items can be cleaned and used again, but some may need to be discarded. Personal cleanliness is also very important. Persons handling pesticides should shower each day after they use pesticides. The pesticide label will state if special protective clothing and devices are needed. Always read the label before handling any pesticides to determine the type of protective equipment recommended.

Handling Contaminated Clothing

Pesticides can cling to and be absorbed by protective clothing. Therefore, it is important to use special care when handling the clothing. In order to handle and wash clothing as safely as possible, know:

- when and which pesticides have been used, and
- the formulation—emulsifiable concentrates (EC) are very difficult to remove from fabrics; wettable powders (WP) benefit from prerinsing.

Wear chemical-resistant gloves when handling clothing which has been exposed to pesticides. Keep protective clothing separate from other clothing until the protective clothing has been laundered.

Most pesticides can be removed from clothing.

However, if undiluted emulsifiable concentrates have spilled on any clothing, discard the clothing (except for spills on the outside of rubber or neoprene gloves and boots). Washing will not remove enough pesticide to make clothing contaminated with concentrates safe to wear. If the pesticide was diluted, then one washing will remove nearly all of the pesticide. Do not wear protective clothing again until it has been washed.

Wash clothing daily when handling pesticides. The longer the clothing is stored before washing, the harder it may be to remove pesticide. Use hot (140°F) water, a full-load cycle, high-phosphate detergent, and a long wash cycle. After the clothing has been washed, air dry them. Do not dry them in a dryer. Run another cycle through the washer with the same setting, water temperature, and detergent. This will "clean" the washer drum of any pesticide that may have been deposited during the previous wash.

Respiratory Devices

When to Use Respiratory Devices

A pesticide applicator should always wear respiratory protective devices if there is any risk of inhaling pesticide vapors or fumes, especially if the label states, "Do not breathe vapors or spray mist," or, "Harmful or fatal if inhaled." The risk of inhaling pesticides is greatest:

- if a person is exposed to pesticides for long periods,
- if a person dilutes or mixes concentrates,
- if sprays or dusts are used,
- if pesticides are highly toxic, or
- if work is performed in an enclosed area.

Types of Respiratory Devices

There are several types of respiratory devices. Each type is useful for only certain activities. There is no all-purpose device. Make certain that the correct one is used. Always read and follow instructions.

Mixing and Loading Pesticides

The most hazardous part of applying pesticides occurs during mixing and loading. At these times, the applicator is handling the pesticide in its most concentrated form, and there is a greater risk of exposure and serious poisoning. The applicator should protect himself and others by following these precautions:

- Read the label before opening the container. If at all possible, don't work alone. Let someone—a spouse or a neighbor—know where the pesticide application is taking place and which pesticide is being used.
- Always measure materials accurately. Use only the amount stated on the label. When pouring a pesticide, keep the container well below eye level to protect eyes and face from exposure. If the concentrate has to be removed from a drum or other large container, always use a pump or threaded and valved piping. Replace pour caps and close bags or other containers immediately, and return containers to the storage area.
- Work outdoors when pouring and mixing pesticides. If work must be done indoors or at night, be sure there is good ventilation and enough light.
- If a metal or plastic container has been emptied, triple-rinse it and empty the rinse water into the spray tank. Measuring cups should also be triple-rinsed and the rinse water emptied into the spray tank.
- If a pesticide is splashed or spilled while mixing or loading, stop working immediately and clean up the spill. If any concentrate has spilled on clothing, remove the contaminated clothing and wash body area affected. Speed is essential.

Storing Pesticides

The way in which pesticides are stored is almost as important as the way they are used. If the pesticide is not stored in a safe place, accidents can happen—children and livestock can be poisoned, pesticide containers can be damaged, and pesticides can be ruined. Read the label to see if any special steps should be taken before storing the pesticide, and then store the material immediately.

Storage Containers

Pesticides should be stored in their original containers with the labels intact. Never put pesticides in other containers, such as pop bottles, feed bags, or open buckets. Dispose of any containers that do not have intact labels.

Check periodically for leaking containers. If a container is defective, it should be repaired. If this is not possible, then transfer the contents to another container with an intact label which has held exactly the same product. Then dispose of the defective container in the proper manner.

Storage Areas

Pesticides should be stored in a locked storage room or cabinet where children, unauthorized people, or animals cannot enter. Make sure the windows are tight—board them up if necessary.

The storage facility can be in a separate building or in a separate area within a building. The area should be used only for pesticides and pesticide equipment. Never store pesticides with food, feed, seed, planting stock, fertilizers, veterinary supplies, or protective equipment. Do not store protective equipment with pesticides. Store herbicides separately from other pesticides.

The storage area should have a concrete floor which is impermeable (that is, one that will not let fluids pass through) and easy to wash. Ideally, the structure should be fire-resistant. When storing large amounts of pesticide, install fire-detection devices and have fire extinguishers and other firefighting equipment readily available. As an extra precaution, let the local fire department know that you are storing large quantities of pesticides, giving them the location and the kind of pesticides being stored. Post warning signs for firefighters and others.

The storage area should be well lit, well ventilated, and well insulated against temperature extremes. Never allow pesticides to become overheated. Do not store them close to any source of heat, as heat may cause liquid formulations to expand and an accident could occur when the containers are opened. Some pesticide formulations catch fire if they become overheated.

Pesticides, especially liquids, also must be protected against freezing. Some pesticide formulations separate at low temperatures, making it difficult or impossible to mix them. Low temperatures also can cause pesticide containers to rupture. The labels of most liquid products state the lowest temperatures for safe storage. Dry formulations packaged in sacks, fiber drums, boxes, or other water-permeable containers should be stored on pallets or metal shelves. Do not store dry materials below shelves containing liquid material—if the liquids leak, they could contaminate the dry formulations. Metal pesticide containers also should be placed on pallets or shelves to help reduce corrosion.

The following supplies should be available in the pesticide storage area: detergent, hand cleaner, and water; absorbent material, such as absorbent clay, sawdust, vermiculite, kitty litter, or paper to soak up spills; flat-faced shovel, broom, and dustpan; fire extinguisher rated for ABC fires; and storage drums for containers that leak.

A pesticide storage facility should never be used for other purposes, even if pesticides are no longer stored there. It is almost impossible to totally decontaminate a pesticide storage facility.

How Long Can Pesticides be Stored?

Before storing pesticides, mark the date of purchase on the container. The shelf life is difficult to predict—manufacturers usually recommend no more than two years. Once a container is opened, the shelf life is greatly reduced. One of the best ways to lower the risk of pesticide accidents is to buy only the amount needed for immediate use. This reduces the need for storage.

Disposing of Pesticide Waste

Improper disposal of pesticide wastes can create serious hazards for humans and the environment. These wastes include excess pesticides, unrinsed empty pesticide containers, and materials containing pesticide residues. Answers to the waste-disposal problem are not easy to come by. Potential problems can be reduced by following the guidelines listed below. These guidelines are subject to revision as new information becomes available.

Plastic and Metal Containers

Triple-rinse empty containers. All empty plastic and metal pesticide containers must be triple-rinsed before they are discarded and the rinse water reused. This is the single most important step in disposing of pesticide containers. No matter how they will eventually be disposed of, containers that have been properly triple-rinsed pose a far smaller hazard to the environment than unrinsed containers.

To triple-rinse containers:

1) Empty the pesticide into the spray tank and let the container drain for 30 seconds.
2) Fill the container 10 to 20 percent full with water (or solvent in some cases) and rinse.
3) Pour the rinse water into the tank and drain the container again for 30 seconds.
4) Repeat steps 2 and 3 two more times.
5) Puncture and flatten the can so that it can't be used again.
6) Another option is to jet-spray the container after it is empty. This method is as effective and is quicker than steps 1 through 4.

The rinse-pour-drain method can be tedious and time-consuming, especially during your busiest season. Jet-spraying is an easier method. An inexpensive jet-spray that attaches to a hose is available from several manufacturers. The jet-sprayer is inserted through the bottom of a container to make a vent. A 60-second spray with a jet-sprayer has the same effect as a triple-rinse.

The idea is to avoid haphazardly dumping pesticide residues on the ground. The rinse water may be put into the spray tank and used on a crop or other site listed on the label, or the rinse water may be put into a storage tank for mixing later in a solution of the same pesticide.

Recycle rinsed containers. Triple-rinsed containers can be recycled. A list of dealers who recycle these containers can be obtained from your county extension office or pesticide dealer. Large pesticide drums also can be returned to the manufacturer.

Applicators who cannot recycle rinsed containers should have them buried at an approved landfill. Under no circumstances should rinsed containers be carelessly discarded. Keep empty containers in your pesticide storage area until you dispose of them.

Paper Containers

Before disposing of paper containers, make sure they are completely empty. Thoroughly empty the contents into application equipment. Then dispose of the bag at an approved landfill.

Note: Some landfill operators may not accept pesticide containers. They are legally liable for environmental and health problems that may occur because of unrinsed containers buried in their landfill. They may not want to take chances with plastic and metal containers that may not have been triple-rinsed or paper containers that may not have been thoroughly emptied. Applicators and landfill operators need to discuss possible solutions. Cooperation is the key to practical, legal container disposal.

Excess Pesticide Mixtures

Excess pesticide mixtures include:

- leftover solutions after application is completed,
- water used to wash the outside of the application equipment,
- spray left in the boom or hoses,
- haul-back solutions from a spraying job interrupted by weather or equipment breakdown, and
- small quantities of material spilled during mixing.

Excess pesticide mixtures should be collected and used again. They can be used on a crop or other site listed on the label, or stored for mixing future solutions of the same pesticide. To make it easy to collect these excess pesticide mixtures, mix pesticides and clean equipment on an asphalt or cement pad equipped with an above-ground tank to hold runoff.

In the Event of a Spill or a Fire:

1) Be prepared—pesticide spills can be a serious threat to humans, livestock, and the environment. Danger can be reduced if it is known in advance what to do in the event of a spill.
2) Know your pesticides. Obtain material safety data sheets (MSDS) and/or emergency response information sheets for the products from the manufacturer. These sheets specify how to handle a specific pesticide during an emergency.
3) Keep emergency numbers handy.
4) Whenever working with pesticides, wear protective clothing. If pesticides are to be transported, carry protective clothing in the truck.
5) The following is a list of things to do if a spill occurs.
   a) Act quickly.
   b) Protect yourself.
   c) Control the spill (stop the leak).
   d) Contain the spill (keep it from spreading).
   e) Guard the site.
   f) Notify the authorities.
   g) Clean up the spill.

Stored Product Grain Fumigation

Fumigation is a very specialized application of pesticide and requires significant attention to detail to maintain safety and ensure satisfactory results.

Fumigation

Grain managers will fumigate some of their stored grain at least once a year. Regulations relating to fumigation change periodically. The decision to fumigate involves thorough planning to arrive at the best solution for each business and ensure employee safety. Some items to consider in the decision-making process include federal/state regulations, cost of fumigating (both self and hired), and feasibility.

If grain personnel are to conduct the fumigation, some key factors to consider include the availability of personnel for the operation, safety equipment required, cost, and maintenance of safety equipment. Include the cost of sealing material (i.e., plastic tape, foam), placards, and lockout devices. Be sure to calculate the cost of obtaining and maintaining applicator certifications and a fumigation business license (if required by state regulatory agency). Insurance companies often provide safety programs for their clients. These programs are effective and can lead to reduced insurance rates.

Once the decision to fumigate is made, someone needs to become certified in the appropriate pesticide applicator category in their state(s). Some state laws require a core, a category, and a practical examination. Certain states also require a certified applicator on site at each location fumigated. Since all fumigants are restricted use pesticides, each person applying the fumigant will need to be certified or be under the direct supervision of a certified applicator.

Some states have "minimum" standards that must be met in addition to federal and label requirements (e.g., Oklahoma has 10 such standards). The applicator must be aware of these standards. One such standard for Oklahoma requires, "All dwellings or places of business within 10 feet of the building being fumigated must be notified in writing in advance of fumigation. All premises within 10 feet must be vacated during the fumigation and aeration periods." This includes scale houses, loading docks, headhouse, galley, and other areas. States often have different recordkeeping requirements. Fumigators working in multiple states must be aware of these requirements and follow them.

All commercial applicators are required to maintain specific records of their pesticide applications. Required information includes:

a) name and address of the person for whom the pesticide was applied;
b) location of the pesticide application;
c) target pest;
d) specific crop or commodity, and site to which the pesticide was applied;
e) year, month, day, and time of application;
f) trade name and EPA registration number of the pesticide applied;
g) amount of the pesticide applied and percentage of active ingredient per unit of the pesticide used; and
h) type and amount of the pesticide disposed of, method of disposal, date(s) of disposal, and location of the disposal site.

These records are to be kept for a minimum of two years at their principal place of business for each self-employed certified commercial applicator, each firm employing a certified commercial applicator, and each person who contracts with a certified commercial applicator to have a restricted use pesticide applied on property owned or operated by another person. Records not required by the EPA, but that should be kept, include length of fumigation time, date of aeration, method of monitoring air, monitoring results, and clearance procedure.

Training material for applicator certification can be obtained from the Cooperative Extension Service in your state or from your State Lead Agency within your state.

Safety Program and Equipment

All references to respirators refer to either full-face gas masks or self-contained breathing apparatus (SCBA).

A thorough safety training program is the first requirement for fumigation. This program should include knowledge of the fumigant to be used, the person who will apply the fumigant, applicator understanding and use of safety equipment (includes knowledge of equipment use and applicator's physical ability), required safety equipment, emergency response and escape programs, monitoring programs, and notification and de-notification. The key to a safety program is to identify and explain the hazards of the operation, how to avoid them, and how to properly use safety equipment. An integral part of a safety program is conducting rehearsals of the fumigation process and emergency evacuation. The safety program should be written down to document how the program will be conducted. This will allow review and improvement of the program when needed, and also meets OSHA regulations.

Figure 1. Sealed bin top.

A substantial amount of safety equipment is required for fumigation. Most safety equipment required by the EPA is due to fumigant labeling. Many safety requirements are spelled out on the fumigant label, thus making them a requirement.

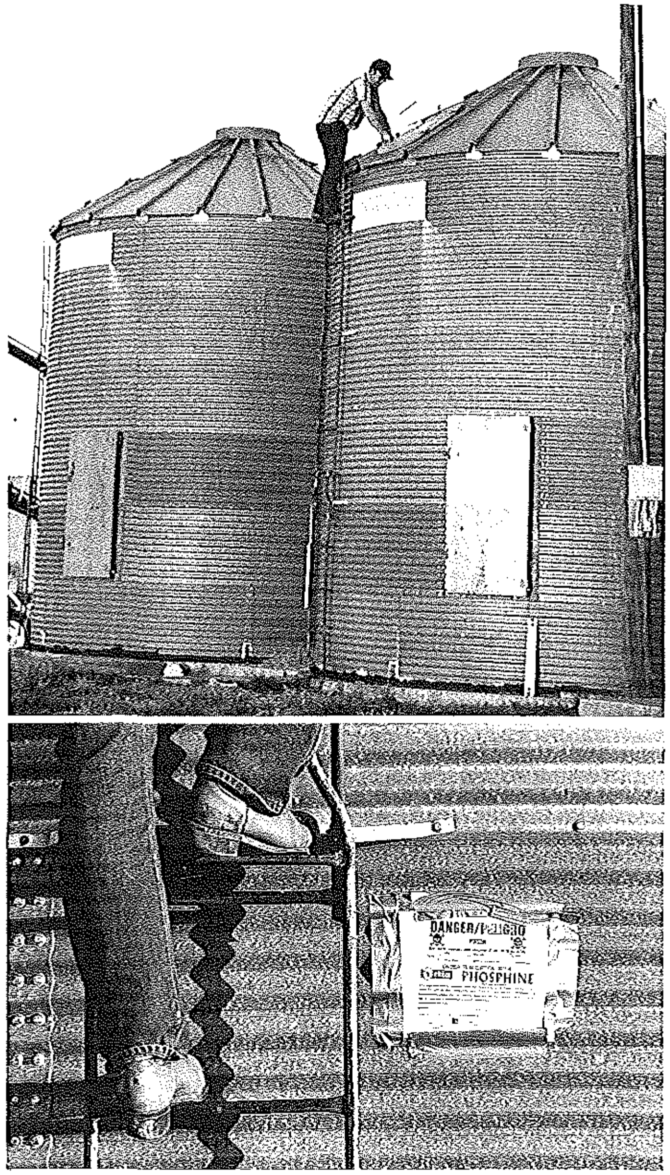
A written equipment maintenance schedule should be followed for all safety equipment. Maintenance schedules are often provided by the manufacturer for each piece of equipment.

Sealant materials (plastic and tape) are a starting place for developing an inventory of safety supplies and equipment. The structure must be sealed (Figure 1) or the

Figure 2. Sealed floor.

job will not be successful (Figure 2) and can endanger employees and other persons.

Placards must be in place on site before fumigation begins. Each entry point should be placarded. This includes tops of bins and entry ways that "seem" inaccessible (Figures 3a and 3b). Some state laws specify the size and color of placards and what is to be written on the placard. Occasionally, placards provided by fumigant companies do not comply with some state requirements for placards. Be sure that the placards contain the name of the fumigant being used, date of release, name and telephone number of applicator, and other needed information. Also, be careful in naming the fumigant. For example, "Phostoxin" will not suffice for "Fumitoxin" on a placard in Oklahoma. It may be better to use "aluminum phosphide" rather than a trade name of one of the aluminum phosphide fumigants. This eliminates any confusion that may occur as to which fumigant trade name should be displayed.



Figures 3a and 3b. Placarding top opening (top). Placarding by ladder access (bottom).

Figure 4. Gas mask and canister.

Lockout devices must be in place before releasing a fumigant. This includes lockouts for equipment and doors. Equipment lockout is required to ensure that no one accidentally starts camload conveyors while personnel are in the structure or augers out grain being fumigated, exposing themselves and others to the fumigant. Conveyor tunnels and other storage access points must be adequately placarded, sealed, and locked. Placards are not to be removed until the fumigant level is at or below the permissible level stated on the label.

Some labels require monitoring of the areas within 10 feet of the fumigated area. If the label includes such a statement, the air must be monitored and the levels recorded, even if the level is zero.

The correct number of full-face respirators (gas masks) with the proper canisters (Figure 4) or SCBAs must be available before releasing the fumigant. Some states require SCBAs to be available on site. Standard respirators will not provide any protection from a fumigant.

Regulations for respirators and SCBAs are under both the EPA and OSHA. OSHA has specific regulations for respirator use which is covered in 29 CFR 1900-1910. Before using respirators, read, understand, and follow OSHA regulations.

Re-entry

For proper re-entry, a method of ventilating the storage must have been established in advance. Also, air monitors must be available and the detection method predetermined. This is a tricky situation. Technically, if the concentration of the fumigant is not known, an SCBA must be worn to enter the area to monitor the air. This can be avoided by either spending the money for monitors that are placed inside the fumigation area and read outside, or those that can draw samples from inside to an outside reading device. The hand-held pump (Figure 5) with tubes (specific for fumigant and level of fumigant) is the standard air monitoring practice. After monitoring the air several times during a fumigation ventilation process, one can enter the ventilated storage areas at later fumigations without an SCBA once it has been documented that the gas concentration during this stage of ventilation is at an appropriate level. The previous air monitoring procedure was approved by a state regulatory official. Before following this example, check with the appropriate regulatory official(s). If an SCBA is required, at least one, and very likely two, must be available. The second SCBA is for emergency use. This can become expensive since one SCBA costs about $1,800.

Notification of local law enforcement officers and fire departments must be made before and after the fumigation job. Be prepared to explain why and how the fumigation is to be conducted. Be sure to include the safety program and aeration process. Some people may think aeration means releasing large quantities of toxic gas into the air. Notification of law and fire officials after aeration simply informs them that the operation is completed.

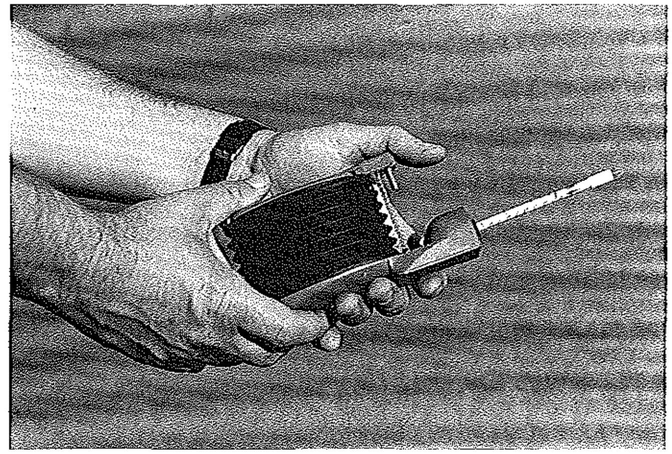


Figure 5. Hand pump and disposable detection tube.

Emergency plans must be available for use during the release of the fumigant, during fumigation, and during aeration or ventilation. These plans should be in writing. This portion of the safety plan should be rehearsed at least twice a year. Rehearsals provide the opportunity to detect problems in the plan, and to correct them. It also allows the workers to become familiar with what to do in case of an emergency.

Remember, all safety equipment must be doubled—one for the certified applicator and one for the assistant.

Aluminum Phosphide Fumigation

The following information has been derived from various aluminum phosphide labels, literature, or safety publications. Many of the labels stress that applicators be trained. The phosphide information is used as a model and other fumigant application requirements will vary significantly.

Aluminum phosphide should be stored in a cool, dry, well-ventilated, and locked area. The storage area should not be in buildings where humans reside or work and should be marked with a sign. While this may create problems for some, it can be overcome by having special storage areas for pesticides. Special storage areas can either be in separate buildings or in areas where no workers are present.

Most phosphide labels suggest opening containers in open air, or near a fan with immediate outside exhaust or one that blows away from the individual opening the container. Never open a flask in a flammable atmosphere—some canisters have been known to flash. Hold the container opening so that it points away from the face and body.

Be sure to wear dry gloves made of cotton or other appropriate materials to prevent moisture on hands from releasing the fumigant. When aluminum phosphide comes into contact with moisture, release of the fumigant begins.

Used aluminum phosphide flasks are to be disposed of by triple-rinsing flasks and stoppers with water. The containers can then be offered for recycling or reconditioning. The flasks can also be disposed of in an approved landfill. Another method is to place empty flasks, without stoppers in place, outdoors or in the structure being fumigated until residue in the flasks is reacted. Then puncture and dispose of flasks in an approved landfill.

Disposal of spent dust must be done carefully because the small amount of residual fumigant can react with water and cause a fire. Generally, if the material is properly exposed, the residual dust will be spent, resulting in a non-hazardous waste. If incompletely exposed pellets or tablets exist after aeration, they must be handled very carefully since they can release the fumigant and are a fire hazard. Placing pellets or tablets on a wood or paper surface on top of the grain, when permissible, makes collection of the dust easier.

If a small amount (five flasks or less) of residual dust remains, it may be disposed on-site by burial or by spreading over the land surface away from inhabited buildings. Three to four pounds of residual dust (three flasks) may be collected in a one-gallon bucket for holding or disposal. Larger quantities of residual dust may be collected in a porous cloth bag (burlap, cotton, or similar material) for holding or transportation to a suitable disposal site. Do not put more than one-half case (seven flasks of tablets, or 10 flasks of pellets) of residual dust in each bag. Do not use plastic bags, drums, dumpsters, or other containers where confinement may occur. Do not put dust into toilets.

Another disposal method is to fill a metal container two-thirds full with water outdoors or in an area that is ventilated immediately to the outside. For each gallon of water, add one-fourth cup of low-sudsing detergent or surfactant. Use no less than 10 gallons of water/detergent solution for each case of spent material. Slowly pour the dust into the container as the water is stirred. Wear appropriate respiratory protection. *Do not cover the container at any time.* Dispose of the water/dust mixture in a sanitary landfill or other suitable burial site approved by local authorities. Where permissible, the slurry may be poured out on the ground. If the tablets or pellets retain any green color, they must be disposed of using the wet procedure. Be sure to follow the directions on the label. Remember, not all labels are the same.

Transfer of incompletely aerated commodity to a new site is permissible. However, the new storage site must be monitored and placarded if more than 0.3 ppm is detected. Workers who handle incompletely aerated commodity must be informed and appropriate measures must be taken to prevent exposures from exceeding the threshold limit values (TLVs) for hydrogen phosphide. This means that if air monitors detect levels between 0.3 ppm and 15 ppm, workers must wear full-face respirators with the appropriate canister. If the detection level is greater than 15 ppm, the workers must wear SCBAs.

Aluminum Phosphide Air Monitoring

There are basically two types of air monitors—disposable and non-disposable. Disposable tubes have an accuracy range of plus or minus 25 percent of the reading. Thus, if the aluminum phosphide indicator tube reading is 0.3 ppm, the actual value range is from 0.225 ppm to 0.375 ppm. To be on the safe side with disposable tubes, a reading of less than 0.225 ppm is preferred to ensure a level of less than 0.3 ppm.

More accurate air monitors are also more costly. They can be set up to monitor the fumigated area automatically without entry. This is more expensive but may be worth the investment, especially if one monitoring machine can pull samples from a large number of storages. Also, if the inside level is monitored from the outside, an SCBA will not be needed unless entering at levels above 15 ppm. Drager offers a monitoring badge that, when worn, notifies the wearer of phosphine levels.

All air monitoring equipment must be well maintained and checked periodically ensure satisfactory operation and accuracy.

Placarding is not to be removed until the treated commodity is aerated down to 0.3 ppm or less. Predetermine the methods to be used for monitoring the fumigated grain before it is fumigated. This includes all fumigation sites—bins, trailers, railcars, and barges.

Full-face respirators (gas masks), with a yellow canister and an olive stripe, are required when the level is from 0.3 ppm to 15 ppm. Above 15 ppm, an SCBA is required. If the level is not known, an SCBA is automatically required.

The cost of respirators varies. However, a full-face respirator with one canister costs approximately $190. An SCBA costs approximately $1,500 to $1,800. Thus the cost for two applicators ranges from $380 to $3,600 for respiratory equipment alone.

Methyl Bromide

The following information has been derived from Great Lakes labels and other information sources.

Methyl bromide is to be stored in a locked, dry, cool, well-ventilated area. Cylinders are to be stored upright and secured to a rack or wall to prevent tipping. Do not subject cylinders to rough handling or mechanical shock, such as dropping, bumping, dragging, or sliding. Do not use rope slings, hooks, tongs, or similar devices to unload cylinders. Transport cylinders using a hand truck, fork truck, or other device to which the cylinder can be firmly secured. Do not remove the valve protection bonnet and safety cap until immediately before use. Replace the safety cap and valve protection bonnet when cylinder is not in use.

When fumigating enclosed spaces, two persons trained in the use of methyl bromide must be present during introduction of the fumigant, at initiation of aeration, and after aeration when testing for re-entry. Two persons do not need to be present if monitoring is conducted remotely—i.e., outside the building being fumigated.

The methyl bromide label states that it is not to be used when the temperature in the space, commodity, or structure to be fumigated is below 40°F. There are exceptions under APHIS quarantine treatment schedules.

Before fumigating with methyl bromide, remove:

a) all food and feed commodities that are not listed on the label;
b) medicinals not sealed in metal or glass;
c) seeds, bulbs, and live plants;
d) horsehair articles;
e) rubber goods (natural latex);
f) carbonless carbon forms and blueprints;
g) cinder blocks; and
h) articles containing sulfur.

Extinguish all open flames, including pilot lights. Turn off electric heating elements. Open all interior doors, openings into overhead areas, and crawl spaces to be treated.

If at all possible, methyl bromide fumigation should be done when the wind is light. Sealing is critical for good methyl bromide and other fumigation. If not done properly, the fumigation can result in failure and can be dangerous to others as well.

Buildings sharing a common wall should be cleared of occupants before fumigation. If this is not feasible, spread a glossy-type building paper along the adjoining wall to prevent spread of the fumigant to undesired areas. Sisal kraft paper, asphalt-laminated paper, heavily oiled draft or wrapping paper, and plastic film are appropriate. In all such cases where the adjoining building is occupied, the building should be checked frequently with a suitable gas detector during fumigation to ensure the safety of the occupants.

Doors or hatches on milling machinery should be opened prior to fumigation. These include elevator boots, conveyor lids, settling chambers doors, dust trunks, and any other openings that will allow fumigant into the equipment. Inside doors, cabinets, lockers, and drawers should also be opened to facilitate treatment and aeration. "Dead" spouts are particularly difficult to penetrate and should be opened before the fumigation.

Placards/posted signs should not be removed until the treated commodity is completely aerated.

Inside Release

Cylinders should be placed by a team of two people, and the location of each cylinder in the building should be mapped. Cylinders should be arranged so that the fumigators can walk away from the released gas as they open each subsequent cylinder.

Because methyl bromide is heavier than air, it is advisable to slightly increase the amount of fumigant released on the top floor. Cylinders should be placed within a room for best distribution into all areas. Cylinders also should be placed in an upright position and the shipping caps removed.

Fans are recommended to distribute the fumigant more quickly and to aid in aeration of the structure after the exposure period. The choice of fan for a given situation may depend upon experience or research data. Generally, one 16-inch fan for every 50,000 cubic feet of space will be sufficient. It is often possible to use heating system fans or other installations already in place for improved circulation or distribution of the fumigant.

All fans should be running while the gas is being released and left running until uniform distribution has been accomplished. They may be turned off from outside the building or by using timers.

Operators should not be in the building longer than 30 minutes while releasing the gas. If it is impossible for one crew to release the gas within this time period, additional experienced crews should be used. Two people should work together while the gas is being released and when clearing the structure.

Outside Release

Releasing methyl bromide outside the space to be fumigated will minimize applicator exposure. The building still must be prepared for fumigation.

Secure the ends of each "shooting" line or hose to each point where the fumigant is to be released, using evaporating pans or plastic sheeting to prevent possible damage to some surfaces. Run each line to the cylinder(s) located outside the area to be treated. Connect each line to the cylinder(s) or manifold.

Open the valves to release the fumigant. Respiratory protection equipment must be available in the event of a major leak or equipment failure.

Aerating the Building

When the exposure period is complete, aeration generally should be started by opening previously sealed doors and windows on the ground level. Ventilators accessible from the outside should be opened at this time.

After partial aeration, a team of a least two trained people with appropriate respiratory protection should begin opening windows, starting at the lower floors and working upward. Fans should be on to assist aeration. Aeration is usually complete in four hours, depending upon weather condition and cross ventilation. No one should be allowed inside the building without respiratory protection until the methyl bromide concentration is below 5 ppm in the work area.

Methyl Bromide Air Monitoring

Aeration is complete when each fumigated site or vehicle is monitored and contains less than 5 ppm methyl bromide in the air space around, and, when feasible, in the mass of the fumigated commodity. If less than 5 ppm methyl bromide is detected, placards may be removed. If 5 ppm or greater is detected, placards must be transferred with the commodity to the other site. Workers who transfer or handle incompletely aerated commodity must be informed and appropriate measures must be taken to prevent exposures from exceeding 5 ppm or greater methyl bromide.

Methyl bromide can be detected with either colormetric tubes or a halide gas detector (electronic or flame). The electronic or audible halide gas detector is the most commonly used type of halide gas detector. The unit emits a sound which increases in intensity and frequency as the concentration of gas increases. With the flame halide gas detector, a flame heats a copper ring. Methyl bromide gas (as well as fluoride, chlorine, and the freons) passing over the heated copper ring will cause the flame to be colored. The color will depend upon the gas concentration. A very light green indicates a low gas concentration, while a royal blue color indicates a high gas concentration.

There are a number of methyl bromide monitoring devices on the market which work well for measuring gas concentration within the fumigation area. Two of them operate on the thermal conductivity principle. One is the Fumiscope manufactured by Robert K. Hassler Company, Altadena, California; the other is the Gow-Mac unit manufactured by the Gow-Mac Instrument Company, Madison, New Jersey.

Fumigation Checklists

The following guidelines and checklists are suggested in order to comply with EPA standards while preparing for and conducting fumigation operations on various types of grain storage structures and transporting vehicles. □

Fumigation Checklist

Prefumigation:	Yes	No	N/A
Applicators and/or technicians certified	______	______	______
Business licensed with state	______	______	______
Training program completed	______	______	______
Persons trained in use of safety equipment	______	______	______
Reasons noted for fumigating (pests)	______	______	______
Commodity characteristics known: temperature greater than 60°F and moisture content known	______	______	______
Dosages calculated before fumigation	______	______	______
Proper amount of fumigant available	______	______	______
Local law enforcement notified	______	______	______
Local fire department notified	______	______	______
Doctor notified	______	______	______
Poison Control Center telephone number posted	______	______	______
Safety equipment tested	______	______	______
Two approved gas masks and canisters or two SCBAs on site	______	______	______
Proper detection equipment available	______	______	______
Fumigation procedure practiced	______	______	______
Escape plan practiced	______	______	______
Placards available	______	______	______
Facility inspected	______	______	______
Lockouts available	______	______	______
Sealing material and plastic sheeting available	______	______	______
Special problems identified (electrical boxes, heaters, cinder blocks)	______	______	______
Electrical, gas, water cut-offs identified	______	______	______
Time required to fumigate determined	______	______	______
Number of qualified personnel available determined	______	______	______
Buildings within 10 feet identified	______	______	______
Storage structure checked to ensure that no one is present	______	______	______
Aeration process reviewed	______	______	______
Facility sealed	______	______	______
Lockouts put in place	______	______	______
Warning signs posted at all entrances	______	______	______
All areas checked for moisture—phosphine will explode and burn when in contact with moisture	______	______	______
Electrical power cut off	______	______	______

Fumigation:	Yes	No	N/A
The name of person doing the fumigation recorded	______	______	______
Date and time of fumigation recorded	______	______	______
Usage rate of fumigant recorded	______	______	______
Fumigation record log sheet signed by personnel	______	______	______
Fumigation starting time noted	______	______	______
Proper fumigant canisters available	______	______	______
SCBAs on site, if required	______	______	______
Fumigators know evacuation plan	______	______	______
Persons evacuated in facilities within 10 feet of fumigated area	______	______	______
Communications established inside to outside	______	______	______
Fumigation begun	______	______	______
Watchman provided, if necessary	______	______	______

Post Fumigation:	Yes	No	N/A
Empty containers disposed of properly	______	______	______
Wait appropriate time to aerate	______	______	______
Facility aerated for appropriate time	______	______	______
Air monitored for level of fumigant	______	______	______
Tunnels monitored for level of fumigant	______	______	______
Monitored levels recorded	______	______	______
Methods of air monitoring recorded	______	______	______
Local law enforcement de-notified	______	______	______
Local fire department de-notified	______	______	______
Doctor de-notified	______	______	______
Placards removed	______	______	______
Electrical power turned on	______	______	______
Lockouts removed	______	______	______
Sealant tape removed	______	______	______
Date and time of aeration recorded	______	______	______
Records for applicators license completed	______	______	______

Equipment Needed to Fumigate Grain:

______ Probes

______ Tape

______ Cotton gloves

______ Plastic sheets

______ Placards

______ Man-in-bin signs

______ Locks

______ Bin re-entry signs

______ Gas mask with appropriate canisters

______ SCBAs (two minimum)

______ Air testing equipment (for fumigant and for oxygen)

______ Harnesses

______ Communication devices with men in bin

17

Chemical Management

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Protectants

Malathion, chlorpyrifos-methyl (Reldan), pirimiphos-methyl (Actellic), synergised pyrethrins, methoprene, *Bacillus thuringiensis* (Dipel), and diatomaceous earth are currently labelled as protectants for grains stored in the United States. However, each individual insecticide listed cannot be applied to all types of grains produced. The three most commonly used insecticides are malathion, chlorpyrifos-methyl, and pirimiphos-methyl, and all are organophosphates.

Malathion has been labelled for all major stored grain commodities since 1958, and for many years it was the primary chemical used to control insect pests in stored grain. The established EPA tolerance is 8 ppm. In recent years, most of the common insect pest species in stored grain have developed various levels of resistance to malathion (Beeman et al. 1982, Zettler 1982, Haliscak and Beeman 1983, Arthur et al. 1988, Halliday et al. 1988, Sumner et al. 1988, Subramanyam et al. 1989, Subramanyam and Harein 1990, Beeman and Wright 1990, and Wienzierl and Porter 1990). The manufacturers notified the EPA of their decision to withdraw the use of malathion on grain in November 1990. Manufacture of this product for grain use will be discontinued.

Chloryprifos-methyl was labelled in 1985 at a tolerance of 6 ppm for barley, oats, rice, sorghum, and wheat. Several recent reports indicate that some populations of the lesser grain borer, *Rhizopertha dominica* (F.), in the midwestern United States may be developing resistance to chlorpyrifos-methyl (Beeman and Wright 1990, Zettler and Cuperus 1990). This species has been removed from the label. Pirimiphos-methyl was labelled in 1986 for corn and sorghum at a tolerance of 8 ppm, and the label specifies that the lesser grain borer will be suppressed, not controlled. Pirimiphos-methyl resistance has been reported for the hairy fungus beetle, *Typhaea stercorea* (L.), (Weinzierl and Porter 1990), and the Indianmeal moth, *Plodia interpunctella* (Hübner) (Sumner et al. 1988). Registrations for both chlorpyrifos-methyl and pirimiphos-methyl may be expanded in the future.

Two chemicals which are rarely used as protectants are methoprene and synergised pyrethrins. Methoprene, an insect growth regulator, is much more expensive than other synthetic insecticides. It occasionally is used as a surface treatment and the tolerance is 5 ppm. Synergised pyrethrins (natural pyrethrins plus piperonyl butoxide synergist) have been registered as protectants for many years, but have not been extensively used because of limited supply, high cost, and the availablity of synthetic insecticides. They also are usually applied to grain surfaces; tolerances are 3 ppm for synergised pyrethrins and 20 ppm for piperonyl butoxide on grains other than oats. The tolerance for oats is 1 ppm for synergised pyrethrins and 8 ppm for piperonyl butoxide.

Diatomaceous earth (Insecto), an inorganic insecticide mixture of soil and the cell walls of diatoms, also has been labelled for many years, but is rarely used in management programs. The toxic effects occur when the insecticide causes cuticle abrasions and breaks in the insect exoskeleton, and the insect eventually dies from dessication (Zettler and Redlinger 1984). This insecticide is only available as a dust formulation which can be irritating to workers. No EPA tolerance is required for diatomaceous earth.

Bacillus thuringiensis is a naturally occuring pathogen isolated from insects and is exempt from tolerance regulations (EPA 1988). It is labelled as a surface application for Lepidopteran larvae, which are the only pests controlled by the available *Bacillus* strains. Recent reports have

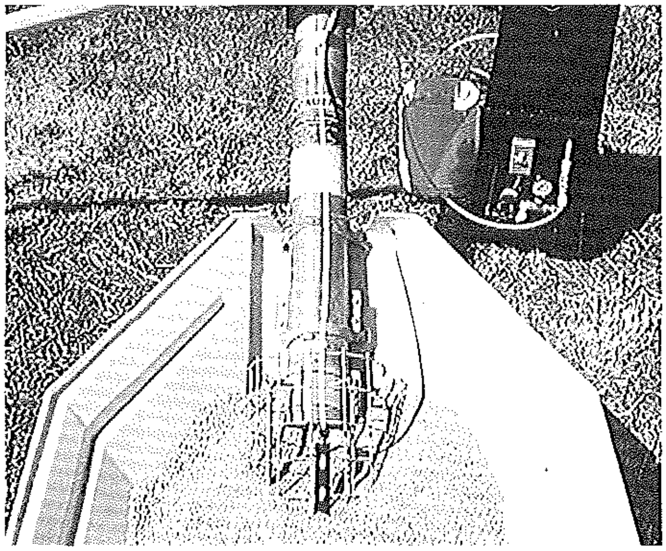

Figure 1. Proper maintenance of spray equipment is essential to ensure even residue distribution.

shown that some Lepidopteran species are developing resistance to *Bacillus thuringiensis* (McGaughey 1985).

Grain must be dried and equilibrated to the desired moisture content before protectants are applied because excessive moisture content increases pesticide degradation and reduces residual efficacy (Samson et al. 1987, 1988). Spray equipment should be properly maintained and calibrated to avoid uneven or inadequate residue distribution caused by malfunctions in the application process (Figure 1). High winds can cause spray drift from the target grain and reduce residue deposition on the grain. Some residue loss occurs during normal spraying operations, and actual deposition can be 10 to 20 percent less than the intended deposition (Bengston et al. 1983, Thomas et al. 1987). Further losses caused by poor application techniques can increase the susceptibility of grain to insect infestation. Also, the commodity temperature and moisture content during storage influences organophosphate residue degradation. When temperature increases, the rate of degradation also increases (LaHue 1974, Desmarchelier 1978, Desmarchelier and Bengston 1979).

It should be emphasized that grain protectants are different from fumigants. Fumigants are eradicants and give no residual control; therefore, they cannot be relied on for long-term protection. Grain protectants offer residual control during storage, but they are not designed to control an infestation that exists at the time the grain is loaded into storage. Infested grain should be fumigated before protectants are applied.

Bins

One of the most important sources of insect infestation is residual grain in the storage bin. Several insect generations could develop in old grain when conditions are conducive to insect population growth and development. Therefore, all trash should be removed from the bin and the immediate surroundings before insecticide treatments are applied (Figure 2). Bins should be washed and swept clean of debris and all litter removed from the ground outside the bins. Any necessary repairs should be completed while the bin is empty.

Chlorpyrifos-methyl, synergised pyrethrins, cyfluthrin (Tempo®), and methoxychlor are labelled as bin treatments before grains are loaded into storage (Figure 3). Synergised pyrethrins are not used because of availability and cost. Methoxychlor has been registered for more than 30 years, but it is rarely used in current programs. Tempo is registered as a bin treatment only. Pirimiphos-methyl is not labelled as a bin treatment.

Some insecticides labelled as crack and crevice treatments in residential and commercial structures can be

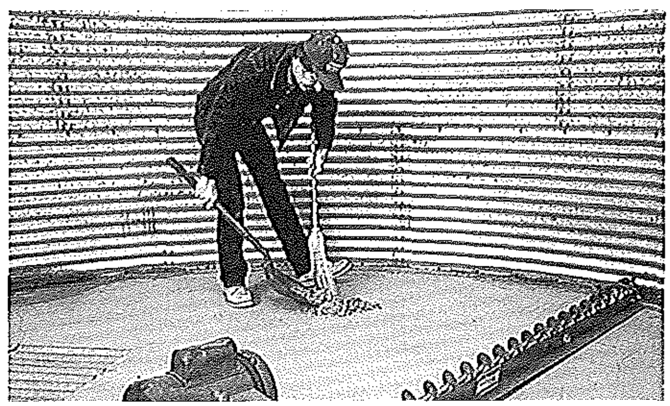

Figure 2. Remove trash before applying insecticide treatments.

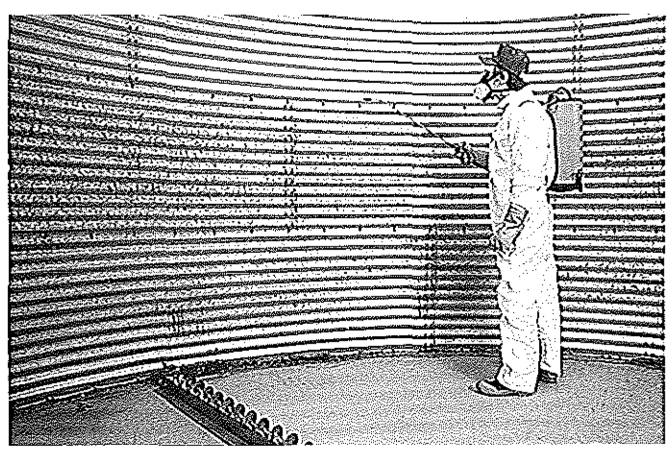

Figure 3. Treating bin before grain is stored.

used for this purpose in empty bins and warehouses. However, they do not have a food tolerance and cannot be used as a general surface application to floors and walls. Consult label directions before using any crack and crevice treatment in bins and warehouses that will be used for grain storage.

Shipholds and Railcars

For many years, shipholds and railcars were routinely treated with malathion prior to loading, but this practice has been curtailed because of increased malathion resistance. Labels for malathion, methoxychlor, and synergised pyrethrins are still operative, but protectants are not usually applied in these structures. Existing insect populations are primarily controlled by fumigation.

Future Trends

Increased emphasis will be placed on methods for trapping and detecting insect pests in stored grain. Pheromone traps and pitfall traps are sensitive to low insect populations and are more effective than traditional approaches, such as sampling by grain trier and sieve monitoring (Cuperus et al. 1990, Arthur et al. 1990). Also, by monitoring grain temperature and moisture content, environmental conditions that promote insect population development can be identified. Cooling grain by aeration can reduce temperature and moisture content and limit insect population development (Cuperus et al. 1986, 1990). Biological control of insect pest species will continue to be an important area of research.

Additional protectant insecticides may be registered in the future, and increased emphasis will be placed on nonchemical control methods by integrating these methods with chemical control programs. Grain quality is an important concern for both the domestic and international markets. New FGIS regulations are more stringent than earlier requirements and demand higher standards for grain sold as food. Integrated Pest Management (IPM) programs should be developed for stored grain. Such programs will include an increased emphasis on sanitation, infestation, prevention, insect detection, temperature and moisture control, regular grain inspection and monitoring, and proper timing and application of pesticide chemicals.

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Special thanks to Gustafson and Beebower Bros. for the use of photos. □

18

Pesticide Alternatives

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Bacillus thuringiensis (*B.t.*) and diatomaceous earth (D.E.) are two of several pesticide alternatives that are presently receiving publicity. *B.t.* is a bacterial pesticide that affects Lepidopteran larvae. Its mode of action is the release of a protein crystal that penetrates the gut lining of an insect. *B.t.* does not directly kill insects by growing colonies within the insect; rather, the insect must ingest the protein crystal. *B.t.* has been permitted by the EPA for use in stored products for many years with excellent results against the Indianmeal moth, *Plodia interpunctella* Hübner (IMM), and almond moth (McGaughey 1985). Because the moths are surface feeders, *B.t.* is relatively inexpensive and is usually recommended as a top dress.

Stored-grain labeled strains of *B.t.* have no impact on stored-grain beetles. However, formulations of *B.t.*, using new species that were developed for beetles, have shown promise and may be available in the future. Drawbacks of *B.t.* include: 1) resistant strains of IMM have been detected and resistance may increase with continued usage, 2) difficulty in adequate distribution, and 3) lack of effectivness on other stored-grain insects, particularly on beetles (McGaughey and Beeman 1988). *B.t.* is a natural pesticide that is effective in many situations against Lepidopteran larvae.

Diatomeceous earth (D.E.) is found in natural deposits throughout the world and is composed of microscopic diatoms. D.E. is an abrasive product that operates by penetrating the cuticle of the insect and allowing dehydration. There appears to be significant variability in effectiveness of this product as well as in claims as to what the product will or will not do. Research over the past three decades indicates that D.E. is effective against most stored-grain insect pests if well distributed throughout the grain (White et al. 1975). However, several references indicate marginal or poor performance of this product (LaHue 1967).

Historically, a major concern with D.E. was that the grain's test weight was lowered and was declared "Sample grade," the lowest Federal Grain Inspection Service (FGIS) designation. However, the FGIS now, if notified, will not test the grain for D.E., but will note its presence on the inspection certificate. Such tested grain will not be labeled Sample grade. D.E. is abrasive to machinery and may cause health problems if inhaled by workers.

Most D.E. formulations do not contain pheromones or insect chemical attractants. It is recommended that D.E. be used as a top dressing for the grain mass immediately after binning to significantly reduce insect movement into the bin. Recommended levels are one pound per 1,000 square feet of surface. As with any grain protectant material, it will not perform well when used on infested grain. D.E. labels recommend that one to two pounds per 1,000 bushels of grain be used and that it should be incorporated throughout the to grain be treated.

Drawbacks of D.E. include: 1) increased wear on machinery, 2) increased worker exposure due to airborne dust, 3) dust-covered and dulled grain appearance, and 4) the requirement of adding significant amounts of the product to the grain. However, D.E. is not a toxic substance and grain treated with D.E. can be fed to livestock without conditioning the grain.

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19

Practical Fumigation Considerations

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Fumigants are pesticides that kill in the gaseous form. As toxic gases, fumigants penetrate into cracks and crevices, the commodity, and throughout the area to be treated. These characteristics also make fumigants the choice for disinfestation and a highly restricted pesticide.

Fumigation Goal: Contain a toxic concentration of gas so that it is evenly distributed and in contact with the target pest long enough to obtain total kill.

A fumigant is a tool that may be needed to help preserve the stored commodity quality by keeping it free of insect pests. Fumigants should only be used when live insects are found in a commodity in large enough numbers to cause damage or the reduction of quality. Fumigation is the most hazardous type of pesticide treatment, it is expensive, provides no long-term residual protection, and may cause resistance problems if conducted repeatedly. Fumigation is needed when no other pesticide or control method can reach the insect infestation. If the insects are already inside the grain kernel, no spray or dust can reach them. The only other methods that will penetrate commodities to kill insects are cold, heat, and radiation. Cooling and heating methods are energy inefficient and expensive, particularly for large bulk volumes of commodity. Radiation is also expensive and has the disadvantage of requiring the commodity to be moved to the radiation facility. Also, radiation is not an accepted method, due to the public's lack of acceptance of irradiated products.

Fumigation Decisions in Stored-product Management

Any treatment considerations should include the following factors:

1) Time of the year—temperature, humidity, wind.
2) Type of problem—insect infestation, mold, etc.
3) Probable cause—will the problem return?
4) Magnitude of the problem—economic losses?
5) Available alternatives—long term effectiveness.
6) Cost of alternatives.
7) Management capabilities and time available.
8) Market destination.

Cuperus et al. 1989

Fumigants exert their effect on pests only during the time in which the gas is present in the insects' environment. After the fumigant diffuses or is aerated out of the product, no residual protection is left behind and the stored product is again susceptible to reinfestation. The objective of fumigation, therefore, is to introduce a killing concentration of gas into all parts of the stored product and to maintain that concentration long enough to kill all stages of insects present.

Fumigants may be applied directly into the fumigated space as gases from pressurized cylinders. Some fumigants are stored as liquids under pressure but expand to a gaseous form when released or after passing through a heat exchanger which is installed between the cylinders and the commodity. This method is often used with methyl bromide. Fumigants also can be generated from solids that react with moisture and heat from the air to release the fumigant. This is the way that phosphine is used as a fumigant. The formulation is a solid containing the active ingredient, such as aluminum or magnesium phosphide, which reacts with moisture in the air to release phosphine according to the following reaction:

$$2AlP + 3H_2O \xrightarrow{>5.5°C} 2AlOH + 2PH_3\uparrow \qquad (1)$$

or

$$Mg_3P_2 + 6H_2O \longrightarrow 3Mg(OH)_2 + 2PH_3\uparrow \qquad (2)$$

In addition, other solids may be present which produce a warning gas and a reaction stabilizer.

$$H_2N - \overset{\displaystyle O}{\overset{|}{C}} - OH \longrightarrow CO_2\uparrow + NH_3\uparrow \qquad (3)$$

The Environmental Protection Agency has initiated a "Label Improvement Program for Fumigants" to help minimize occupational exposure to fumigants. Changes on the label to better define user information, warnings, and necessary precautionary measures will directly affect how fumigants are used and who uses them. Three features of the program are of prime importance:

1) The revised label directs that at least two "trained persons" be present during the principal fumigation operation. It is now required that the licensed fumigator be present during the application and aeration of the fumigant.
2) The use of approved respirator protection devices is required during application of the fumigant when concentrations of the fumigant exceed prescribed levels or if the concentrations are unknown.
3) Specified direct-reading detector devices are required to monitor fumigant concentrations, ensuring that they remain at prescribed levels as a condition of re-entry or transfer of treated grain.

The selection of an appropriate fumigant is of utmost importance. Special consideration must be given to many factors, including toxicity to the pest, volatility, penetrability, corrosiveness, safety, flammability, residue tolerances, offensive odors, method of application, safety equipment required, and economics.

Fumigant Types

Only two fumigants remain for treating stored products—phosphine-producing materials and methyl bromide. Two other fumigants, chloropicrin and sulfuryl fluoride (Vikane®), are used for structural fumigation, but they are not allowed as fumigants for food or animal feed.

Phosphine Fumigants

Phosphine-producing formulations have become the predominant fumigants used for the disinfestation of stored products throughout the world. They are available in solid formulations of aluminum phosphide or magnesium phosphide.

Phosphine has no adverse effects on germination of seeds when applied at label dosage rates and is the choice of fumigants for seeds or malting barley (Hanson et al. 1987). It also is widely used in the fumigation of processed foods, since fumigant residues are not usually a problem with phosphine. One disadvantage of phosphine is that it can react with certain metals. These include copper and its alloys (i.e., brass, bronze), as well as gold and silver, resulting in the corrosion or discoloration of these metals. If the corrosion is extensive, electrical or mechanical systems using these metals may fail (Bond et al. 1984). Thus, damage to contact points, telephones, computers, and other electronic equipment can occur. This problem is rare and apparently only occurs when there is a high concentration of phosphine in combination with high humidity and high temperature, but care still needs to be exercised. In most stored-product situations, there is little that could be harmed by phosphine.

Solid aluminum phosphide formulations, which release hydrogen phosphide (phosphine) gas when exposed to moisture and heat, are available in tablets, pellets, and powder packed in paper (sachets, blankets, ropes). If the liberation of hydrogen phosphide occurs too rapidly in a confined area, an explosion or fire can occur. To control the rate of release, aluminum phosphide is formulated with other compounds, such as ammonium carbonate or aluminum stearate and calcium oxide, which control the release rate and lower the combustibility of the mixture. In formulations containing ammonium carbamate, carbon dioxide and ammonia are released along with the phosphine as shown in reaction 3. These products serve both as a warning gas (garlic odor) and a retarding gas for the production of phosphine. Under certain circumstances where phosphine cannot diffuse out of a localized area, such as when the pellets are piled or emerged in water, its concentration can build up to 1.79 percent (17,900 ppm), which is the point of spontaneous ignition for phosphine. In most cases, a fire never results from phosphine fumigation. However, where the fumigant is poorly applied, situations can occur such as trays of formulation getting covered by the covering tarpaulin, causing high concentrations of phosphine to accumulate in the tray. Proper fumigation practices result in concentrations that are probably no more than one fiftieth of the amount that would result in a fire (Figure 1).

Manufacturers of aluminum phosphide fumigants indicate that there is a delay before heavy concentrations of phosphine are released from commercial formulations. Usually, dangerous amounts of phosphine are released after one-half to one and one-half hours with pellets, or one to two hours with tablets. The time required for phosphine release is much shorter on warm, humid days and much

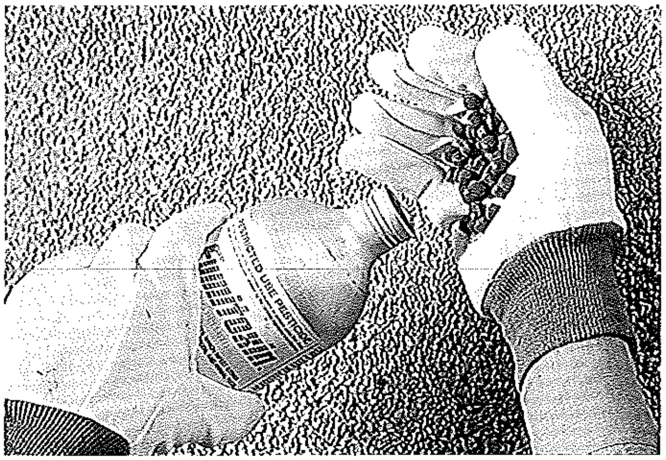

Figure 1. Phosphine fumigation.

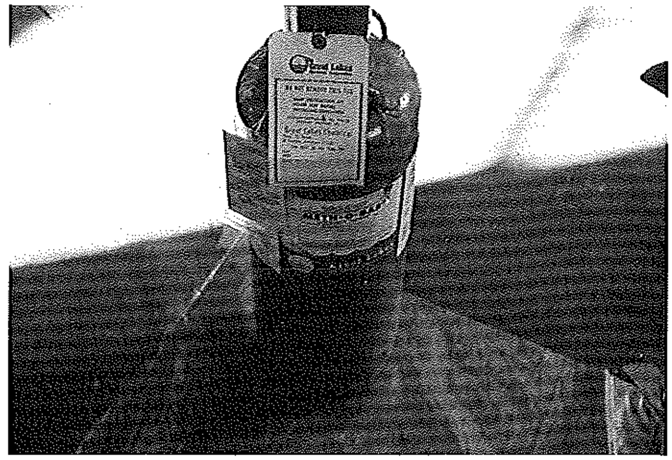

Figure 2. Methyl bromide container.

longer on dry, cold days. With grain temperatures above 70°F, decomposition should be complete in three days. With low temperatures and low grain moisture (below 10 percent), appreciable amounts of gas may be evolved for five days or longer. At 40 to 53°F, the manufacturer recommends a minimum exposure period of 10 days, while at 68°F and above only three days are needed.

Phosphine is only slightly heavier than air (20 percent heavier); therefore, it will diffuse rapidly through the stored product because it is a small molecule and is not strongly absorbed by most commodities. This combination of the low absorption loss, great mixing capacity of phosphine, and the exposure time of three to 10 days means that bins treated with this material must be very gastight. Sealing is one of the most important aspects of fumigation, especially when using phosphine. If the facilities have holes for gas to leak out, the fumigation is almost certainly doomed to failure. Even probing formulation into the grain does not hold sufficient gas to give proper results if the headspace above the grain is not sealed. Gas will simply be evolved and be swept out of the facility as it reaches the headspace area. Leaks in the areas covered by grain will also let gas escape and may well result in a fumigation failure. With a fairly airtight structure, this gas loss is not a problem because the leaked gas is minimal during the fumigation. In Australia, some fumigations require that a leak test be passed before the structure and its contents can be fumigated. This has been shown to result in the construction of better facilities and a strong emphasis being placed on sealing prior to fumigation (Banks and Ripp 1984, Banks and Annis 1981, Banks 1990, Newman 1990). For further information on sealing, see Technical Release ESPC 073033 from the National Pest Control Association.

Methyl Bromide

Methyl bromide can be used for a variety of fumigations besides stored grain. It is used to fumigate raw and processed commodities, structures, soil, and shipments under quarantine. In addition to being an all-purpose fumigant for the professional fumigator, it has some advantages, such as reduced fumigator exposure, economy, effectiveness, and speed. In large bulk storage facilities where methyl bromide is used, some type of recirculation system is usually employed to achieve an even distribution of the fumigant after application. Fans can be used to distribute methyl bromide in smaller facilities and under tarpaulins. Detection equipment and respiratory equipment are mandatory when using methyl bromide. The detection of methyl bromide is accomplished by one of several methods. Tubes that have chemicals which react with the methyl bromide are available and are used for determining when it is safe to reenter a facility after aeration. During the fumigation, thermal conductivity devices are available for determining concentrations. In addition, infrared and gas chromatographic instruments are available. For further information, see the bulletin on fumigant detection, available from the National Pest Control Association (1983). Professional fumigators who have all the required equipment and use methyl bromide regularly enjoy its advantages.

Methyl bromide is a simple, small, very active, naturally occurring molecule. It is odorless, nonflammable, and will extinguish flames. It has a low boiling point of 38.5°F, so it vaporizes quite rapidly. It will evaporate quickly at lower temperatures, but faster when the temperatures exceed 60°F. Under ordinary conditions, methyl bromide boils to gas almost immediately. When methyl bromide is

Table 1. Selected fumigants for treating structures[1].

	Hydrogen Phosphide (Phosphine, PH_3)	Methyl Bromide (CH_3Br)
Gas Form	Tablets, pellets, plates, sachets	Cans, pressure cylinders
Speed of kill	Slow	Quick
Penetration	Excellent	Good
Ease of aeration	Excellent	Good
Sorption	Some	Yes
Sp.Gr. (Air=1.0)	1.214	3.27
Odor	Carbide, garlic	None
Boiling point	-87.4°C	3.6°C
Skin absorption	Negligible	Yes (Slow)
Threshold limit value	0.3 ppm	5 ppm
Skin blistering	No	Yes
Flammability	Self-combustible above 1.79%	No
Reacts with	Copper, silver, gold	Sulfur and aluminum
Gas mask[2]	Self-contained breathing apparatus or organic vapor is usable only if $\leq$ 15 ppm	Self-contained breathing apparatus
Canister	Yellow with gray stripe	Not approved

[1]Taken in part from chart made available by The Industrial Fumigant Company, Olathe, Kansas.
[2]A self-contained breathing apparatus is required at concentrations above 15 ppm for phosphine and at all concentrations above 5 ppm for methyl bromide.

used in large fumigations and application times must be short, it is necessary to use a heat exchanger to vaporize the fumigant as it is applied from the cylinders.

Methyl bromide gas is 3.27 times heavier than air. This means it tends to fall when it is first released. This is one reason that stored grain should be leveled. Otherwise, the fumigant will settle in the valleys and then diffuse through the grain. The high peaks in the grain may not get as much or enough fumigant to kill all the pests. It is also the reason that recirculation of methyl bromide using fans is often employed during and shortly after application.

Cans of methyl bromide can be used to fumigate a small space, but they require a special "can opener" often called a "Jiffy" or "Star" opener. These openers puncture the can and allow the methyl bromide to escape through polyethylene tubing. Before the can is opened, the tubing can be inserted into a rail car, truck trailer, bin plenum, or fan housing. It is important that the gasket on the puncturing knife be in good condition to prevent leaks (Figure 2).

Steel cylinders can be fitted with special metering devices to fumigate small places, such as rail cars, or the gas applied can be measured by loss of weight from a cylinder. For example, a full cylinder that weighs 118 pounds should weigh 93 pounds after applying 25 pounds of gas to a 10,000-bushel bin of corn (two pounds per 1,000 cubic feet in a bin of 12,500 cubic feet).

In a very simple fumigation of a small bin, the cylinder is placed upon a scale. After the safety bonnet is removed, the safety cap is removed. A crescent wrench probably will be necessary. A polyethylene shooting hose with brass fittings is attached to the cylinder. The far end of the hose is attached firmly in the headspace of the bin. It is often expedient to place a small piece of plastic or a tray below the end of the application tube to prevent liquid from coming into contact with the commodity. The valve is then opened. After the correct number of pounds are in the bin, the valve is closed. The sealed bin is left undisturbed for 24 hours and then opened to air out. Turning on the bin fan will help remove the fumigant quickly from the bin. Warning signs should not be removed until gas levels are below 5 ppm (Figure 3). Equipment must be on hand to determine when the concentration falls below 5 ppm (0.02g/m³) for re-entry into the facility.

Recirculation is often required with methyl bromide. Generally, circulation is not difficult and can be facilitated with existing fans or additional small, portable fans. Recirculation of methyl bromide often requires significant air movement, compared to "closed loop" phosphine fumigation. Using the bin fan(s) means that circulation may be completed in a few minutes to an hour. Fans are left on until the fumigant has cycled approximately three times through the return ductwork. The time is determined by how long it takes to detect the gas passing through the grain mass once. For example, if it takes 12 minutes to detect the gas, then fans are left running for 24 more minutes for a total of 36 minutes.

Fumigation of railcars and trucks carrying grain cannot be done with methyl bromide unless the vehicle is stationary. Fumigation in transit is not allowed because of the difficulty in holding the gas when air is moving over the vehicle. Again, an advantage of methyl bromide is that the fumigation of the standing vehicle can be done in 24 hours or less so that demurrage is minimal. Often, railcars and truck trailers are so leaky that the only way to obtain a successful fumigation is to tarp the entire vehicle for fumigation.

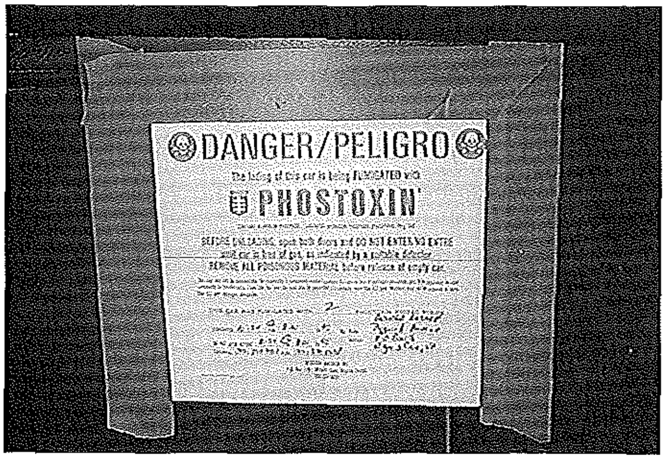

Figure 3. Fumigation placarding required by law.

Another advantage to using methyl bromide is that it won't harm electronic equipment and wiring. But at high doses and under certain conditions, it can harm seed germination (Blackith and Lubatti 1965, Hanson et al. 1987, Leesch et al. 1979, Powell 1975). If rodents are the target, only one-fourth pound per 1,000 cubic feet is required for 12 to 24 hours. Phosphine and chloropicrin will also kill rodents. This amount won't harm seed germination. Higher rates of methyl bromide (for insects) for more than 24 hours at warm (85°+F) temperatures and high moisture (12+percent) should be avoided for seeds. One disadvantage to the use of methyl bromide is that it should not be used with certain materials. It imparts an odor to objects containing sulfur compounds, such as vulcanized rubber, feathers, hair, furs, woolens, full fat soya flour, sponge rubber, foam rubber, viscose rayons, photographic paper, and cinder blocks.

Methyl bromide does require less time to kill insects than phosphine. While phosphine requires from three to 10 days, depending on the temperature, methyl bromide exposure times usually range from a few hours to one day. This short exposure is oftentimes advantageous in treating commodities with quick turnover times in the marketing channel. When fumigating with methyl bromide at low temperatures (<60°F), the exposure time is kept constant and the dosage is increased, while when fumigating with phosphine, the dosage is kept the same and the exposure time is lengthened.

Resistance

Concern about resistance of stored-grain insects to fumigants has spread to the U.S. The widespread and sometimes frequent use of phosphine-generating fumigants, especially when used improperly, can lead to resistance problems (Zettler and Cuperus 1990). Part of a plan to avoid or delay resistance is to occasionally alternate fumigants. Of course, excellent fumigation technique that results in 100 percent kill will prevent survival of insects that can lead to the development of resistant populations. The major factor which contributes to the development of resistance to either phosphine or methyl bromide is poor sealing of fumigation facilities. Poor sealing results in insect exposure to sublethal doses of fumigant, which causes resistance through selection pressure. Poor sealing is also the most common cause of fumigation failures.

Safety

Finally, safety when fumigating with methyl bromide or phosphine is very important. For methyl bromide, the fumigator must wear loose clothing to avoid trapping the gas. Also, jewelry, watches, adhesive bandages, or any article that may trap the fumigant should be removed when applying methyl bromide. Burns can result if high concentrations of vapors or liquid methyl bromide is trapped next to the skin. A full-face shield should be worn when opening cans or cylinders to prevent fumigant injury. If phosphine levels are unknown during application or aeration, the fumigator must wear a self-contained breathing apparatus (SCBA). Only when the gas concentration is below 5 ppm may anyone be allowed in the area. It is important to wear gloves when applying phosphine to keep the dust of the formulation off the damp skin. However, when applying methyl bromide, gloves should *not* be worn because they can trap liquid fumigant against the skin and cause burns. When applying or aerating either phosphine or methyl bromide, gas detection devices must be used to determine whether or not the threshold limit value (TLV) is exceeded and respiratory protection is necessary.

Fumigation Effectiveness

Understanding how fumigants react in commodities is an essential step in developing the know-how to effectively and safely use fumigants.

Sorption

When a fumigant gas attaches itself to the surface of a commodity particle or kernel or penetrates into the kernel, it slows movement through the grain mass and disrupts penetration of the fumigant through the commodity mass. However, some sorption must occur if the fumigant is to reach all stages of pest insects, especially those that develop within the kernel. When sorbed into a kernel, some fumigants react with materials in the commodity to form other chemical compounds that may be permanent, and thus form residues. Methyl bromide is particularly vulnerable to this type of chemical reaction. When this reaction takes place, the methyl group becomes attached to some molecules in the commodity, while the bromine atom is released as bromide ion. Some of the intact methyl bromide molecules will also remain in the commodity until they either react or are desorbed by diffusing out of the commodity. Thus, the amount of methyl bromide inside commodities is related to the amount of aeration that has taken place and the reaction rate with components of the commodity. This has necessitated the establishment of residue limits or tolerances for the amount of bromide permitted in grain and other commodities. Each time a commodity is fumigated with methyl bromide, it accumulates more bromide as residue. Therefore, care must be taken not to fumigate commodities more than is necessary because eventually the residues of bromide may exceed the tolerance limit.

Residues of phosphine tend to be very low compared to those resulting from methyl bromide fumigation. Phosphine reacts to form phosphate, which is a natural component of living organisms. Furthermore, the amount of phosphate added by phosphine fumigation is negligible compared with the amount naturally occurring in living tissue. Therefore, tolerances for residues resulting from phosphine fumigation are measured as phosphine. Because the phosphine molecule is small and diffuses even faster than methyl bromide, residues of phosphine disappear from grain very quickly after aeration begins. Residues of phosphine are measured in parts-per-billion (ppb), while those of methyl bromide are measured in quantities ten times larger, namely parts-per-million (ppm).

Temperature

Temperature influences the distribution of fumigants in grain and affects their ability to kill insects. Temperature also influences the rate of phosphine and methyl bromide release and movement after application. Since for every 10-degree rise in temperature a reaction will double, it is easy to see how the temperature increases or decreases the reaction that releases phosphine from the formulation. At temperatures below 40°F (5.5°C), activity of the fumigant molecule is reduced significantly, sorption of fumigant vapors into grain kernels is increased, and distribution is less uniform throughout the grain mass. At colder temperatures, gases move more slowly and insects breathe less. Thus, it takes longer for the fumigant vapors to reach insects in the grain, less gas is actually available for controlling the pests, and, since the insects are less active, less gas enters their bodies. Desorption may take longer at cold temperatures because grain retains more fumigants longer at low temperatures, thus requiring prolonged ventilation periods.

Moisture

The moisture content of the stored-product environment also influences the penetration of fumigant gases by altering the rate of sorption. In general, high-moisture commodities require an increased dosage or an extended exposure to compensate for the reduced penetration and increased sorption. However, as previously mentioned, adequate moisture is necessary for the generation of phosphine from solid formulations. Although most grain that will support insect development contains sufficient moisture to start the chemical reaction, dry grain (less than 10 percent moisture) will extend the time required for solid fumigant decomposition.

Grain Type and Condition

Various grains have different characteristics that can affect fumigations. The surface area of individual grain kernels is a factor influencing the dosage required to treat various commodities. For example, because of its smaller size and more spherical shape, sorghum has higher total surface area than wheat. Increased surface means greater sorption loss, which reduces the amount of fumigant left in the space between the grain kernels, and further reduces the amount of fumigant available to penetrate throughout the grain. To compensate for this increased loss, higher dosage rates are required in sorghum than in wheat, particularly when fumigants are used that are easily sorbed by the grain. The makeup of the outside coat on grain may change the sorption of the fumigant into the kernel.

The Type and Amount of Dockage in Grain

The type and amount of dockage in grain has a pronounced effect on the sorption, distribution of fumigants, and potential failures. When the grain mass contains large amounts of dockage, such as crust, chaff, or broken kernels, the fumigant vapors are rapidly sorbed by this material and further penetration into the grain is impaired. Dockage usually is found in the center of grain during storage because of the way facilities are filled. Unfortunately, these same areas, such as the top center and the center of the grain mass, are frequently sites that attract the greatest number of insects. When isolated "pockets" of dockage occur within a grain mass, fumigant vapors may pass around such pockets and follow the path of least resistance down through the intergranular area of the grain. Sometimes probing phosphine formulation down into the center

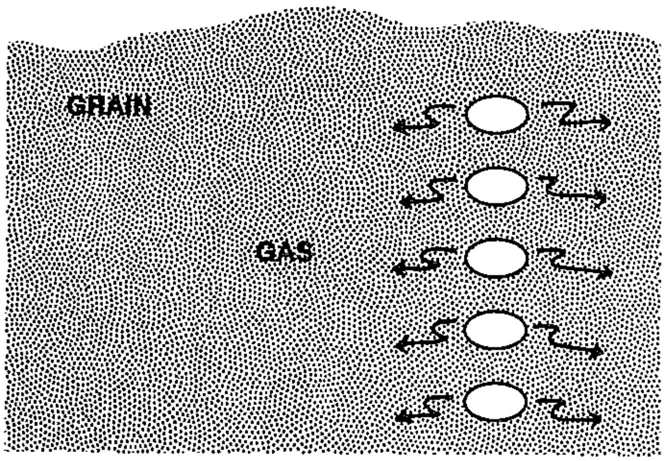

Figure 4. Release of phosphine grain fumigant.

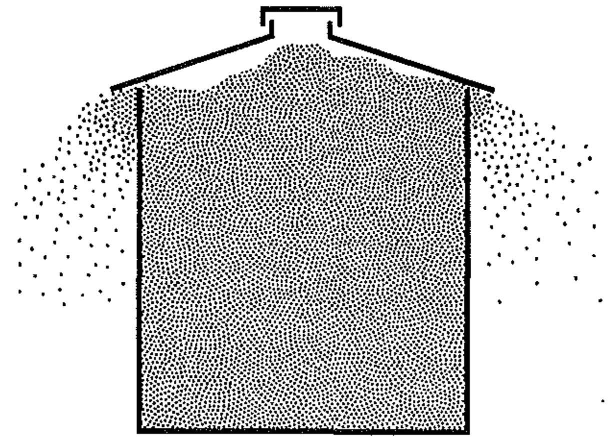
Figure 5. Grain bin with sites of gas escape.

of the grain mass helps get better penetration of the gas to these areas where dockage pockets frequently occur. Fumigant distribution patterns may be adversely affected in grain that has settled or compacted unevenly during long storage periods or in storages vibrated by nearby traffic and railroads.

Insects

In the various developmental stages (egg, larva, pupa, and adult), stored-product pests differ in their susceptibility and resistance to fumigants. Beetles and other insects that develop outside grain kernels usually are more susceptible to fumigants than certain moth and beetle species that develop inside grain kernels. The pupae and eggs which respire very little are the most difficult to kill, while the young larvae are relatively susceptible because they are active and heavily respiring.

Heavy infestations in which large amounts of dust, damaged grain, webbing, and cast skins have accumulated are more difficult to control because these materials adversely affect the penetration and diffusion of fumigants.

Structure

A fumigant, whether applied initially as a gas, liquid, or solid, eventually moves through space, penetrates the commodity, and is taken in by the insect in the form of a gas (Figure 4). The gastightness of the storage facility or grain bin greatly influences the retention of the fumigant. Metal bins with caulked or welded seams or concrete bins will still lose some gas, but they are generally better suited for fumigation than loosely constructed wooden bins.

The size and shape of the storage structure affects both distribution and retention of fumigants. The height of a structure often determines the type of fumigant used and the method of application. When grain depths exceed 40 feet, special forced distribution techniques using circulation equipment or other methods may be required to obtain satisfactory control.

Wind and heat expansion are major factors influencing gas loss. Winds around a structure create pressure gradients across its surface, resulting in rapid loss of fumigant concentrations on the surface and on the downwind side of the storage. The expansion of headspace air due to solar heating of roofs and walls followed by nighttime cooling can result in a "pumping" of the fumigant from the bin. Large flat storages that contain more surface than grain depth are particularly susceptible to gas loss due to wind and heat expansion. The greatest gas loss frequently occurs at the surface and in the headspace above the surface—a location that often contains the highest insect populations. Furthermore, when the grain surface is uneven with large peaks and valleys, the distribution of fumigants through the grain will also be uneven (Figure 5). Air access points, such as roof vents, grain surface, aeration fans, and exhausters, must be sealed.

Dosage and Time of Exposure

Because fumigants act in the gaseous state, the dosage necessary to kill an insect is related to the temperature, the concentration of gas surrounding the insect, the insect's respiration rate, and the length of time an insect is exposed to the specific concentration of fumigant. There is a general relationship for most fumigants between concentration and time—high concentrations require shorter exposure time and low concentrations require longer exposure time to achieve comparable kill. In phosphine fumigations, the length of time exposed often is more important than the concentration of gas (Bond et al. 1969, Banks and Sharp 1986). This is due in part to the fact that the rate of uptake of phosphine by insects is somewhat time dependent.

Variations in recommended dosages generally are based on sorption differences of commodities and the relative gastightness of different storage structures. For example, dosage requirements for wooden bins are higher than those for steel or concrete bins. Because phosphine is less affected by sorption loss in various commodities, the rates of application for most commodities are virtually the same and depend primarily on the type of storage structure being treated and its gastightness. This contrasts with methyl bromide, where rates vary with commodity because of sorption differences between commodities.

Fumigation Procedure

Preparation

Before a fumigation is started, a thorough inspection is necessary and some immediate questions need to be asked:

- Is there a good chance that the structure can be fumigated successfully? (Will it hold the gas?)
- How will the air be tested after fumigation to ensure that the levels are under 0.3 ppm for phosphine or 5 ppm for methyl bromide?
- What is the amount of space occupied (cubic feet) by the commodity and total space to be fumigated?
- Can the structure be made reasonably airtight?
- Is the grain surface level?
- What materials were used to build the structure? (Fumigants will pass through cinder blocks with no difficulty and methyl bromide will react with them.)
- Are there cracks in the ceiling, walls, or floors that must be sealed?
- Are there floor drains, cable conduits, water pipes, windows, doors, or other openings that will require sealing?
- How will air conditioning ducts and ventilation fans be sealed?
- Will interior partitions interfere with fumigation circulation?
- Are the interior partitions gastight so that they will keep the fumigant from entering other parts of the structure?
- Does the area to be fumigated contain electrical equipment or wiring? (Phosphine may react with copper wire.)
- Are all parts of the building sealed off from human access? If not, can these operations be shut down during the fumigation?
- Where are the electrical outlets and main panels? What voltage are they?
- Will the circuits be live during fumigation? Can the outlets be used to operate fumigant circulating fans?
- Does the adjacent building have air conditioning or other air intakes that could draw the fumigant inside, particularly during aeration?
- How will the structure be aerated after fumigation? Are there exhaust fans? Where are the fan switches? Are there windows and doors that can be opened for cross ventilation?
- Does the building contain any high priority items that may have to be shipped out within a few hours notice?
- Is the structure to be fumigated located so that operations may attract bystanders? If so, consider asking for police assistance to augment guards.
- Where are the nearest medical and fire facilities?
- What is the telephone number of the nearest poison control center or hospital?
- What safety equipment is available?
- Are all personnel properly trained? If not, what is the availability of training?
- Should a professional fumigator be hired? Remember, since fumigants are "restricted use" pesticides, the person who fumigates with phosphine or methyl bromide must be a certified fumigant applicator. Certification is done by each state.

Once these measures have been considered, prepare a checklist of things to do and of materials needed. Don't rely upon memory.

Sealing

In the fumigation of structures, the walls must be relatively gastight and the building openings closable and/or sealable. It is most important that the structure be well sealed prior to fumigating. The grain surface, storage vents, and doors may require special attention. Proper sealing of the fumigation facility prior to fumigation will often make the difference between success or failure of the treatment. Most windows, except on the most modern of buildings, will require some sealing. The older, wooden window frames and sashes usually will need to be completely covered with polyethylene sheeting. Other types of windows may be adequately sealed with tape or strips of plastic. The single most important factor responsible for fumigation failures is poor sealing. It cannot be overstressed that in order to use fumigants successfully, it is imperative that the facility in which fumigation takes place, be it a building, bin, or tarpaulin, must be gastight. As stated before, leaky facilities not only result in failures, they contribute to insect resistance problems.

Leveling Grain

Level the grain surface and break up any crusted areas that have formed. When grain is peaked, the action of fumigants is similar to rain on a hillside. The heavier-than-air gases simply slide around the peak, resulting in poor penetration and survival of pests in the peaked portion of the grain. Moldy or crusted areas near the grain surface generally are caused by moisture condensation when warmer air in the grain rises to the surface and encounters cold air above the grain. These areas are sometimes hidden from view just below the grain surface. Failure to locate and break up these areas will result in uneven penetration of grain fumigants, and may lead to further deterioration of the grain from mold development and invasion of the grain by insects that feed on grain molds.

Evacuation of Structure and Other Preliminaries

It is important for the fumigator to work closely with management to ensure that the evacuation of personnel is complete prior to fumigation. This will necessitate the use of an employee roster, so that each employee can be accounted for before releasing the gas. At this time, prepare warning signs, make final arrangements for security, and establish one or more two-person teams that will release the fumigant and perform initial post fumigation activities. It will also be necessary to accomplish a complete walk-through of the entire premise just before application. While conducting this visual inspection, call out in a loud voice to alert anyone who otherwise may not have been noticed. When this walk-through has been completed, building exits should be locked to prevent re-entry. It also is recommended that local fire and police departments and any private security companies be notified of your intent to fumigate, the fumigant to be used, the proposed date of fumigation, the safety equipment required for re-entry, and the fire hazard rating. Pertinent medical organizations should also be given copies of all available literature (labeling information and the material safety data sheet) from the fumigant manufacturer.

Rehearsal and Placement of Fumigant

The value of a rehearsal for the fumigant release and subsequent procedures cannot be overemphasized. Each member of the two-man release team(s) will need to know exactly where each cylinder or canister of fumigants is located and how long it will take to complete the release of the fumigant. Cylinder valves need to be quickly opened and closed to be sure they are in working order, and canisters of aluminum phosphide should be placed at exposure locations. If auxiliary air movement is required, fans must be tested before releasing the fumigant. Gas flames and any electrical equipment that will produce a high temperature must be turned off. Participants conducting and supervising the fumigation should be briefed on the availability of medical and other emergency arrangements and facilities. Warning signs (placards) should be posted at this time.

When fumigants must be released from inside the structure, the route must be planned that will take the two-person team(s) away from the gas, toward a safe exit. There should not be any need to return to an area being fumigated. One two-person team is normally used, but, if necessary, other teams may be added to reduce the release time or the chance of exposure.

Cylinders of gas should be released carefully and in succession. It is usually better to have all cylinders opened by one person, while the partner double checks to be sure that none are missed. Steady the cylinder with one hand while the valve is turned open with the other hand. Open the cylinders all the way to avoid nozzles from freezing shut. Of course, all personnel making the application inside must wear self-contained breathing apparatus. Research of phosphine should include all aspects, from cannisters, placarding, and pellet or tablet cannister placement, to the deplacarding procedures.

Aerating the Structure

Once the exposure period is complete, aeration should be started by opening windows, doors, fans, and vents that can be opened without entering the structure. Attempt to provide cross ventilation by opening ventilators or aeration fans that are accessible from the outside. When opening windows and doors for cross ventilation, wear respiratory protective gear. The ground floor should be allowed to aerate until an approved fumigant detector shows that the fumigant concentration has diminished to the point where it is safe to enter the structure while wearing an approved gas mask and protective clothing (Mackinson et al. 1978). At this time, two people (or teams of two people) should begin opening windows, starting at the bottom and working upward. These technicians should not try to open all windows on any single floor the first time through, but should only open those windows that are necessary for cross ventilation, and then return to the outside as soon as possible. The teams should not remain inside the structure for prolonged periods (no more than 15 minutes). Workers should always work in teams so that each worker can see his/her partner and be seen by the partner as well. The fans should be turned on and allowed to run when aeration begins and continue until aeration is complete. After the structure has been partially aerated, the technicians, wearing gas masks, should open as many of the remaining windows and vents as needed to complete the aeration. No warning placards should be removed, nor should anyone be allowed inside the building without an SCBA until an approved fumigant detector has shown that all parts of the structure are safe. Once the aeration has been completed, usually in two or three hours, the structure can be returned to the control of management for normal operations. Previously notified authorities should be informed that the fumigation is finished. Upon completion of aeration and the clearing of the facility for re-entry, the fumigator should pick up and dispose of the spent residual resulting from a phosphine fumigation. This residual is composed mainly of aluminum hydroxide; however, some unreacted aluminum phosphide still remains in the dust, so the dust must be deactivated and disposed of properly. Instructions for residual dust deactivation are part of the labelling of phosphine formulations and must be carefully followed. In most cases, fires resulting from phosphine fumigations occur because the residual dusts are improperly confined in a container, allowing high concentrations of phosphine from the residual dust to accumulate.

Fumigation Failures

The following list outlines the most frequent causes of fumigation failures in stored grain:

1) **Improper sealing.** Fumigators will often attempt to fumigate a 150,000-bushel bin without sealing the vents and try to disperse the fumigant in the top six feet of grain. There usually are enough wind currents to suck the fumigant out and cause inadequate penetration.
2) **Grain peaks.** Stored products are peaked with excessive fine materials in the top center. With excessive fines and a steep angle of the grain, fumigation almost always will result in a failure.
3) **Poor distribution.** Many applicators do not adequately distribute the fumigant throughout the grain mass. To improve chances of success, distribute the fumigant as much as possible. Probing the solid formulation is helpful in getting better distribution.
4) **Temperature.** Fumigants will not work well below 50°F. If fumigation is done under these situations, it will likely be a waste of time. Fumigate at temperatures of 65°F or higher.
5) **Insect populations.** Know what kind of insects are causing problems. Know the severity of the problems and what alternatives are available. For example, Indianmeal moths might be controlled by a top-dressing with a compound that is cheaper than fumigation.

How to Fumigate Grain with Phosphine

Empty Bin Preparation

Fumigating grain can result in an insect-free product if the fumigant is applied properly. This section outlines simple instructions to eliminate or prevent an infestation in stored grain.

Safety Equipment—The following is a list of safety equipment needed to treat grain with phosphine:

- Gas monitoring equipment capable of detecting hydrogen phosphide down to 0.3 ppm.
- Dust mask (especially when working with moldy grain).
- At least two gas masks with filter canisters capable of filtering hydrogen phosphide. The canister gas mask must be worn in phosphine levels only in the range of 0.3 to 15 ppm.
- At least two SCBAs for use when concentrations of phosphine exceed 15 ppm or when the phosphine level is unknown.

Labor—Phosphine is a restricted-use chemical and requires state certification, even for its purchase. Most states require a certified applicator be present when phosphine is applied. Federal law states that a minimum of two trained fumigators are required to enter a structure for treatment. Each state has specific laws concerning who can handle fumigants. Agencies within your state can provide more details.

Dosage Rate—Several factors affect the dosage rate used when fumigating with phosphine. These factors include:

- Temperature of the grain.
- Tightness of the bin.
- Weather conditions and anticipated wind (wind is usually low in the late afternoon).
- The target insect (weevils and lesser grain borers are harder to kill than flour beetles).

Fumigating Small (3,000- to 25,000-bushel) Grain Bins with Phosphine Fumigant

Assemble all of the necessary supplies to perform a successful fumigation:

- Phosphine tablets or pellets.
- Probe (1.25 inches in diameter, PVC ridged pipe).
- Cotton work gloves.
- Phosphine placard signs.
- Hand sprayer.
- Polyethylene sheeting.
- Tape/adhesive.

- Approved gas mask for hydrogen phosphide.
- Self-contained breathing apparatus or canisters.
- Detection equipment.

The applicator is responsible for reading and following the fumigant label. An instruction manual, which can provide more detailed information, is available from your supplier.

Determine your target pest. Determine the volume to be treated. Remember that aluminum phosphide gas is 1.21 times heavier than air. (For all practical purposes, consider hydrogen phosphide to be equal in weight to air.) As the gas fills the volume of the bin, it does not differentiate between grain mass and bin headspace.

Fumigation—Do not open the bin top and scatter fumigant on the surface. This is a common misuse of phosphine that results in a failed attempt to eliminate pests. The following steps explain how a grain bin can be successfully fumigated:

1) Always use at least two people to fumigate. Never fumigate alone!
2) Outside the bin, pre-cut a piece of poly sheeting to fit over the surface of the grain. Use the bin as a template to measure the poly, and allow for extra poly to tuck around the edges of the grain and for grain peaks. (The grain should not have a peak.)
3) The fumigator should only be in the bin for a maximum of 15 minutes, because the headspace of the bin can reach a temperature of 140°F. Take precautions to protect against heat exhaustion.
4) One person should pull the poly sheeting to the farthest end of the bin and secure it by tucking it down in between the grain and the metal side walls.
5) The other person should probe the phosphine tablets or pellets on five-foot centers by starting at the farthest point form the escape hatch and working toward the ladder. Probe about 10 to 20 tablets or 50 to 100 pellets per probe. The probe should be pushed in as fast as possible.
6) Open cannisters outside of the bin.
7) Using detection equipment, take a gas reading if it is suspected that the gas concentration level is approaching 0.1 ppm. If a gas level of 0.3 ppm is detected, a gas mask must be worn by all people in the bin.
8) After the last probe is made, pull the poly sheeting toward the bin opening and secure it with a piece of cord or rope. Extend the cord out of the bin entry, and then seal the hatch. This will allow for the removal of the poly without anyone having to climb into the bin after the fumigation is complete.
9) To finish the fumigation, place the fumigant into the aeration fans and cover the ends of the fans with 4 mil poly. The fans must be left off during the entire fumigation. **Note:** Make sure the aeration duct is dry before adding phosphine fumigant.
10) Place placard signs on all doors and near ladders. Place signs where they will be visible to youths as well as adults.
11) Lock the bin securely after the gas has been added. Doublecheck all possible entrances.
12) Spray the perimeter of the bin at ground level with an approved insecticide to help prevent reinfestation. Weeds and any obsolete equipment should also be removed.
13) Following the fumigation, remove the poly sheeting from the surface of the grain and the aeration fans. The sheeting can be reused. Placard signs must always be removed after the gas has been properly monitored.
14) After the gas has been vented, there is no residual effect. For this reason, it would be best to apply an approved protectant to the surface of the commodity after the fumigation.

Fumigating a Flat Storage of Grain with Phosphine Fumigant

Fumigating flat storages is a very physical, difficult, potentially dangerous, labor intensive, and hot job. The following directions outline the proper method of fumigating with phosphine to kill all stages of insect life.

Preparation

Fumigant—Tablets are preferred over pellets. Tablets take one to two days longer to break down than pellets.

Labor—Use enough people to rapidly and easily complete the job. Walking in grain for 30 to 45 minutes in a zig-zag manner is hard, physical work. Heat exhaustion is a hazard, in addition to the fact that fumigators are working with a poisonous gas.

Dosage—Follow label instructions for flat storage and the type of formulation to be used.

Materials Needed to Fumigate a 100,000-bushel Flat Storage

- Phosphine-producing formulation.
- One PVC pipe (4 to 5 feet long) per fumigator.
- Duffle bag (to carry the fumigant).

- Approved respiratory equipment.
- Gas detection equipment.
- Plenty of drinking water.
- 4 mil poly sheeting.
- Masking tape.
- Strapping tape.
- Phosphine warning signs.
- Locks and chains for doors.

How to Fumigate a Flat Storage of Grain

1) Leave all vents and end doors open.
2) At least two people should climb onto the roof and cover the roof vents with 4 mil poly sheeting or poly bags. Use strapping tape to secure the poly over the roof vents. Cut off any excess poly—otherwise, the wind will work it loose.
3) Seal the remaining doors and vents and any openings necessary to retain the gas.
4) One person (or more) should lag behind the probers and gather empty flasks and caps. Containers should be discarded in duffel bags that are carried along.
5) Use two or more people to probe, depending on the size of the flat.
6) Check the gas concentration from time to time with a gas detection device. If the concentration reaches 0.3 ppm, a gas mask must be worn.
7) After getting to the opposite end of the flat storage, exit and take a rest! Drink liquids and check each person for symptoms of heat exhaustion and poisoning. Heat exhaustion and heat strokes can be serious. Proper equipment can protect workers from the gas—common sense is the only protection from the heat.
8) Apply 150 to 250 pellets or 30 to 50 tablets into each aeration fan. The fumigant placed in the aeration system should penetrate the bottom five to 10 feet of the bin. **Note:** On larger flats, the vent duct is not perforated until 15 to 25 feet into the flat storage.
9) Lock all doors and place properly labeled warning signs on all four sides of the fumigated flat storage buildings. Allow the building to stay under gas for the full amount of time recommended on the label. The duration of the fumigation varies according to the temperature. Ventilate the bin until detection equipment shows that gas concentration below 0.3 ppm.

Fumigating Metal Grain Bins and Silos with Phosphine

Fumigating large metal grain bins with phosphine is much easier than fumigating flat storages or small grain bins. The information in this section applies to bins that range from 25,000 to 250,000 bushels, with diameters of 36 to 50 feet. Any storage larger than this will require a different fumigation technique.

Materials Needed to Fumigate a 100,000-bushel Metal Bin

- Phosphine-producing formulation.
- A watch.
- 4 mil poly sheeting.
- Respiratory and detection equipment.
- Masking and strapping tape.
- Warning signs.
- Locks.

How to Fumigate a 25,000- to 250,000-bushel Metal Bin or Silo with Phosphine Fumigant

The best method is to fill an empty bin while intermittently metering in phosphine as the grain is loaded. If the grain in a bin is already infested and cannot be transferred to an empty bin, the following procedures should be followed:

1) Start with an inverted cone on the grain surface.
2) Probe the outer ring of the bin (along the wall) with a small portion of the dosage rate.
3) Pull the core out of the bin and turn it around on top of the inverted cone.
4) While the core is being rotated, phosphine will periodically be placed in the top of the transfer system, preferably as near the bin being fumigated as possible. Avoid placing the fumigant in the bottom portion of the transfer system.

   Warning: If phosphine is administered into the dump or bottom of the transfer system, the pellets/tablets can become lodged in voids and emit gas into the tunnel or other occupiable areas.
5) It is not necessary to turn the entire bin to effectively use solid fumigant. However, the center of the bin will need to be pulled down and rotated so that the pellets/tablets will be pulled to the bottom (within 20 to 30 feet of the bottom).
6) Three-fourths of the entire dosage rate goes into the core.
7) Find out the turning speed of the leg that transfers the grain (measured in bushels per hour).
8) There are several ways to determine when the fumigant has been pulled to the bottom or near the bottom:
   - Take gas readings at the bottom of the grain transfer

system while applying the gas at the top of the bin.

- Place a large amount of confetti or ping-pong balls in the bottom of the inverted cone, and start the coring process. When these materials exit the bin, they will quickly surface in the lower transfer system. Take careful notes on the exact time it takes to turn the bin.

9) How far will phosphine gas travel? A good rule of thumb is 25 to 30 feet in any direction. Remember that phosphine is about the same weight as air.

10) If the confetti/ping-pong ball method has been used to determine the exact coring time, divide the length of time by the number of flasks required to fumigate the bin. The sum of these figures will provide the number of minutes between the dispensing of each flask.

For example:

$$\frac{TT}{NF} = X$$

TT = Turning time
NF = Number of flasks being added to the core
X = Lapsed time between dispensing each flask

Note: If the coring time and time dose are unknown, use your best judgment. In most cases, if you have a center draw and a center drop, and you start with an inverted cone, it usually takes 20 to 45 minutes to core the average-sized silo. For help in determining estimated rotation time, call a professional fumigator.

11) After everything is turned off, hold back a small portion of fumigant to be administered through the manway without entering the bin. Most gas is lost through leaks in the headspace. The additional gas compensates for this loss.

12) If the roof vents can be safely covered with poly tape, do so. Occasionally, this can be dangerous and other measures must be taken. One way to seal hard-to-reach vents is to seal them prior to administering the gas from the inside of the bin. If the grain level is down, use a ladder inside the bin. Thorough sealing is important, but it is not worth risking a life!

13) Consult the phosphine label to determine the required duration of the fumigation, according to the ambient temperature of the commodity.

14) Lock and secure the bin. Place proper warning signs on all entryways and ladders. Write the name of the bin's fumigant on chalkboards and bin charts in controller rooms and scale houses. Make sure every employee knows that the storage is under gas and the hazards involved with fumigation.

15) Aerate the bin until gas detection equipment shows that gas levels are below 0.3 ppm.

16) Grain insects can immediately reenter the bin after fumigation. Fumigants do not have any residual effect, so it is best to apply a top dress grain protectant to combat any reoccurrence.

Summary

The handling and use of fumigants to control pests in structures is an endeavor that should not be taken lightly. Carelessness or ignorance can result in death of the fumigator or innocent bystanders, destruction of the usefulness of the product being treated, or failure to control the pest. Since fumigants are labeled as restricted pesticides, training and certification is required before they can be purchased and used. Consideration of the recommendations presented herein and strict adherence to the manufacturer's Environmental Protection Agency (EPA) approved label will ensure a safe and effective fumigation.

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Closed Loop Fumigation Systems

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Background

"Probe" or "probe and tarp" fumigation has been the conventional method of fumigating stored grain for decades. In probe fumigation, about three-quarters of the fumigant dosage is probed from one to five feet into the surface grain mass, while the remaining fumigant is placed in aeration ducts in the base of the structure. Partially filled bins are "tarped" with 4 to 6 mil plastic sheeting placed over the surface to limit the fumigated volume and minimize leakage. In probe fumigation, labor expenses make up one-half to two-thirds of total fumigation costs.

Concrete silos are typically fumigated using automatic pellet dispensers as grain is turned. But, unless there are other sound management reasons for turning grain, the electrical and labor costs of turning and the additional grain dust shrink from handling damage (1/4 to 1/2 percent) are considered fumigation costs.

Closed loop fumigation (CLF) was originally developed as a recirculation process for methyl bromide fumigation in the U.S. and other major grain-producing countries. Methyl bromide recirculation was reported in the 1920s. The J-System®, a low airflow fumigation recirculation process for use with phosphine, was developed in the late 1970s and patented by James S. Cook at Houston, Texas, in 1980.

CLF uses low-pressure, low-volume centrifugal blowers to draw fumigant/air mixtures through pipes from the headspace and push the gas into the base of structures, forcing it to flow upward through the grain to the headspace in a closed loop cycle. CLF offers an alternative to traditional probe and tarp fumigation of round and flat steel storage structures or fumigating concrete silos as grain is turned.

Commercial fumigators have used portable CLF for country elevator and terminals storage and for export facility ship hold fumigation in the U.S. since the mid- to late 1980s. CLF installations systems were installed in grain storage structures at Kansas, Oklahoma, and Texas elevators in the late 1980s. They have been tested at Oklahoma elevators from 1990 to 1994.

Advantages of Closed Loop Fumigation

Closed loop fumigation reduces worker chemical exposure and improves fumigant distribution and efficacy, thus reducing the incidence of fumigation failures. CLF also reduces housekeeping while improving elevator facility safety. The cost of fumigant is typically reduced from 25 to 50 percent through CLF's efficient application technology.

Safety

During probe fumigation, fumigant pellets/tablets probed into warm, moist grain often begin to release phosphine gas before workers complete the application. Potential for exposure is greatest in large, flat storage or round steel tanks due to the time needed to complete the probing (and tarping) process. Dispensing pellets into the bucket elevator pit is hazardous because part of the pellets spill out of the cups and fall in the leg boot, releasing gas in the basement. A stalled leg or conveyor loaded with pellets creates a safety hazard that requires monitoring and may require the use of a self-contained breathing apparatus (SCBA).

Compared to conventional fumigation, CLF greatly reduces worker exposure to fumigant gases. If properly developed and managed, CLF requires little bin entry time. In some cases, all application is done from outside the storage. Elevators and surrounding neighborhoods have less risk from grain dust explosion hazards when CLF is used to replace turning. Less turning reduces housekeeping, so workers have less exposure to toxic gases or chronic dust health hazards.

Fumigation Timing and Speed

In both single and multiple tank or silo configurations, closed loop fumigation systems reduce application and fumigant purge time (venting to below 0.3 ppm). If storage units at grain storage facilities are equipped with CLF and storages are sealed, fumigant application in all units can typically be completed and CLF blowers started by two workers in one to three hours.

In storage facilities without aeration, CLF blowers are used to purge phosphine gas from the structure when fumigation is complete. This allows the air quality in the facility to be cleared to acceptable levels for worker reentry more rapidly than by using natural gravity venting. Several days can be saved in market down-time per fumigation with CLF.

Increased Effectiveness

Closed loop fumigation generally results in higher kill effectiveness, even at lower dosage application levels, compared to conventional fumigation. The incidence of fumigation failures is greatly reduced as gas is distributed more rapidly and completely throughout the structure for more uniform exposure to all insect life stages. CLF facilitates the simultaneous fumigation of all storage units, eliminating reinfestation of fumigated storages by insects moving from adjacent structures.

Reduced Housekeeping

In concrete facilities, closed loop fumigation systems help reduce grain dust generation, accumulation, and emissions by reducing grain turning. This improves worker health conditions and eliminates lost grain revenue.

CLF Economics

Potential Savings in Fumigation Costs

The use of closed loop fumigation systems has many economic benefits, because CLF can reduce:

1. the amount of fumigant required,
2. grain turning expense,
3. grain dust weight losses,
4. labor expense, and
5. health and insurance costs.

While CLF advantages are not easily quantified in terms of increased fumigation effectiveness and worker safety, the use of CLF systems does reduce fumigation operating costs per bushel. A summary of potential cost savings for various types of grain storage facilities is presented in Tables 1 and 2.

Construction Costs

Costs for CLF installations in individual 100- to 130-foot concrete silos are currently estimated to range between $600 and $1,000 per silo, depending on the piping installation and blower design and size. Inside piping and blowers are more expensive; therefore, external piping systems are recommended. Labor costs vary widely on

Table 1. Cost reductions from closed loop fumigation versus conventional probe methods.

	Conventional	Closed Loop
Labor (sealing and probing)	.25¢/bu.	.20¢/bu.
Fumigant	.30¢/bu.	.15¢/bu.
Supplies and overhead	.60¢/bu.	.60¢/bu.
Total cost/bu.	1.15¢/bu.	.95¢/bu.
Projected annual savings		.20¢/bu.

*Electricity for operation of the CLF blower system is ignored, since it is projected at less than .001¢/bu.

Table 2. Cost reductions from closed loop fumigation versus turning with automatic dispenser.

	Conventional	Closed Loop
Labor (sealing)	.20¢/bu	.20¢/bu.
Labor (turning)	.10¢/bu.	——
Fumigant	.30¢/bu	.15¢/bu
Supplies and overhead	.30¢/bu.	.30¢/bu.
Fumigation cost/bu.	.90¢/bu.	.65¢/bu.
Grain turning electricity	.40¢/bu.	——
Grain turning shrink	.75¢/bu.	——
Total cost Fumigation and turning	2.05¢/bu.	.65¢/bu.
Projected annual savings		1.40¢/bu.

*Electricity for operation of the CLF blower system is ignored, since it is projected at less than .001¢/bu.

internal system installation, based on the difficulty of installing pipes or tubing through roofs and securing them to sidewalls.

To make CLF systems for concrete silos more competitive, grouping several silos together into a common gas collection and distribution manifold system is recommended, rather than plumbing each silo separately with its own blower and piping system (Figure 1). Estimated construction expenses for typical concrete silo (multi-tank, manifolded approach), large steel, and corrugated steel bin applications are provided in Table 3. Manifolding two or more steel bins together to use a common blower can also reduce installation costs and increase management operation flexibility.

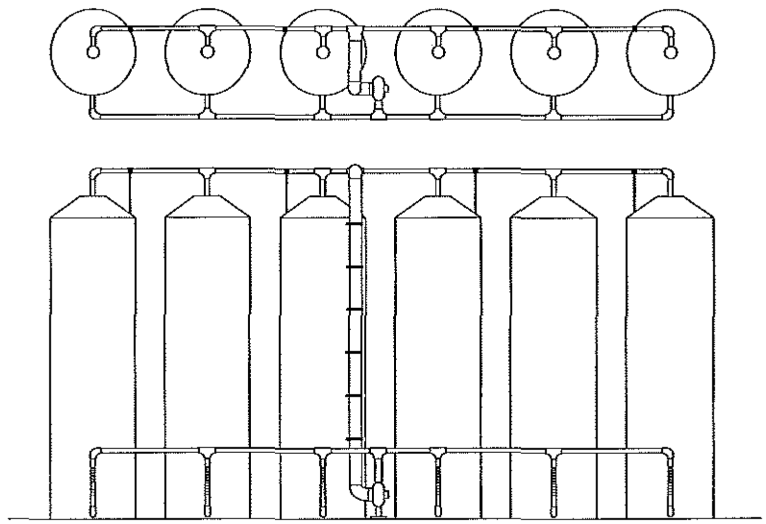

Figure 1. Concrete silos manifolded together using one CLF blower and one vertical pipe.

Economic Analysis

In large steel bins, CLF systems provide lower fumigation costs relative to probe and tarp fumigation. In concrete silos, fumigating with the closed loop system is cheaper than using automatic pellet dispensers while turning grain, if an additional grain turning for fumigation is eliminated. While concrete silo applications provide the highest potential operating cost savings (by eliminating grain turning), they also represent higher construction costs per bushel if each silo is piped separately, due to smaller grain volumes. But when multiple silos are manifolded to operate as a single unit, as shown in Table 4, concrete silo CLF systems are competitive with large steel storage tanks. Thus, CLF return on investment can be similar for concrete and steel tank installations if concrete tanks are manifolded.

The projected payback period for all three CLF system applications ranges from 4.1 to 5.3 years. For all three systems, internal rates of return, a measure of annual cost savings in relation to the initial investment, range from 18 to 24 percent. Elevator managers who can obtain funds at less than an 18 percent after-tax interest rate should find the CLF systems to be a good investment.

Table 3. Estimated construction costs.

	25-40,000 bu. concrete silo x 8-10 silos manifolded = 200-400,000 bu.	**200-350,000 bu. corrugated steel bin**	**300-500,000 bu. welded steel tank**
Centrifugal blower specification	Single blower 1/2 - 1 HP	Single blower 1/4 - 1 HP	Two blowers 1/4 - 1 HP
Blower costs	\$450-\$600	\$350-\$600	\$700-\$1,200
Ducting materials	\$1,200-\$1,500	\$400-\$600	\$800-\$1,000
Installation labor	\$1,000-\$1,500	\$900-\$1,200	\$1,500-\$1,800
Total costs	\$2,650-\$3,600	\$1,650-\$2,400	\$3,000- \$4,000
Total cost/bu.	0.9-1.32¢/bu.	0.7-0.83¢/bu.	0.8 to 1.0¢/bu.

Table 4. Summary of costs and benefits of closed loop fumigation systems.

	Fumigate while turning in 8 x 25,000 bu. = 200,000 bu. concrete silos	**Probe and tarp in 200,000 bu. corrugated steel bin**	**Probe and tarp in 300,000 bu. round steel bin**
Total construction cost	\$2,650	\$1,650	\$3,000
Construction costs/bu.	1.32¢/bu.	.83¢/bu.	1.0¢
Cost reduction per bu.*	0.25¢/bu.	0.20¢/bu.	0.20¢/bu.
Payback period	5.3 years	4.1 years	5.0 years
Internal rate of return	18.2%	23.9%	19.4%

*fumigant and labor

CLF Costs of an Oklahoma Elevator

Construction costs for a system completed during the Fall of 1993 in Oklahoma (Figure 2) are summarized in Table 5. This installation involved four 200,000-bushel, corrugated steel bins. Each pair of bins is served by a 1 hp centrifugal blower connected to the CLF piping manifold. This blower delivers about 900 cfm to 400,000 bushels for a gas flow of about 0.002 cfm/bu. This system delivers about six air changes per day (four hours/air change) on two bins, or 12 air changes per day on one bin. The installation cost per bin was $1,368, or 0.68¢ per bushel. The manifolded CLF system design, which allowed each blower to service two bins, helped to reduce the total cost.

Table 5. Installation costs of a closed loop fumigation system at an 800,000-bushel Oklahoma country elevator.

2 TEFC blowers (1 hp. each)	$840	
Ducting materials (6" PVC pipe)	$1,080	
Flashing	$101	
Pipe support clamp brackets	$598	
Misc. hardware (rubber boots, bolts, screws, etc.)	$428	
Bucket truck rental	$1,411	
Millwright labor (construction foreman and electrician)	$1,015	
External installation costs	$4,633	
External installation cost for four 200,000 bu. bins	$1,158	(0.58¢/bu.)
Estimated cost of elevator labor; 4 men x 20 hours = 80 man hours @ $10/man hour	$800	($200/bin)
Total Installation Cost/bin	$1,358	(0.68¢/bu.)

Table 6. Summary of costs and benefits of closed loop fumigation systems.

	Initial estimate for 4 corrugated steel bins (800,000 bu.)	Actual costs for 4 corrugated steel bins (800,000 bu.)
Total construction cost	$1,500	$1,358
Construction costs per bu.	0.75¢/bu.	0.68¢
Cost reduction per bu.	.20¢	.15¢
Payback period	4.1 years	4.5 years
Internal rate of return	23.9%	21.7%

To minimize fabrication time and cost, elevator personnel pre-assembled exterior plumbing on the ground. The rental of a bucket truck from a local electric cooperative at $25 per hour helped speed up final installation of vertical suction piping (Figure 2) to reduce labor costs. During 1994 operation, the elevator reduced the normal fumigant dosage by one-third, and measured fumigant concentrations of 350 to 400 ppm at the recirculation blower during the third day of fumigation.

Summary of Cost Benefits

Costs and benefits of the closed loop fumigation system for these 200,000-bushel, corrugated steel bins were close to initial estimates (Table 6). Lower than expected construction costs were offset by lower savings in initial fumigant dosage (reduced dosage by 33 percent, versus 50 percent). At current fumigant application cost levels, the system payback is about four years. At current levels of fumigant and labor savings, the CLF system is yielding the elevator 22 percent on their one-time investment of $1,358 per bin.

Phosphine Gas Generation Rates

Continuous recirculation during the initial two to three days of fumigation pushes gas to all areas of the grain mass. Table 7 shows that at 70 to 75°F and 91 percent R.H., phosphine pellets reach 90 percent breakdown in 15 to 21 hours, while 90 percent tablet breakdown occurs in 21 to 36 hours, depending on the product. Table 7 lists times required for 10, 50, and 90 percent breakdown of tablets and pellets of four phosphine products. Maximum concentrations for each product are listed in the table, based on the theoretical concentration of 720 ppm from 1 gram (1 tablet or 5 pellets).

According to Table 7, gas release times varied significantly between products for pellets and tablets at 0 to 22°C (68-72°F) and 91 percent R.H. For each fumigant (Phostoxin®, Gastoxin®, etc.), gas release rates vary substantially with changes in temperature and/or humidity. Using CLF, gas is more uniformly distributed throughout a structure within the first two days when gas release concentrations are low (60 to 70 ppm at $T_{10\%}$).

CLF systems do not operate like aeration systems because gas distribution is not dependent on gas flow rate. For example, even though gas flow may be five times as high at the center of a bin than at the wall/floor junction, gas readings at both locations may be equal after one or two days of CLF fan operation.

With improved gas distribution, the total phosphine required for CLF can be substantially lower. Equal or improved results from fumigation have been reported using 50 percent of the fumigant required with probe methods. Instead of using maximum label requirements, some operators are able to reduce dosage levels to minimum label requirements with better results. However, during initial use of CLF, operators should apply the higher dosages until they are familiar with their CLF system and have achieved successful fumigation results. This helps offset failures, if structures are inadequately sealed.

Table 7. Breakdown rates for aluminum phosphide fumigants*—dosage 1 tablet or 5 pellets (1 gram) per cubic meter (theoretical concentration = 720 ppm PH_3).

	Times for 10%, 50%, and 90% breakdown			
Product	**T10% (hrs)**	**T50% (hrs)**	**T90% (hrs)**	**Max. concentration (ppm PH3)**
Fumitoxin® tablets	3.4	10.1	21.3	600
Fumitoxin® pellets	4.3	11.5	21.2	725
Gastoxin® tablets	4.2	14.7	26.3	635
Gastoxin® pellets	3.3	12.2	21.4	660
Phostek® tablets	4.5	16.5	36.5	635
Phostek® pellets	1.3	8.0	14.5	690
Phostoxin® tablets	3.5	16.4	26.7	670
Phostoxin® pellets	2.4	10.4	19.1	695

*@ 20 to 22°C (68 to 72°F) and 91 percent R.H.
Source: Degesch America, 8/10/94

CLF Fumigation Procedures

Sealing Structures

Sealing bin or silo openings is primary in successful CLF system operation. Phosphine concentration levels of 100 to 150 ppm are needed for at least 72 hours to penetrate kernels and kill insect eggs and larvae. Welded steel and concrete tanks are usually sealed tighter than bolted steel tanks, unless bolted tanks were well caulked during construction.

Roof to sidewall air gaps, mid-roof panel overlaps, and exposed spaces between roof panel ridges and fill rings are critical sealing areas in corrugated steel tanks. Open roof panel ends under fill ring flashing collect grain dust and make natural insect breeding places. These openings should be sealed with a foam sealer. For standard bolted tanks without intensive caulking, recirculation airflow rates should be higher (0.004 to 0.008 cfm/bu. range) than for welded steel or concrete tanks.

Phosphine Application

In CLF structures such as corrugated steel tanks that have leaks, phosphine tablets may be preferred over pellets because of slower gas release. In tightly sealed structures, such as welded steel and concrete tanks, pellets will provide a faster, more uniform concentration buildup. Successful fumigation is based on maintaining an adequate minimum concentration of 100 ppm for at least three to five days.

After placing the phosphine pellets or tablets on the grain surface in the structure headspace and sealing the structure, the CLF blower can be turned on immediately or after a two- or three-hour delay. The air/gas mixture is pulled from the storage headspace through a five- to six-inch diameter duct (tube, pipe, or hose) into the suction side of the blower, then pushed through a duct into the base of the storage, forcing it up through the grain back to the storage bin headspace.

Blower Operation Options

The blower can be operated continuously, but if the structure is not tightly sealed, less gas loss occurs if the blower is operated until the gas distribution is uniform (two to three days), and then shut off for two or three days. During shut-off periods, the fumigant remains in the grain and interstice air, unless convection currents cause it to leak out of the structure. This is especially important in corrugated steel tanks and flat storages with poorly sealed roofs and sidewalls. Total fumigation time should be calculated based on grain moisture and temperature factors per the fumigant label.

Gas Level Monitoring

While a new CLF system is being used for the first time, gas concentration levels should be monitored daily at key locations in the storage throughout the fumigant recirculation period to develop valuable management data. These recorded gas level monitoring data should be filed and maintained for future reference and comparison against future monitoring data.

Operators should start by using high label rates (85 to

100 percent of maximum or normal probe dosages) during the first application of the new system, and then monitor to make sure gas levels are adequate. If initial gas readings are sufficiently high and stable for several days, application levels may be reduced by stages during future fumigations. If satisfactory gas levels and kill results warrant, application may be reduced to minimum label rates for the type of structure being fumigated.

Purging Structures After Fumigation

When possible, aeration blowers should be used to purge fumigant gas from structures. If aeration is not available, CLF blowers can be used to vent storage structures. CLF blowers that provide 0.002 to 0.01 cfm/bu. airflow should be operated continuously for two to three days when venting storages because of non-uniform air distribution. Monitor air at access and entry points to be sure fumigant levels are well below the minimum worker re-entry threshold levels.

When CLF blowers are used for purging, disconnect the suction hose at the blower inlet, open the roof hatch or vents, and turn the blower on. Open vents or hatches must be located away from fresh air supplies of blowers. If blowers are roof mounted, a fresh air supply may need to be ducted to the blower from several feet away, so that exhaust air is not recirculated. Prevailing winds need to be considered and standpipes may be needed to avoid dilution of fresh air.

If blowers are inside the storage as shown in Figure 3, the blower air supply must be controlled from the outside to avoid the need for SCBA-equipped personnel to change the piping prior to venting or purging the fumigant (Noyes 1993). On externally mounted blower and piping systems where the tank or silo has no aeration system, remove the suction return pipe and open roof exhaust vents or doors and operate the blower to purge the tank.

Regardless of the method used for venting the gas, monitor the air quality or gas level in each storage structure with appropriate gas sampling equipment, preferably through remote sampling tubes, before entering the stor-

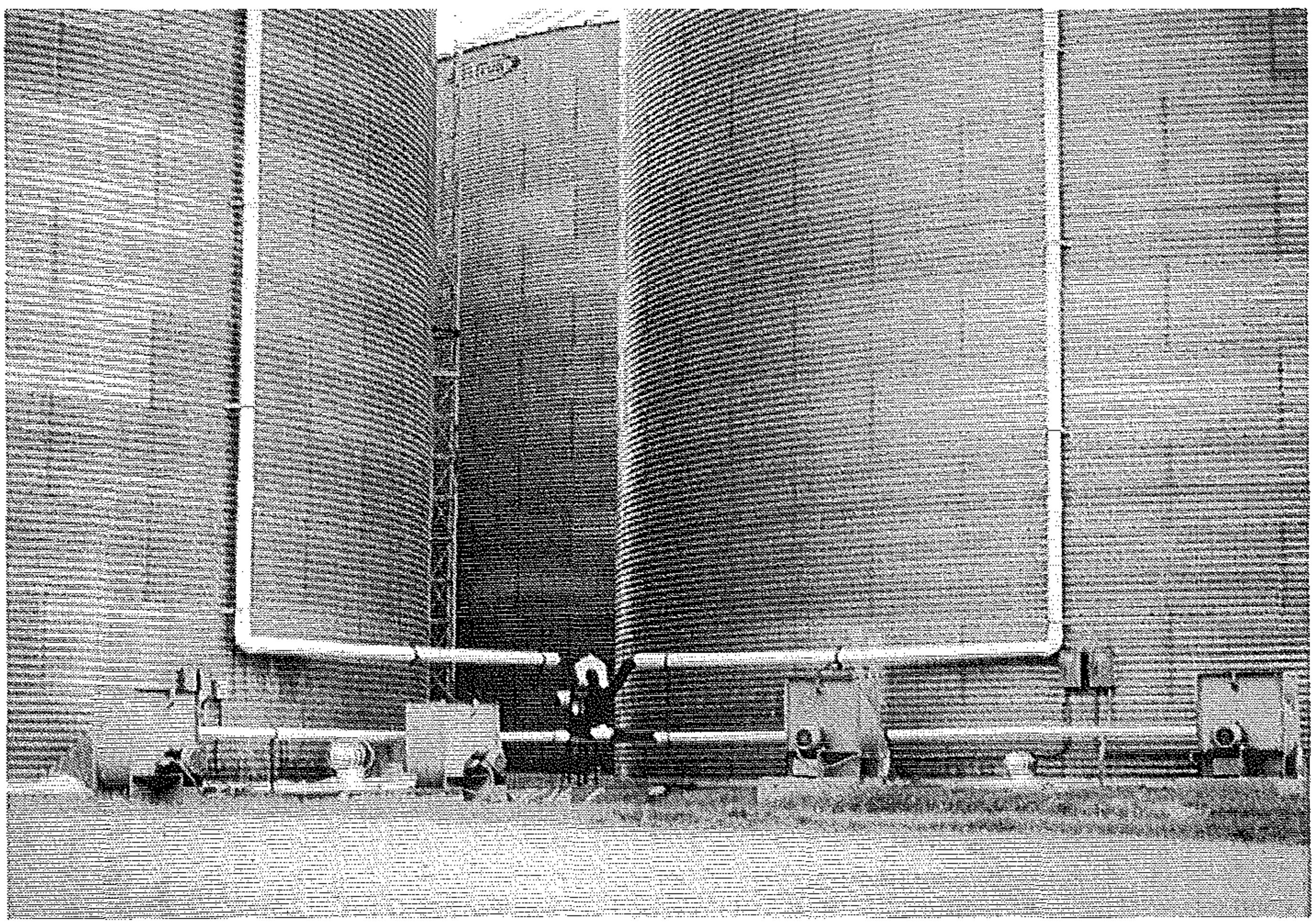

Figure 2. Two large, corrugated steel tanks manifolded to one CLF blower.

age. Air samples must be taken inside the bin at entrances and in work areas of the storage and recorded to confirm that the fumigant has been satisfactorily purged. Work space air samples should be taken and data recorded before workers resume normal re-entry to ensure safe concentration levels of phosphine gas below 0.225 ppm (0.3 ppm x .75—phosphine gas monitoring tube accuracy ranges from about ± 5-25 precent) for phosphine gas sampling tubes, depending on the tube range and the manufacturer.

Blower Specifications

Blowers used for phosphine gas handling should be manufactured from materials that are resistant to chemical deterioration. Aluminum or plastic wheels and housings are preferred because they are also spark resistant. Steel blower wheels and housings should be coated with epoxy or some other tough, spark resistant materials. Gas flow rates range from 0.002 to 0.010 cfm/bu., to provide a total air change every 50 to 250 minutes, or about six to 24 changes per day. Normal aeration at 0.1 cfm/bu. displaces one air change in a full bin in five minutes—20 times faster than a CLF blower delivering 0.005 cfm/bu. (Noyes 1993).

Gas flow rates of 0.002 to 0.005 cfm/bu. with air exchange times of 250 to 100 minutes (4.2 to 1.7 hours/cycle) are quite low relative to tank or silo volume. Table 8 illustrates a range of blower sizes, power requirements, and airflows for a series of blowers suitable for use in CLF gas recirculation systems (Anon. 1993, Anon. 1994).

A basic closed loop fumigation system blower and duct design for a single 20 foot x 100-130 foot concrete silo uses a 1/12 HP centrifugal blower with a four-inch inlet and outlet. This blower operates at one- to two-inch water column (W.C.) static pressure at 140 to 199 cfm through 20,000 to 50,000 bushel silos and tanks, and provides one

Table 8. CLF blower specifications.

Model	HP	CFM				
Static press.	(inches W.C.)	1" S.P.	2" S.P.	3" S.P.	4" S.P.	5" S.P.
A-3*	1/12	199	140	---	---	---
6P**	1/4	320	265	240	200	---
A-4B*	1/3	340	250	---	---	---
B-8*	1/3	343	294	227	125	---
7P1**	1/3	550	400	300	250	---
B-9*	1/2	490	450	380	310	200
7P2**	1/2	700	625	575	450	375
8P1**	1	980	930	870	565	---
8P2**	2	1,210	1,140	1,080	1,010	940
8P3**	3	1,280	1,230	1,170	1,100	1,030

* Degesch America, Inc., Weyers Cave, Va.
** Cincinnati Fan and Ventilator Co, Inc. Cincinnati, Ohio.
Note: These aluminum blowers with split housings may require caulking at the housing seam to avoid gas leaks. Check with soap solution while running.

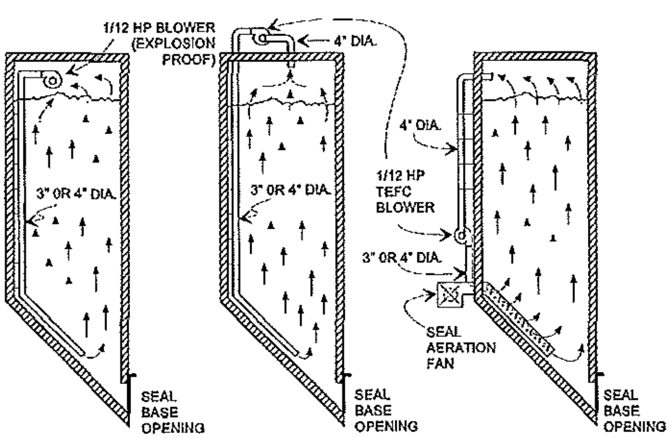

Figure 3. CLF systems for individual concrete silos.

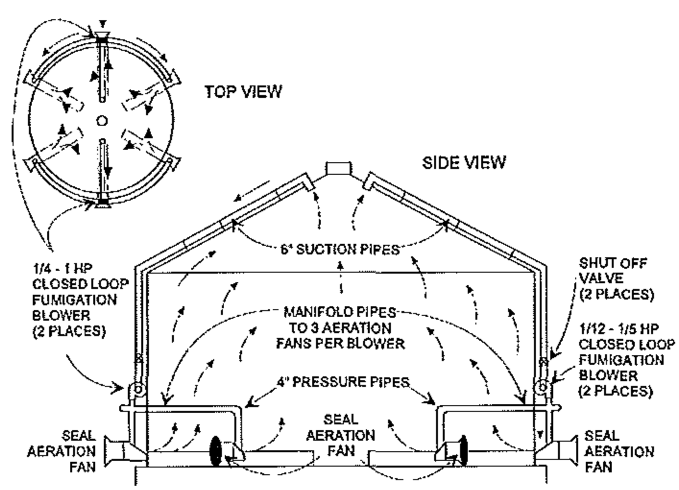

Figure 4. Two CLF blowers with separate pipe manifolds on large, welded steel or concrete tanks.

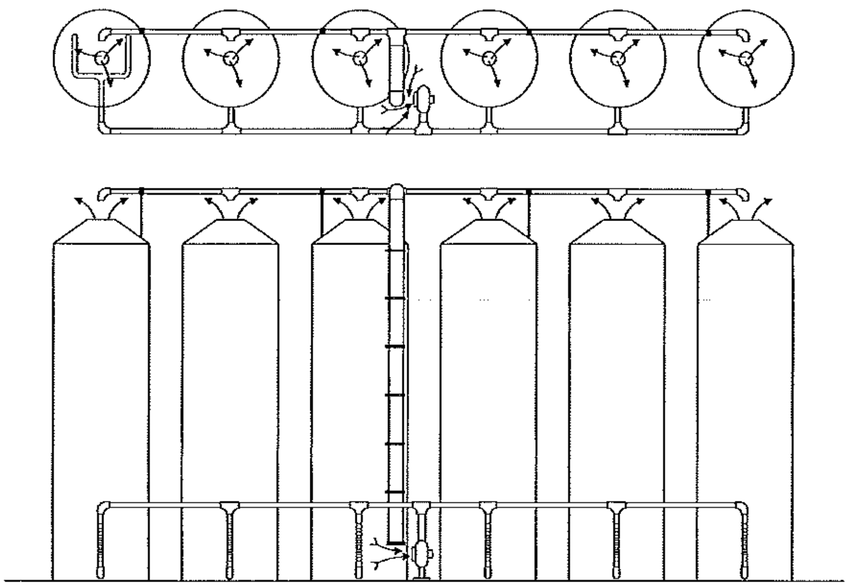

Figure 5. Silo or tank venting options.

get more uniform gas distribution. In hopper bottom tanks, a single pipe placed down the slope to within two to three feet of the bottom of the hopper provides improved distribution. The hopper acts as a gas distribution funnel, with the hopper slope distance offsetting the direct flow distance up the center of the silo, especially if the grain surface is peaked.

Figure 5 illustrates the piping setup for CLF blowers to vent phosphine gas from silos. If the piping system and blower are mounted inside elevator head houses or inside the silo as shown in Figure 3, explosion-proof motors, switches, wiring conduits, and controls are required according to electrical codes.

CLF piping inside silos is not recommended because it is extremely difficult to anchor securely. If piping is placed inside, metal piping should be used to eliminate static electricity generated by grain sliding on PVC pipe. Grain pressure in 100- to 130-foot grain depths places great stress on piping mounted inside silos, so fastening pipes securely to inside walls at three-foot intervals is critical. If an interior ladder is available, mount the duct against the wall and ladder brackets or side rails for convenience and structural stability.

Outside blower and pipe mounting is preferred. Either schedule 80 PVC plastic or metal (aluminum or lightweight galvanized piping) works well. Salvaged aluminum irrigation pipes or tubing make good CLF piping systems. Outside mounting brackets can be spaced at eight- to 12-foot intervals. PVC pipe is a popular duct material due to its light weight, chemical resistance, low cost, and ease of fabrication and assembly.

For external CLF blowers, suction pipes must extend through the silo roof into the headspace (Figures 1, 3, and 4). The pressure pipe can be installed through the roof and along the inside wall to the base (i.e., secured to the ladder side-rail down the wall), or installed down the outside of the tank and into the grain at the base of the wall. The blower can be installed near the base with a long suction pipe and a short pressure pipe, or on top of the silos with a short suction line and a long pressure line. If aeration systems are involved, the pressure pipe connects into the aeration blower transition.

air exchange every one to two hours or 12 to 24 changes per day.

Older concrete silos have internal wall vents at the roof which are difficult to seal. Combining several silos to form a larger storage volume simplifies installation and reduces installation expense. Suction and pressure pipes from multiple silos can be manifolded to one larger blower to simplify operation and reduce control costs (Figure 1). For 50,000- to 100,000-bushel storages, 1/4 to 1/3 HP blowers delivering 250 to 550 cfm at one to two inches W.C. combined suction and positive static pressures are recommended (Table 8). Steel tanks with 100,000 to 400,000 bushels volume may use one 1/4 to 1 1/2 HP blower or use two smaller blowers when suction and pressure piping must be split, depending on the layout of the aeration system and required gas distribution piping (Figure 4).

Piping Design

Concrete Silos

In 15- to 25-foot diameter individual concrete or steel silos, an open-ended pipe or tube that discharges at the bottom of the vertical sidewall or extends down slope to the center of the silo is the typical design. Figure 3 shows the pipe and blower for a one-way sloped or cone hopper bottom silo. In 30- to 50-foot diameter concrete silos, a pressure manifold from a single blower with connections to two, three, or four aeration blower transitions and under-floor ducts spaced evenly around the tank or silo perimeter should be used to

Steel Tanks

Getting uniform gas distribution is more difficult in large diameter tanks than in tall silos, where the silo diameter is much smaller than the grain depth. On 50- to 130-foot diameter tanks with aeration blowers mounted on one side of the tank, one CLF blower may be adequate. If blowers are spaced symmetrically around the base, a CLF piping system design using two smaller blowers may be simpler and less expensive than one large blower with extensive larger piping or hose systems (Figure 4).

For large tanks, gas flow rates of 0.005 to 0.01 cfm/bu. (one air change in about one to two hours) will offset poor distribution duct patterns and accelerate getting lethal gas levels to all parts of the storage. Figure 5 shows the CLF system modified so that blowers are used for venting the gas when fumigation time has been completed. Tanks with aeration systems should use aeration blowers to vent the fumigant gases. Immediately after venting, operators should reseal aeration blower openings to keep insects from reinfesting the storage at the base level.

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21

Resistance to Chemicals

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Why Accurate Application and Doses Are Important

Resistance to pesticides is the ability of a strain of insects to tolerate doses of toxicants which would prove lethal to a normal population of insects of the same species. Resistance results when occasional resistant individuals arise in a population and survive the pesticide treatment. These survivors then reproduce and confer the resistance to their offspring in succeeding generations.

The pesticide dose can influence the development of resistance in several ways. If dosage is too high, insect pests may be exposed to significant residues for a longer time causing increased resistance. If the dosage is too low, marginally resistant insects may survive and reproduce, giving resistance a foothold from which it can intensify. Thus, accurate dosage is a two-edged sword. Ideally, the dose must be sufficiently large in concentration to kill the pest (or otherwise render non-viable), yet small enough to prevent the accumulation of unsafe and illegal residues on food products or contamination of the environment.

In actual practice, it is difficult to expose each individual insect to a lethal dose of pesticide because it is virtually impossible to reach every niche where an insect might hide or otherwise avoid coming in contact with the pesticide. For residual pesticides, the chemical may not be delivered directly to the pest, but must be applied to food, fiber, and other agricultural products on the assumption that the pest will accumulate a lethal dose by feeding or moving through the treated material. This is particularly important if the pest population is resistant because the labeled dose cannot be arbitrarily increased. In addition, highly resistant insects may not be susceptible to legal doses.

Although it is not illegal to use less than the labeled dose, low doses are common (Arthur et al. 1987, Arthur et al. 1991, Halliday et al. 1991, Redlinger 1976, Redlinger and Simonaitis 1977) and can be costly in terms of low levels of resistance (Redlinger et al. 1988, Zettler et al. 1986, Zettler and Cuperus 1990). There is probably no way to avoid high-level resistance short of applying doses so high as to be unsafe or illegal, switching to an alternative pesticide, or abstaining from pesticide use altogether. Thus, in the long-term interest of minimizing resistance, it would be best to use as close to the recommended dosage as possible without exceeding it.

Cross-Resistance

Thirty years of malathion use for control of stored-grain pests in the United States has led to widespread resistance in the red flour beetle and Indianmeal moth, but not in other pest species. Malathion resistance in the lesser grain borer has been reported to be infrequent or marginal in the Midwest and absent in South Carolina (Haliscak and Beeman 1983, Horton 1984). More recently, Zettler and Cuperus (1990) found lesser grain borer populations in Oklahoma to be uniformly resistant to malathion, but it was not determined whether this resistance was marginal or severe. Weevils (*Sitophilus* spp.) are very sensitive to malathion and apparently have not developed resistance, even after decades of exposure.

Fortunately, malathion resistance usually does not confer cross-resistance to other protectants—not even to other organophosphates. Thus, malathion-resistant red flour beetles are not cross-resistant to chlorpyrifos-methyl or pirimiphos-methyl (Bansode and Campbell 1979, Subramanyam et al. 1989, Beeman and Wright 1990). The same is true of malathion-resistant Indianmeal moths (Beeman et al. 1982). The reason for this specificity is the presence in most insects of esterases that specifically metabolize malathion, but not other insecticides. Individuals containing these esterases are selected in malathion-treated populations, leading to a predominance of malathion-specific resistance. Insect strains already resistant to malathion may subsequently develop resistance to another protectant, but the two events are independent. Also, the likelihood or intensity of subsequent resistance does not seem to be affected by the prior presence or absence of malathion resistance.

Chlorpyrifos-methyl and pirimiphos-methyl were introduced as new stored-grain protectants in 1985 and 1986, respectively. Resistance to these protectants was unknown in the United States prior to 1986. Thus, it is likely that cases of such resistance reported since then arose as a direct result of recent pest exposure to chlorpyrifos-methyl and pirimiphos-methyl themselves, and not because of pre-existing resistance or cross-resistance. Weevils infesting stored products have not been tested for resistance to chlorpyrifos-methyl and pirimiphos-methyl since 1985. Red flour beetle, flat and rusty grain beetle, and Indianmeal moth populations are still uniformly susceptible in all areas tested (Arthur et al. 1988, Halliday et al. 1988, Subramanyam et al. 1989, Beeman and Wright 1990, Zettler and Cuperus 1990).

Resistance to chlorpyrifos-methyl and pirimiphos-methyl is beginning to appear in at least three species of stored-product insect pests, but the severity of resistance in these cases is mild or has not been determined. In 1988, Arthur et al. reported low-level resistance (less than or equal to five-fold) to pirimiphos-methyl in two strains of the almond moth from Georgia and Alabama out of 13 tested. There was some evidence of cross-resistance to chlorpyrifos-methyl and dichlorvos. Subramanyam et al. (1989) found resistance to chlorpyrifos-methyl in four Minnesota strains of the sawtoothed grain beetle out of six tested. None were cross-resistant to pirimiphos-methyl. The severity of resistance was not tested, but most of the individuals in each of the four populations were at least somewhat resistant. Beeman and Wright (1990) found marginal or incipient resistance to chlorpyrifos-methyl in a few strains of the sawtoothed grain beetle and the lesser grain borer collected in Kansas, although most strains of both species were susceptible. In contrast, Zettler and Cuperus (1990) found that all strains of the lesser grain borer collected in Oklahoma were at least mildly resistant to chlorpyrifos-methyl, and were all cross-resistant to dichlorvos. In general, resistance to chlorpyrifos-methyl, pirimiphos-methyl, or dichlorvos is expected to confer broad cross-resistance to many other organophosphate insecticides (unlike the special case of malathion).

Cases of resistance to the biological insecticide *Bacillus thuringiensis* (*B.t.*) and to the fumigant phosphine have been reported in field strains of stored-grain insect pests in the United States in recent years. Resistance to *B.t.* occurred in the Indianmeal moth and almond moth (McGaughey 1985, McGaughey and Beeman 1988), and phosphine resistance was detected in the red flour beetle, Indianmeal moth, and almond moth (Zettler et al. 1989, Zettler and Cuperus 1990). Because of the unique chemistry, metabolism, and mechanisms of toxicity of these types of insecticides, resistance to biological agents does not extend to chemical insecticides, and fumigant resistance does not extend to non-fumigant agents. In the case of moth resistance to *B.t.*, a correlation was seen between *B.t.* usage and the occurrence of resistance. In addition, the intensity of resistance was high (McGaughey 1985). In the case of phosphine, no control failure due to the presence of phosphine-resistant pests has been reported in the United States, although such cases have occurred in Pakistan, Bangladesh, and Australia. The intensity of phosphine resistance in the United States is low (Zettler 1991). However, the experience of other countries suggests that phosphine resistance may intensify in the future.

Resistance Management

The management of pesticide resistance is the use of methods that extend the number of generations that a given pest population can be controlled economically by a pesticide (Roush 1989). Although many tactics have been devised to manage resistance, little has been done in actual practice to accomplish this feat. However, in order to manage resistance, one must be able to manipulate or control those factors which contribute to resistance. These factors include the genetic makeup of the pest, its reproductive potential, its behavioral and ecological capabilities, as well as the chemical and its methods of application.

Resistance management should be aimed at conserving susceptibility by reducing frequencies of resistant alleles, decreasing the dominance of resistance, and minimizing fitness of resistant genotypes (Leeper et al. 1986). The most promising tactics for accomplishing this can be grouped into three categories: 1) management by moderation, 2) management by saturation, and 3) management by multiple attack (Georghiou 1983).

Management by Moderation

Management by moderation is based on the premise that susceptible genes in a population must be conserved or replenished. The most effective way to do this is to avoid pesticide applications altogether. However, moderation can be accomplished by 1) releasing susceptible individuals or by immigration of susceptibles from adjacent populations, 2) reducing the dose of pesticide to the point that some susceptibles survive the selection pressure, 3) providing untreated refuges for susceptibles to avoid treatment, 4) reducing the frequency of applications to lower overall selection pressure, 5) avoiding persistent compounds or formulations which increase selection pressure, 6) targeting those life stages which are most susceptible, and 7) using selective pesticides that do not put selection pressure on other species.

Management by Saturation

Management by saturation occurs when the defense mechanisms of the insect are saturated by dosages that can overcome resistance. Applying dosages high enough to be lethal to susceptibles as well as to heterozygous-resistant individuals in effect renders the resistance genes functionally recessive. This approach might be useful where a high dose of rapidly decaying pesticide is feasible (i.e., fumigants), or where compounds lack mammalian toxicity (i.e., juvenile hormone mimic, bacterial toxin). This approach might be ineffective against strains where selection has already given rise to a high frequency of homogyzous-resistant individuals (Georghiou 1983). Synergists (i.e., piperonyl butoxide, Kitazin-P) can be useful in some circumstances to eliminate the resistant genotypes by blocking or minimizing the resistance mechanism (Roush 1989).

Management by Multiple Attack

Management by multiple attack involves using mixtures of chemicals and alternations (rotations). The usefulness of mixtures is based on the premise that resistance is delayed because a mixture acts on more than one biochemical site. Insects that survive one of the chemicals in the mixture are killed by another. Results from recent experimental models suggest that mixtures might be especially effective for managing resistance, while results from actual experimental trials suggest that mixtures do not consistently suppress resistance development (Tabashnik 1989). The usefulness of rotations is based on the assumption that individuals resistant to one chemical have substantially lower biotic fitness than susceptibles to the extent that the frequency of resistant individuals declines during the intervals between applications of that chemical.

In view of the fact that few of these resistance management tactics have ever been put into practice and others are either impractical or too expensive to achieve, it is likely that the most effective management program will be one in which emphasis is placed on reducing pesticide use and developing alternative controls.

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Part IV: Commodity Inspection and Management

22

FDA and FGIS Commodity Inspection for Insects

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The Food and Drug Administration (FDA) and the Federal Grain Inspection Service (FGIS) are both responsible for inspection of dried beans, peas, lentils, rice, and other processed grain commodities, such as flour, corn meal, and cereals (Figure 1). While both agencies are responsible for inspection, their purposes and authorities regarding the inspection of these products are entirely different.

The FDA is the regulatory agency of the federal government responsible for verifying that products sold in interstate commerce are manufactured, packed, and held in compliance with the requirements of the Food, Drug, and Cosmetic Act. The FDA inspections are designed to fulfill this requirement. Insect contamination is an integral part of these inspections.

The FGIS is the inspection service agency of the federal government responsible for providing inspection information upon request of buyers or sellers to determine product quality. The purpose of FGIS inspections is to facilitate marketing by providing the results of inspections. The FGIS does not regulate the quality of products in the marketplace or establish mandatory quality limits. Information on insect contamination is also provided.

Figure 1. Grain commodities.

The FDA inspects establishments that manufacture, pack, and hold food products to ensure that they do not become adulterated with insects. The FDA also establishes actionable insect limits for these products, and periodically inspects finished products to ensure that products exceeding these limits are not sold in interstate commerce.

FDA Establishment Inspections

The FDA has established regulations titled, "Current Good Manufacturing Practice in Manufacturing, Packing, or Holding Food" (Title 21, Part 110, Code of Federal Regulations), which provide the basic sanitation requirements for establishments. The FDA inspectors periodically verify compliance with these regulations through on-site inspections. Insect infestation within the establishment is a critical factor that inspectors must evaluate. The regulations require that no pests shall be allowed in any area of a food plant. Pests are defined as any objectionable animals or insects, including birds, rodents, flies, and larvae. Establishment inspections are performed according to the FDA Inspection Operations Manual procedures. Copies of the handbook may be obtained by contacting the Food and Drug Administration, Freedom of Information (HFI-35), 5600 Fishers Lane, Rockville, Maryland 20857.

Recently, the Grain Insect Interagency Task Force, chaired by the Deputy Administrator of the Federal Grain Inspection Service and comprised of representatives from other governmental agencies, requested that the FDA establish a position on insects found in insect traps within the facility. The FDA responded to the task force by establishing a policy that insects found in insect population monitoring traps will not be considered as evidence that food is prepared, packed, or held under unsanitary conditions, or that food itself is filthy. The FDA considers the use of insect population monitoring devices as an excellent adjunct to preventative sanitation procedures.

If insect infestation is found in the establishment during inspection, the establishment is requested to voluntarily correct the problem. If the problem is not corrected, the FDA may request a court to issue an injunction against an establishment to stem the flow of violative products in interstate commerce, and to correct the condition in the establishment. The injunction is a civil restraint issued by the court to prevent violations of the Food and Cosmetic Act.

FDA Product Inspections

The FDA periodically samples products during establishment inspections and in response to consumer complaints to determine if products conform with the Federal Food, Drug, and Cosmetic Act. Samples are taken according to the FDA's Inspection Operations Manual. Insects and insect fragments in raw agricultural products and processed products are factors that are evaluated. It is recognized that some foods, even when produced according to proper manufacturing practice, contain natural or unavoidable defects at low levels that are not hazardous to health. The FDA establishes maximum levels for these defects and uses these levels when deciding whether to recommend regulatory action. These levels are commonly referred to as defect action levels (DAL). For example, the current DAL for wheat flour is 75 insect fragments in 50 grams of flour, and 50 insect fragments in 50 grams of corn meal. Copies of the current defect action levels are found in the FDA's Compliance Policy Guides, which may be obtained upon request from the Industry Programs Branch (HFF-326), Center for Food Safety and Applied Nutrition, Food and Drug Administration, 200 C Street SW, Washington D.C. 20204.

The FDA may seize products that have been found to exceed the defect action levels for insect fragments. Seizure is a civil action against the goods and is designed to quickly remove violative goods from consumer channels. Based on decisions made by the FDA and the court, the product may be reconditioned to bring it in compliance. If reconditioning is not possible, the product is condemned or destroyed.

FGIS Inspections

All inspections performed by the FGIS on processed products are only performed upon request. That is, no person is required to have these products inspected by the FGIS. Typically, FGIS inspections are performed when a purchaser requires an inspection as part of the transaction to ensure the quality of the product. Most government purchases require an FGIS inspection as a term of the contract. These purchases include needy family feeding, school lunch, overseas famine relief, and military feeding programs.

The FGIS does not establish mandatory quality limits for these products. However, the FGIS does establish standards for rice, beans, peas, and lentils which include limits on insects. These limits are only benchmarks for product quality and are not mandatory limits for sale purposes. Purchasers determine what factors should be tested and what quality limits are acceptable for their needs. The FGIS has a memorandum of understanding with the FDA to report the results of any inspection which appear to violate the Food, Drug, and Cosmetic Act to the FDA for determination of regulatory action.

FGIS Facility Inspections

Most purchase agreements specifically state that products offered to the FGIS for inspection must be produced under the Current Good Manufacturing Practice in Manufacturing, Processing, Packing or Holding of Human Foods

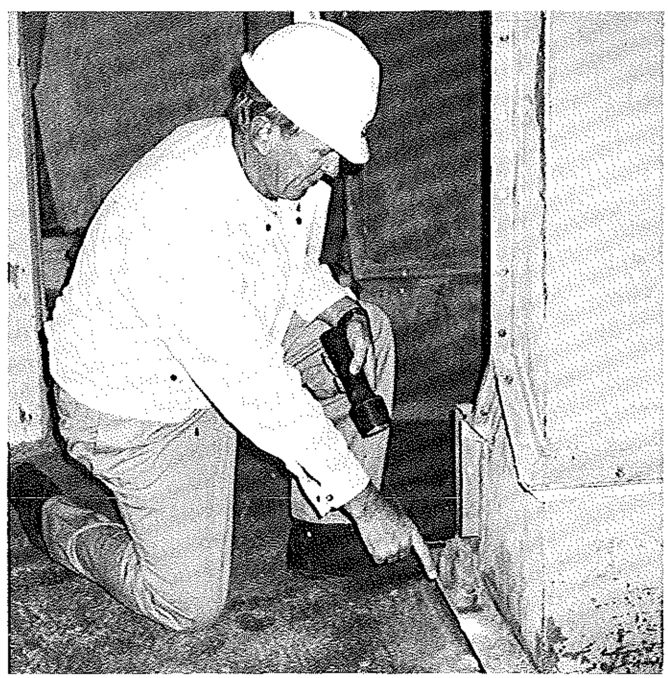

Figure 2. FGIS facility inspection.

Figure 3. FGIS commodity sampling.

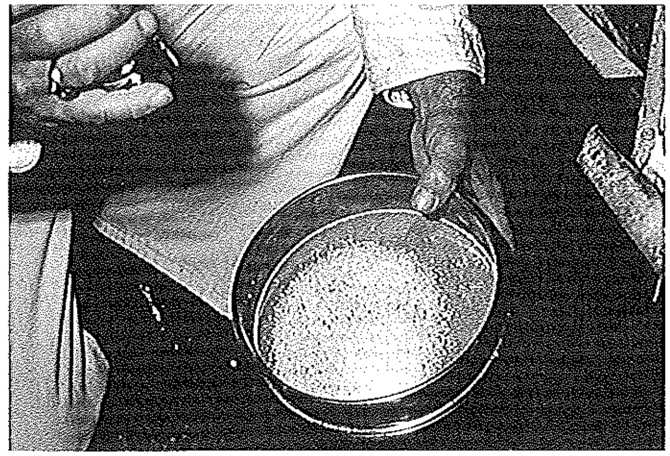

Figure 4. FGIS visual product examination.

established by the FDA. The FGIS begins its inspection by determining the sanitary condition of the facility before production and during production, as necessary. The FGIS performs sanitation inspections in accordance with its Sanitation Inspection Handbook which is based on FDA regulations (Figure 2). Insect infestation is one critical part of the inspection. Some important provisions are:

1) The handbook specifies that if any dispute arises concerning an interpretation as to unsanitary condition, the FDA may be required to examine the conditions. The FDA's decision is final. If the FDA is unable to make an examination, the FGIS' decision is final.
2) The handbook provides the general procedures for withholding of inspection services for a correctable unsanitary plant condition.

Although FGIS personnel have no authority to close an unsanitary plant, the FGIS does have the authority to withhold inspection services for unsanitary conditions. When an FGIS inspection is required as a term of the purchase agreement, the product cannot be sold to the intended purchaser. Under the memorandum of understanding, the FGIS informs the FDA of facilities that are found to be unsanitary.

Copies of the Sanitation Inspection Handbook may be obtained upon request form the USDA-APHIS, Printing and Distribution Section, G-100 Federal Building, Hyattsville, Maryland 20782.

FGIS Product Examinations

During an FGIS inspection, the lot of commodity is examined for the presence of insects on or around the lot. Samples are drawn and examined for insects. Samples of rice, beans, peas, and lentils are visually examined at the FGIS field offices throughout the United States. Samples of processed commodities are sent to the FGIS Commodity Testing Laboratory in Beltsville, Maryland for microscopic examination for insect fragments.

The FGIS samples and inspects products in accordance with its handbooks and standards (Figures 3 and 4). The following is a list of the appropriate handbooks and standards:

- Dry Peas, Split Peas, and Lentils Inspection Handbook.
- Processed Commodities Inspection Handbook.
- Dry Bean Inspection Handbook.
- Rice Inspection Handbook.
- U.S. Standards for Dry Peas, Split Peas, and Lentils.
- U.S. Standards for Dry Beans.
- U.S. Standards for Rice.

Copies of the handbooks and standards may be obtained upon request from:

USDA-APHIS
Printing and Distribution Section
G-100 Federal Building
Hyattsville, Maryland 20782.

During the inspection of the product, if the FGIS finds insects or insect fragments in amounts exceeding the FDA defect action level, the lot is considered adulterated with insects. The inspection results are reported to the producer and the FDA for their investigation.

The FGIS does not have authority to seize products, control the disposition of products, or arbitrate resolutions to customer complaints regarding insect infestation. □

23

How to Use Insect Traps in a Warehouse

David Mueller, Insects Limited, Inc.

A tool to determine the presence or absence of potentially harmful pest insects is needed where stored commodities are held for extended lengths of time. Pheromone-baited traps are excellent tools for this purpose.

All pheromone-baited traps were not created equal. Traps for moths may act differently than beetle traps (Figures 1 and 2). One cannot treat all stored-product pests the same when it comes to recommending an effective trapping program. Long-lived insect adults (e.g., flour beetles) tend to be less attracted to pheromone-baited traps than short-lived insect adults. A flour beetle adult that lives for 12 to 18 months does not react as dramatically as an Indianmeal moth adult that may only live in this stage for one to two weeks.

Know the Pest

Knowing the pest is half the battle in controlling it when establishing and managing a grain, bulk commodity, or bagged product pest management program. This holds true when one tries to interpret the results and data from such a trapping program.

Common Insect Pests in Grain and Processed Food

Tables 1 and 2 summarize the results of surveys conducted in 1980 and in 1988, and show the frequency at which stored-product insects were found in raw grain and processed food (Mueller 1988, 1989).

Table 1. Most frequently found stored-product insects in raw grain in the United States.

Rank	Species	Number of States Responding 1980	1988
1	Indianmeal moth*	27	30
2	Sawtoothed grain beetle	20	23
3	Red flour beetle*	16	26
4	Rice weevil	19	19
5	Confused flour beetle*	17	11
6	Flat grain beetle	7	18
7	Granary weevil	8	13
8	Foreign grain beetle	7	11
9	Lesser grain borer*	8	10
10	Angoumois grain moth*	10	3

*A pheromone lure is commercially available for this stored-product insect pest.

Table 2. Most frequently found insects in processed food in the United States.

Rank	Species	Number of States Responding 1980	1988
1	Indianmeal moth*	29	40
2	Sawtoothed grain beetle	33	38
3	Red flour beetle*	24	24
4	Dermestids*	24	23
5	Confused flour beetle*	15	20
6	Cigarette beetle*	13	15
7	Drugstore beetle*	6	11
8	Flat grain beetle	0	3
9	Rice weevil	0	2
10	Granary weevil	0	2

*A pheromone lure is commercially available for this stored-product insect pest.

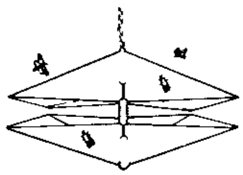

Figure 1. Moth trap.

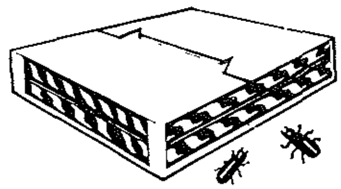

Figure 2. Beetle trap.

Figure 3. Trapping systems are significant tools to use in an integrated pest management program in warehouses.

Pheromone-baited traps can be used in a variety of ways to assist in a warehouse pest management program:

1) Inspection of bagged commodities,
2) Identification of pests or the potential for pest infestation,
3) Determination of the extent of the problem, and
4) Evaluation of a particular treatment or control method.

Traps

It is important to recognize that there is not always one type of trap that is best to use in a pest monitoring program in warehouses. It is important to match the specific trap to the environmental conditions in each particular situation. Some examples of this would be: 1) dusty areas vs. areas that are not dusty, 2) hot vs. cold temperatures, and 3) outdoor vs. indoor use.

Too much dust can cause sticky traps to be ineffective. In this situation, alterations to the sticky trap can prevent an excessive build-up of dust, or a pitfall-type trap could be incorporated (Figure 4). The Barak pitfall-type trap is shown in Chapter 23.

Dusty warehouses offer challenges for conventional sticky glue traps. In these extreme conditions, a sticky trap may become useless after several days, or even after several hours. The selection of a trap that can deflect the dust, or a pitfall-type trap that does not include glue as the entrapment mechanism, will need to be implemented.

Placement of traps will depend on the temperature in the warehouse. In the spring, the ceiling of the unheated warehouse offers optimum conditions for the growth and development of stored-product insects. As the temperature gradients in the warehouse change during the summer months, the harsh conditions near the top of these facilities may hinder the capture of insects in a monitoring program.

Outdoor Trapping

Trapping for stored-product insects around the outside of a stored-product warehouse can offer several advantages in an overall pest management strategy. The trap selected for outdoor trapping must be able to withstand the weather (e.g., plastic construction) and should not be prone to becoming saturated with insects quickly.

By placing pheromone-baited traps on the outer perimeter of a storage facility, potentially destructive insects can be intercepted or lured away from stored food and grain. A feral population of many of the most common stored-product insect pests is available outdoors throughout the United States and Canada (Vick 1988). Thus, the outdoor pheromone trapping technique can help the modern pest manager predict the arrival of indoor populations of insects and prevent many from causing an infestation (Cogburn 1988).

Trap Placement

There is no exact number of traps that should be placed in a warehouse to detect the presence or absence of pest insects. The number of traps needed can change according to several factors determined by the trained person implementing and re-evaluating a trapping program. Some factors to consider are:

1) quality assurance standards by management,
2) seed vs. finished goods,
3) pharmaceutical vs. raw intermediate products, and
4) popcorn vs. field corn.

Important questions to ask are:

- What is the goal of a sanitation program? Is the goal zero insect tolerance?
- Is an attempt being made to mass trap out a population, or to just monitor a pest population?

Figure 5 illustrates a situation where one trap per 100,000 cubic feet is placed in a finished grocery product warehouse. The pest management inspector checks each trap weekly. A record of the results is kept in a separate log away from the physical trap itself. A map should be made of each trapping location. Each trap in this

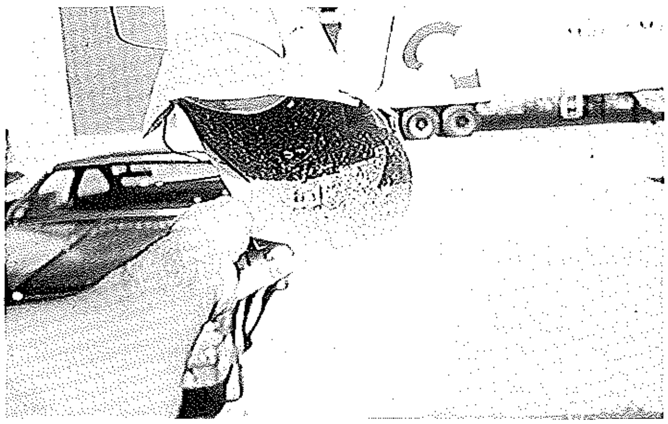

Figure 4. Sticky traps can be ineffective where dust levels are excessive.

practical example contains two lures: 1) *Plodia* complex (Indianmeal moth), and 2) *Trogoderma* complex (warehouse beetle, *T. glabrium*, furniture cabinet beetle, khapra beetle). An optional lure for the cigarette beetle could be placed in each trap in some situations.

After determining that this warehouse contained little or no detectable target pests in half of the facility, the traps were moved to the half of the warehouse where insects were found in the pheromone-baited traps. Another approach that can be used instead of moving the traps is to employ more traps in a uniform grid pattern in the suspect areas of the warehouse. After several days or a week, these traps are checked and recorded again. At this point, there is one trap per 50,000 cubic feet. If the pest management inspector has more time, he/she can tighten the grid even further to pin-point this infestation (one trap per 10,000 cubic feet). The inspector can then start visually searching for signs of an active infestation in the areas where the most insects were captured. This could be caste skins of *Trogoderma* larva; odor distinctive to certain insects (e.g., flour beetles and roaches); webbing on bags, flaps of the bags, or the surface/side-walls of a grain bin; pupa casing in corrugated cardboard; or actual live insects on finished product.

In this actual warehouse, old code-dated rolled oats were found to be infested with Indianmeal moths, sawtoothed grain beetles, and flour beetles. Some nearby dog food also contained large stored-product insects that could have entered this warehouse from the often opened dock door. The cost of this program for pheromone-baited traps/lures would typically run about $250 to $300 per year. The time needed to count and record seven traps each week would be about 30 minutes.

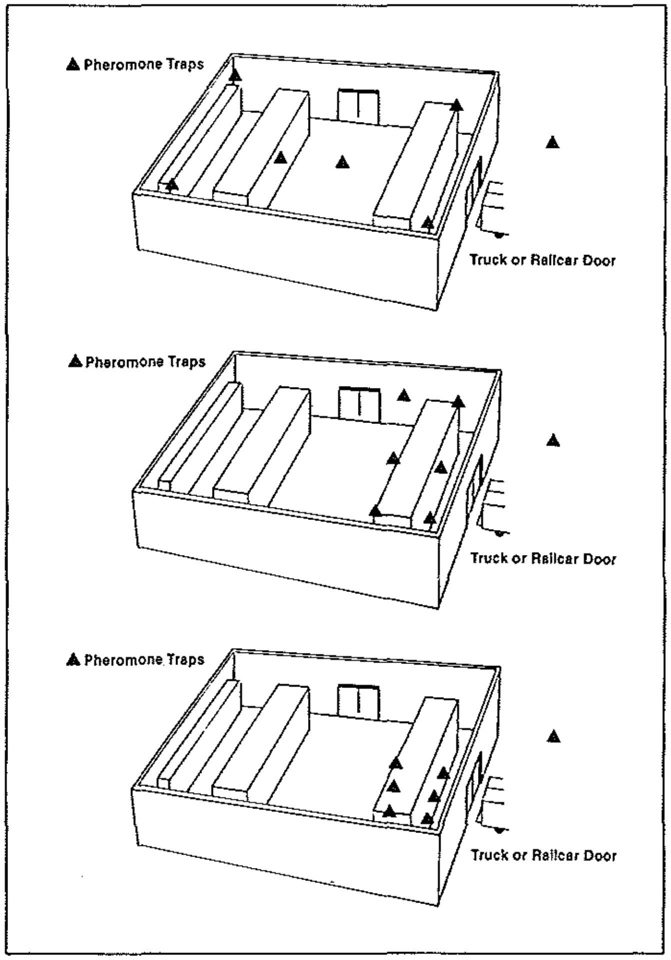

Figure 5. Monitoring for stored-product insects in a finished foods warehouse.

Interpreting Trap Catch

A common misconception in a strategy used to manage grain, bulk commodities, and bagged products using pheromone-baited traps is that there is a set numerical threshold for action or reaction. There is no magic number for determining action. A trained pest management inspector must weigh all factors before making a decision. The key to interpreting trap catch is to look for increases in numbers of insects from one trapping period to the next (e.g., 1 - 5 - 30).

It is often easy to see when an outbreak occurs. At this time, the pest management inspector can recommend appropriate corrective action (e.g., chemical, non-chemical, sanitation, discarding product).

A Plan for Pest Management for the Popcorn and Seed Industry

Purpose: To establish an on-going, year-round pest management program to eliminate any damage incurred by insects, rodents, or birds. This would include both physical damage to the popcorn and the defacing of the packaging that contains the popcorn.

History of the Problem

The popcorn and seed industries in the United States are making rapid advances in the manipulation of the genetic structure of plants in order to create varieties that are more productive. However, even with amount of technology available, most seed companies are years behind other processed food disciplines in the protection of their stored commodities from stored-product insect pests and rodents.

I. Monitoring and Inspection

- A. Pheromone traps
  1. Indianmeal moth traps
  2. Angoumois grain moth traps
  3. Grain probes in bulk bins
  4. Recordkeeping is essential
  5. Replacement of traps and lures
- B. Glue boards and Ketch-alls / rodent inspection
  1. Dock and loading areas
  2. Critical points in the operation
- C. Visual inspection
  1. Insects
     - a. Inbound packaging materials
     - b. Webbing from moths
  2. Rodents
     - a. Black-light inspections / inbound
     - b. Fecal pellets
  3. Birds
     - a. Nests
     - b. Feces

II. Building to Keep Out Pests

- A. Insects
- B. Rodents
- C. Birds

III. Non-chemical Control

- A. Cold storage
  1. 50°F with 50 percent R.H.
  2. Insect activity in cold temperatures
     - a. Reduces activity
     - b. No reproduction
- B. Anticipation of winter storage / fumigate before winter
- C. Mice in cold storage
  1. Insulation, be aware
- D. Lighting / placement is critical
  1. Indoor
  2. Outdoor
- E. Beneficial insects (non-food areas)

IV. Chemical Control of Bulk Seed Storage

- A. Timed pyrethrin dispensers *(replacing vapona strips)
  1. 32-day aerosol cans of two percent natural pyrethrin
  2. Top dress with Actellic, Reldan, or Dipel
- B. Pheromone traps
  1. Moth trap / every fourth bin (outside the bins)
  2. Grain probes in the bins (one per 5,000 bushels)
  3. Check every two weeks / July-November
  4. Critical check before processing
- C. Routine fumigation of bulk bins
  1. Phostoxin Tablets / 45 to 60 tablets per 1,000 cubic feet
  2. Phostoxin Pellets / 165 to 300 pellets per 1,000 cubic feet
  3. New Degesch Mini-Ropes (one per 4,000 cubic feet) *retains the dust in the commodity
- D. Empty bin treatment
  1. Beneficial insects
  2. Chemical residues
     - a. Tempo®
     - b. Reldan
  3. Fumigation; Chloropicrin
- E. Perimeter control
  1. Weeds
  2. Bare ground herbicides
  3. Gravel or blacktop
  4. Tempo or Reldan
     - a. Where to spray / one foot up side and two feet away from bin
     - b. How to use / see label instructions
     - c. How often to spray / twice a summer
  5. Spillage clean-up / important

V. Chemical Control in Seed Warehouses and Processing Areas

- A. ULD Treatments (Ultra Low Dosage); *replace vapona
  1. Check pheromone traps / once per week and record catch
  2. Minor threshold: if total catch exceeds 10 moths per week
     - a. Apply remotely if possible (timer)
     - b. Particle size; 15 to 30 micron

3. Three percent Pyrethrin
4. Types of ULD equipment; Micro-Gen
5. Safety equipment to use
   a. Proper respirators
   b. Draeger detection tubes before re-entry

B. Fumigation with metal phosphide (Phostoxin)
1. Trained, certified, and experienced
2. Safety
3. Proper storage / cool, dry, well ventilated, locked
4. Cold temperature fumigation
   a. Magnesium phosphide
      1. Degesch Fumi-Strip
      2. Degesch Fumi-Cel
5. Inert gases
6. Aerate to safe level
7. Proper safety equipment available
8. Draeger detection equipment

VI. Rodent Control Program

A. Outdoor
1. Bait stations / tamper proof
2. Rodenticide
   a. Grain based / Talon Weatherbloc, Vengence
   b. Liquid bait, summer
   c. Safety
3. Building them out

B. Outdoor perimeter control
1. Weed abatement
2. Bait stations, every 60 feet
3. Ditches and standing water
4. Rats need water every day
5. Gravel 24 inches perimeter
6. All doors should fit tightly

VII. Bird Control

A. Cooperative venture with surrounding groups
1. City
2. Grain companies

B. Farm machinery sheds

C. Warehouses
1. Close doors
2. Plastic strips
3. Rid-A-Bird perches (restricted use pesticide)
4. Avicides
5. Bird netting
6. Sticky Bird Repellent

Limitations

Pheromone-baited traps have some limitations in the management of grain, bulk commodities, and bagged products. These traps are very sensitive to the target insects being monitored. However, other insects often are present and go undetected because of a lack of effective or efficient trapping systems. In one field situation, cigarette beetles were extensively monitored and managed with limited applications of chemical insecticides only to find that several pallets of oats were highly infested with a hidden population of flour beetles.

The entomologists' and chemists' inabilities to duplicate the exact chemical messenger or messengers have not given us a complete choice of effective pheromones with which to work. The beetle pheromones seem to be much harder to identify than the moths. However, results demonstrated by the lesser grain borer aggregation pheromone hint that when the components are discovered and mixed in commercial pheromones in the correct combinations, they can work well to detect the presence or absence of a target insect pest. Advances in biotechnology and the potential cloning of these precise chemical messengers will overcome some of these limitations.

Conclusions

The use of pheromone-baited traps to determine the presence or absence of a pest population in storage facilities is an exciting new step toward a total pest management program. The interest in pheromones in recent years has been fueled by their potential to modify the behavior of pests and to attract them to traps. By monitoring the change in trap catch over time in warehouses containing stored products, action levels can be decided and the judicious use of control methods can be prescribed when population growth is observed in one or more areas of a facility.

The practical application of pheromone-baited traps to alter insect behavior and prevent reproduction is helping provide the grain, bulk commodity, and bagged product industries with the option of a total pest management strategy.

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24

The Design of Traps for Stored-product Insects

Alan Barak, USDA-APHIS

New interest in the availability and use of traps for stored-product insects has paralleled the identification and synthesis of pheromones and attractants of major pest species. Regulatory requirements for reduced or zero tolerance of insect infestation, damage, and contamination have made early detection and control of insects essential. Traps for the early detection, monitoring, and control of such insects have proven to be valuable in the continuing effort to protect food and fiber from insect damage or loss.

Based on use, traps for stored-product insects fall into four general categories: 1) light traps; 2) aerial traps, including sticky and funnel types; 3) surface-deployed traps for crawling insects, including harborage, sticky and pitfall types, and food or bait-bag traps; and 4) bulk grain and commodity traps, which include the perforated probe traps. These traps may utilize pheromones, attractants, or both, and some may be used unbaited. These categories may overlap, as traps have been adopted for different purposes and for species other than those for which they were originally designed.

Figure 1. A blacklight trap with electrocuting grid, suitable for all flying stored-product moths and beetles.

Light Traps

Light traps are commonly used for fly control in pharmaceutical and food processing areas and have limited use in stored-product insect management. These traps use blacklight (UV) lamps, to which a wide variety of insects, including stored-product species, are attracted. Though uncommon, some traps may utilize only lights and collection containers. The most successful are the electric grid types which use blacklight to attract flying insects to an electrified grid (Figure 1). One system is of the electrocution type. Commercial electrocution models use from single 20-watt UV lamps up to two 40-watt lamps and electric grids powered by transformers with low-current (9ma) and high-voltage (5,000v) outputs. These traps have been designed to be mounted in corners, on walls (or flush mounted), or suspended from ceilings. Experience has shown that traps should be mounted low for fly control, but would be most efficient for stored-product insects if mounted higher. Traps mounted overhead cannot be placed in areas where debris could drop onto a product or into sensitive equipment. Traps have been designed for easy access to collection trays to encourage frequent cleaning. A weekly cleaning is recommended since contents of collection trays can become infested with dermestids, thus serving as a possible source of infestation in the storage environment.

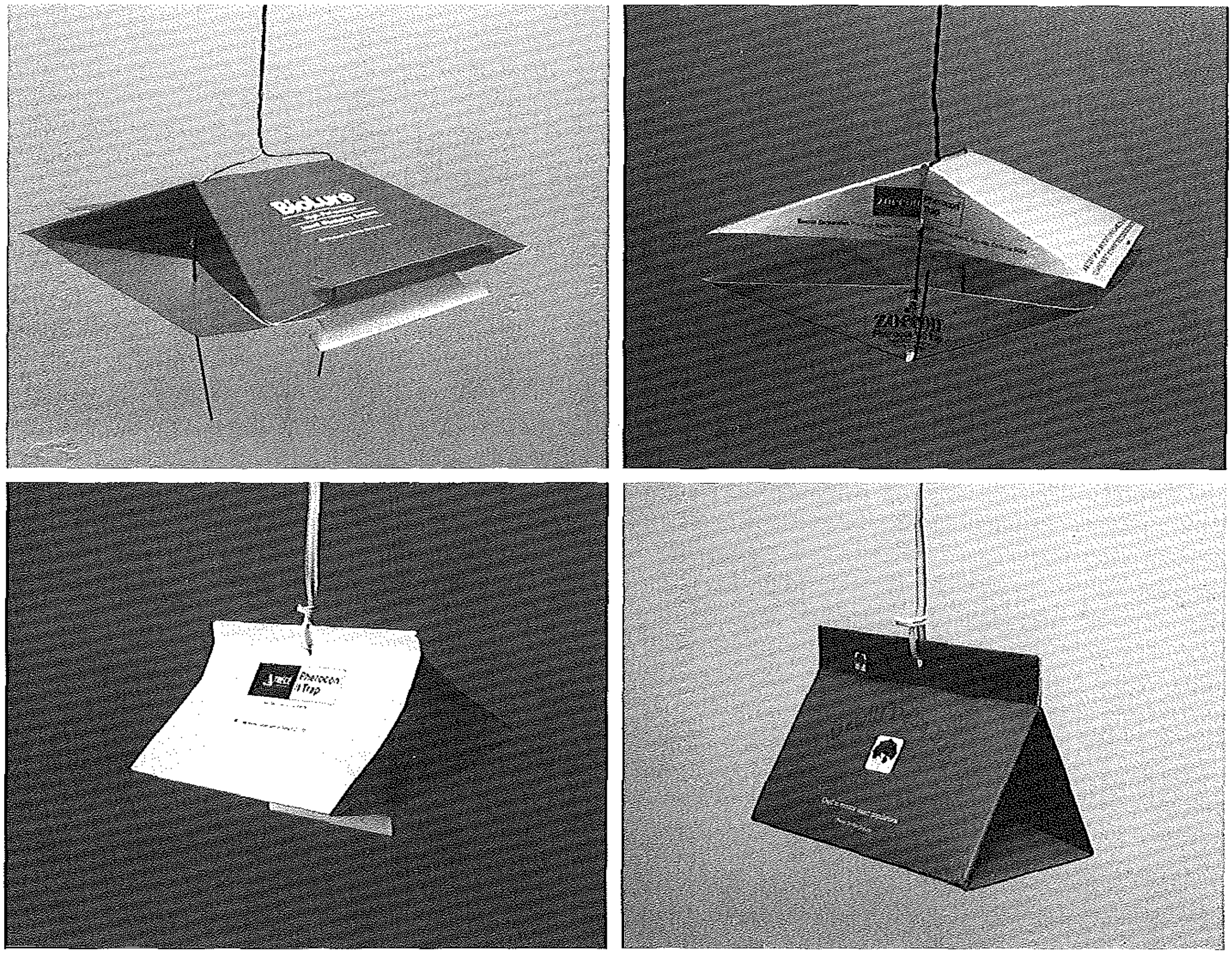

Figure 2. Aerial pheromone sticky traps are available commercially. These traps are suitable for a number of species which fly as adults.

Lepidoptera		**Coleoptera**	
Indianmeal moth	*Plodia interpunctella*	Warehouse beetle	*Trogoderma variabile*
Mediterranean flour moth	*Anagasta kuehniella*	Larger cabinet beetle	*Trogoderma inclusum*
Tobacco moth	*Ephestia elutella*	Lesser grain borer	*Rhyzopertha dominica*
Almond moth	*Cadra cautella*	Larger grain borer	*Prostephanus truncatus*
Raisin moth	*Cadra figulilella*		

A second type of trap silently immobilizes insects with a low-current (2ma), low-voltage (76v to 79v) grid. Current is pulsed with a one-second pulse every eight seconds. A commercial model uses two 15-watt UV lamps. Insects attracted by the lamps land on the grid and are stunned by the pulse, causing them to drop onto a sticky board. The sticky board is easily replaced, which encourages timely and convenient monitoring, as well as more reliable identification. These traps do not produce airborne contamination from disintegrating insect bodies; therefore, they can be used near sensitive areas.

For stored-product insects, light traps are primarily used to monitor insect activity, although they may have some value in reducing migrants—especially mated females. The contents of collection trays or boards can provide continuing information on population trends and species composition.

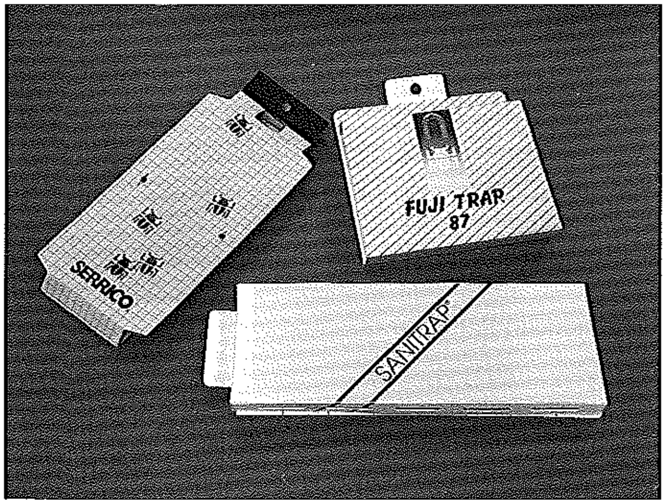

Figure 3. Various sticky pheromone traps used for:
Cigarette beetle - *Lasioderma serricorne* - Adults

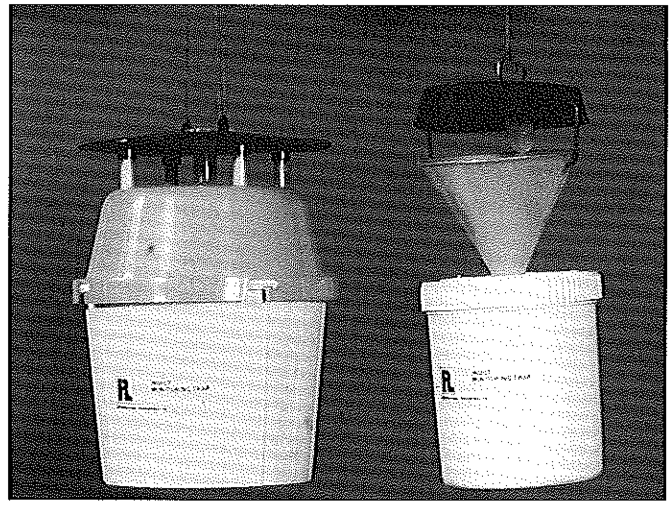

Figure 4. An early (right) and current commercial plastic funnel trap. This is a permanent trap, and is used for the common moth species and other flying species, above.

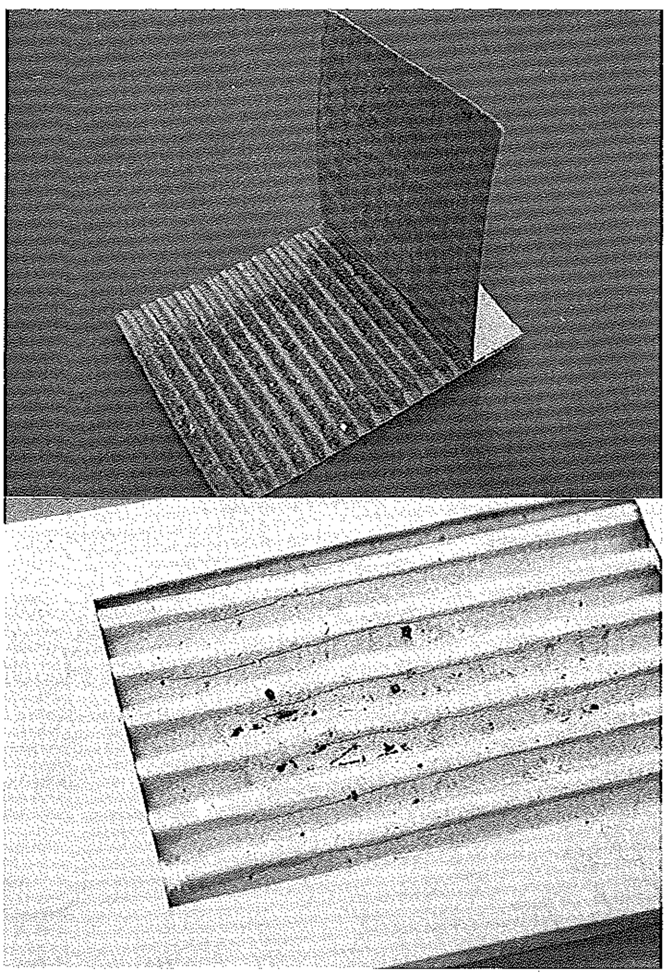

Figure 5. An early corrugated food trap used for *Trogoderma* larvae (top) and cannibalized remains of adults in trap after food has been depleted.

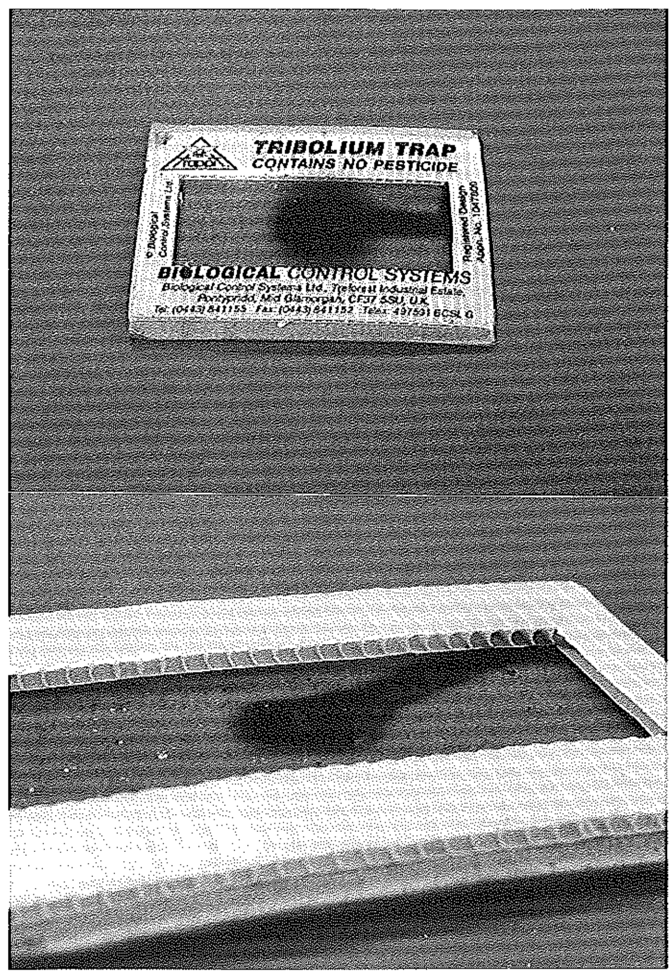

Figure 6. A corrugated, sticky pheromone trap. This trap is suitable for:
Confused flour beetle - *Tribolium confusum* - Adults

Blacklight lamps lose effectiveness over time, and lamps should be routinely replaced every 6 to 12 months.

Aerial Traps

Numerous designs of sticky traps (Figure 2) have been used for flying stored-product insects, mainly the moths.

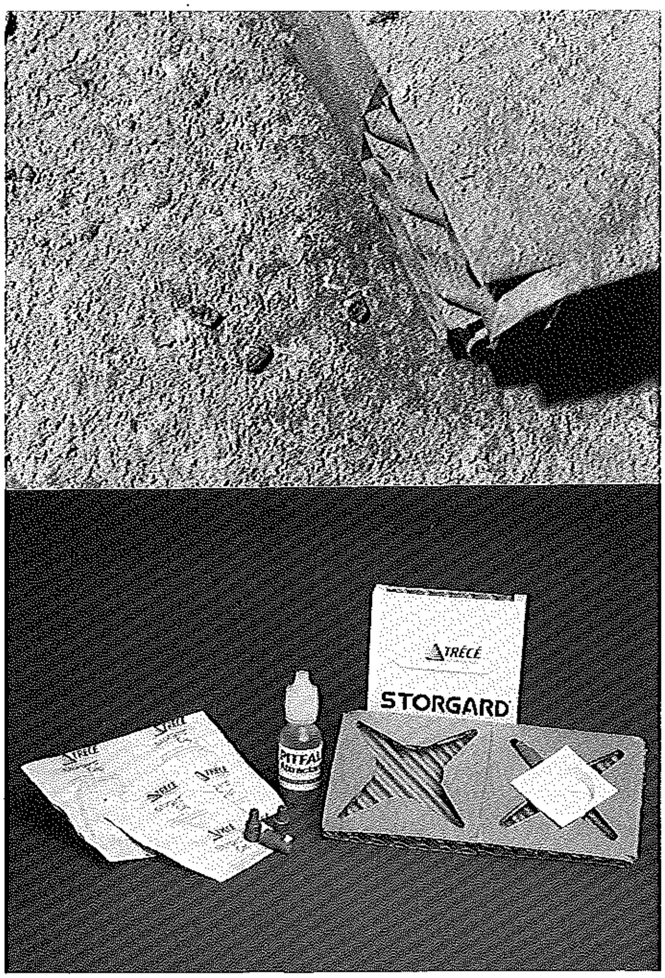

Figure 7. A combination food attractant and multiple-pheromone lure corrugated trap. The early design (top) used an insecticide and had no provision for pheromone lures or collection of adults. A later version, with a wheat germ and oat oil food attractant pitfall device, can hold multiple pheromone lures (bottom). This trap has been used for adults or larvae (A/L) of:

Confused flour beetle	*Tribolium confusum*	A
Red flour beetle	*Tribolium castaneum*	A
Sawtoothed grain beetle	*Oryzaephilus surinamensis*	A
Merchant grain beetle	*Oryzaephilus mercator*	A
Warehouse beetle	*Trogoderma variabile*	A/L
Larger cabinet beetle	*Trogoderma inclusum*	A/L
Khapra beetle	*Trogoderma granarium*	A/L
Black carpet beetles	*Attagenus unicolor* (spp.)	A/L
Carpet beetles	*Anthrenus* spp.	A/L

These traps have been adopted for use based on designs originally used for pre-harvest insects. Insects are entrapped by contact with adhesives after being lured into the trap by pheromone lures. Other sticky trap designs, such as boards, screens, paper strips, hollow tubes, and large-vaned wing traps, have been used by others to trap stored-product moths and beetles. Various designs of commercial sticky traps used to trap cigarette beetles (*Lasioderma serricorne*) are shown in Figure 3. These have been suspended in the air or attached to walls or vertical surfaces.

Small funnel pheromone traps also have been designed and used to collect wild *Trogoderma* for biological studies. A larger funnel trap specifically designed for stored-product moths was developed to monitor almond moths, tobacco moths, and Mediterranean flour moths (Figure 4). A plastic funnel with an attached protective lid and suspended pheromone lure in the center attracts moths. The moths then flutter or drop through a funnel into a detachable plastic bucket. An improved design is now used commercially, which consists of a dust cover integrated with a funnel and catch bucket cover. Vertical, multiple-funnel traps designed for bark beetles also have been used with pheromones to monitor and mass trap the lesser grain borer, *Rhyzopertha dominica*.

Surface Traps

Trapping is not a new concept. In 1924, rough cloths suspended over and in contact with grain surfaces were used to trap the khapra beetle, *Trogoderma granarium*. The larvae crawled up the cloth prior to pupation, and the cloth was then boiled or destroyed. Boards or sacks lying on the surface also were used to collect larvae. The basic harborage-type traps provide a hiding place, taking advantage of the insects' preference for crevices and their positive tactile response. Traps made of several layers of burlap, bound at one edge to make a contact harborage trap, have also been used for khapra beetles. As early as 1931, wood blocks, hinged to form narrow wedge-shaped crevices, were used to trap confused flour beetles, *Tribolium confusum*. Small boxes with cloth pads treated with fish meal or an extract have been used to trap carpet beetles in homes. Later, corrugated paper pieces with food bait in the flutes were developed (Figure 5).

An improvement over the early corrugated, food-bait traps is the bait-bag trap, an attractive food blend wrapped within a wire mesh or perforated envelope. A wire-mesh food packet was used to survey for stored-product species in California. This type has been improved and is used successfully for multiple species, although it is not in common usage in the United States.

Corrugated and harborage traps have been modified to contain insecticides, pathogens, sticky surfaces, pitfall devices, funnel devices, pheromones or pheromone lures, and combinations of the above. A sticky trap for confused flour beetles (Figure 6) also uses an aggregation pheromone lure. The sticky surface is actually a type of pitfall, since the flutes of the corrugated portion are elevated over the sticky surface so that beetles fall onto the glue. It has been observed that insects are not easily lured into walking on glue surfaces. While effective, corrugated traps may have some disadvantages. For some species or designs, the trap may need to be destroyed for inspection, and trap assembly may be time consuming if large numbers are needed.

Corrugated traps were used in the first field tests of pheromones for *Attagenus* spp. and *Trogoderma* spp. Males of two species of insects were attracted and killed, but adult males died outside the trap, hindering recovery and counting. Further, no larvae were trapped. Subsequently, a pitfall device containing wheat germ oil as an attractant for larvae or feeding adults was added. No insecticides were needed, as the oil killed trapped insects by suffocation. This trap had chambers to accept up to four pheromone lures, as well as an air chamber to provide for vertical dispersion of odors and movement of insects (Figure 7). This design used single-faced, corrugated paper, since it was more difficult to look for and to dislodge insects from double-faced paper traps without destroying the traps in the process. With multiple, folded layers of single-faced, corrugated paper, a biased cut prevented the trap from collapsing upon itself, and allowed insects access from all sides. A moisture-resistant jacket protected the trap and held it together. This trap will increase in utility as pheromone lures for more species become available.

A new design for a trap for khapra beetles takes advantage of insect behavior and meets specific use requirements. The trap:

a) attracts both adults and larvae,
b) contains little or no food material,
c) contains no insecticides,
d) can be wall mounted to reduce losses, and
e) remains functional for long periods.

In the khapra beetle trap, the pheromone lure is positioned over a plastic tray which contains a food attractant (wheat germ or sesame oil) so that males are lured over or toward the edge of the tray (Figure 8). This prevents males from aggregating around the lure or within the flutes, rather than in the pitfall collection tray. The khapra beetle trap is mounted on a vertical surface with foam tape. A gap is created between the trap and the surface by the thickness of foam mounting tape. The trap jacket is designed with flaps that fold out to bridge this gap. The trap without flaps was not as effective for *Trogoderma* males and larvae. The importance of intimate substrate contact is shown in Figure 8. Some designs allow insects, especially those in smaller stages, to get under, rather than into the traps. In the khapra beetle trap, perimeter flaps act as ramps to improve access, and rear flaps guide insects directly to the pitfall collection tray. Khapra beetle larvae have a migratory phase prior to pupation in which they will crawl upwards, and wall mounting a trap exploits this behavior. Since khapra beetle traps are left in place for several months, they were designed to accommodate long duration lures, and a provision was made for a replaceable collection device so that the trap and lure could be left in place after servicing.

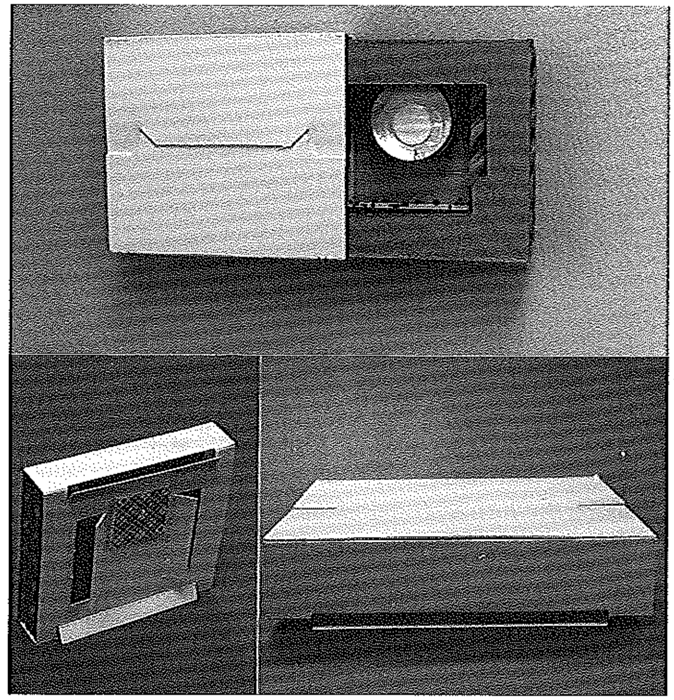

Figure 8. A wall-mounted food attractant and pheromone trap. This trap can be used for adults and/or larvae (A/L) of:

Confused flour beetle	*Tribolium confusum*	A
Red flour beetle	*Tribolium castaneum*	A
Sawtoothed grain beetle	*Oryzaephilus surinamensis*	A
Merchant grain beetle	*Oryzaephilus mercator*	A
Warehouse beetle	*Trogoderma variabile*	A/L
Larger cabinet beetle	*Trogoderma inclusum*	A/L
Khapra beetle	*Trogoderma granarium*	A/L
Black carpet beetles	*Attagenus unicolor* and (spp.)	A/L
Carpet beetles	*Anthrenus* spp.	A/L

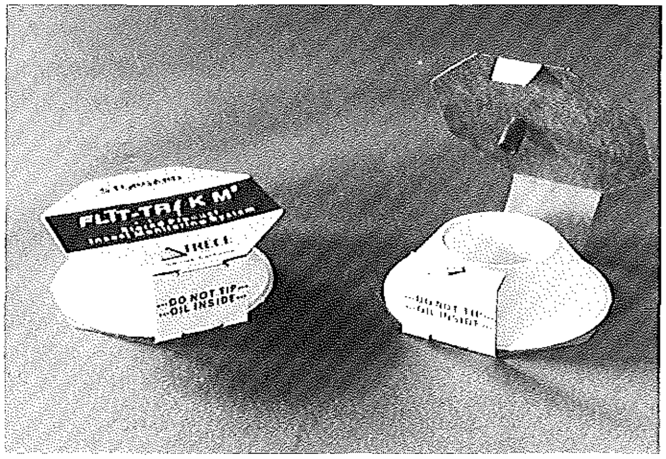

Figure 9. A floor-type pitfall adult Tribolium trap which positions the lure over the pitfall.

Recent tests have resulted in the use of ground wheat germ bait in the vertically mounted khapra beetle trap. This was done so that small larvae, the predominant form trapped, could be reared to a size where identification was possible. This also increased the number of *Trogoderma* larvae either trapped or recovered.

A recent *Tribolium* trap (Figure 9) designed for floor or flat surface placement incorporates both the lure positioning and pitfall method as in the vertical wall mount khapra beetle trap. However, a corrugated housing is not used, as the pitfall stands free, and is enclosed by a jacket which holds the lure in place while deterring dust accumulation. This trap could be capable also of using certain food baits.

Designing traps which combine both food attractants and pheromones may have additional merits, since it is known that food odors and a pheromone will act in synergy to trap maize weevils, *Sitophilus zeamais*. This may also be true for other species which feed as adults or utilize aggregation pheromones.

Bulk Grain and Commodity Traps

Although aerial traps have been used to monitor granary headspace, and surface traps are used on or just under grain surfaces or attached to bin walls, other traps have been designed specifically for use within bulk grain. They are perforated metal or plastic probes designed to be inserted into grain bulks and trap insects which crawl through the holes and fall into the collection device. Multiple, independently-sectioned and perforated brass probe traps also have been used in ecological studies. Mesh-covered pitfall traps situated flush with the grain surface have been used alone and in conjunction with perforated cylinders, with or without food attractants. The first grain probe traps (Figure 10) were brass and had a cylindrical, perforated upper section to allow insects to enter and to drop through an enclosed funnel. A screen below the funnel (a vial in later versions) collected trapped insects. Insect escapes were reduced by coating the inside of the collection vial with Fluon®. Perforation size was later increased to catch larger insects commonly found in stored corn. The high cost of fabricated brass traps encouraged the development of a perforated probe made of Lexan® plastic. Plastic traps had improved efficiency and were serviced more easily. The plastic trap was more rigid than brass, transparent for easy inspection, and had thick walls allowing for downward angled holes to be drilled into the body. Research proved that increasing hole size from 2.8mm to 3.8mm in diameter improved the capture of flat grain beetles, *Cryptolestes pusillus*, in corn and red flour beetles, *Tribolium castaneum*, in wheat. Another probe trap was developed with the perforated section made from an inexpensive stock piece of tubular polyethylene. Under

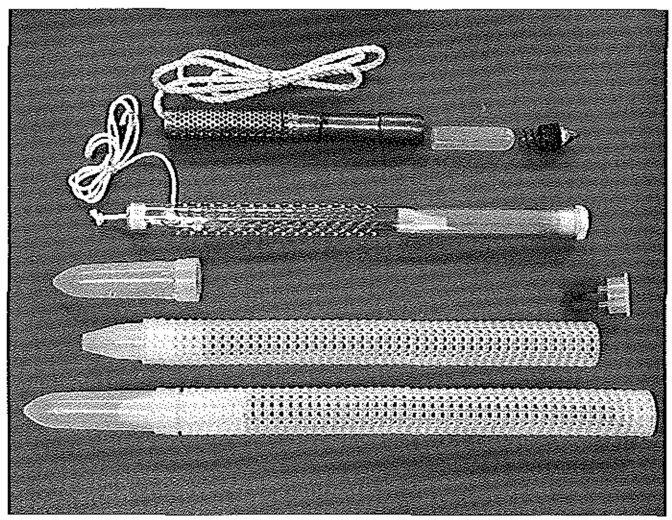

Figure 10. Probe traps for bulk grain and commodities. These traps can be used with or without attractants, and have trapped many common grain infesting species, including:

Red flour beetle	*Tribolium castaneum*
Flat and rusty grain beetles	*Cryptolestes* spp.
Sawtoothed grain beetle	*Oryzaephilus surinamensis*
Larger black flour beetle	*Cyaneus angustus*
Rice, maize, and granary weevils	*Sitophilus* spp.
Lesser grain borer	*Rhyzopertha dominica*
Foreign grain beetle	*Ahasverus advena*
Hairy fungus beetle	*Typhaea stercorea*
Cadelle	*Tenebroides mauritanicus*

certain conditions, this trap was more effective than the Lexan probe, probably due to both the larger trap diameter (and therefore greater trap-to-grain surface ratio) and its greater number of holes. An important benefit is that this type of trap is considered disposable, allowing for use where trap damage or loss is unavoidable, or where traps are placed in a commodity upon request by the consignee and without intent to recover.

Environmental and Use Factors

The Trapping Environment

Although trapping of stored-product insects usually takes place within a structure, a trap must be able to withstand and function under a variety of conditions similar to traps designed for outdoor use. Airborne dust, vehicle traffic, moisture, human or animal interference, commodity movement, extreme temperatures, and public acceptance are important factors.

Dust

Where dust is a problem, wing traps can be closed to reduce opening size. With the addition of flaps (Figure 2), dust contamination can be reduced while providing a funnel-like opening for the insects. Glues used in aerial traps for moths are able to absorb considerable dust and still be effective. However, oily or dusty deposits will reduce the effectiveness of plastic funnel trap for moths. Reduced effectiveness of traps due to excessive dust (or insect scales) may affect the accuracy of predictions.

Reduction of dust was accomplished in a different way with a trap designed for cigarette beetles (Figure 3). Slotted side panels reduced dust contamination, resulting in longer trap life and better catches.

Trap Damage

Vehicle or foot traffic and sanitation activities may hinder placement of a trap in a desired location or may result in trap losses. Traps placed on floors are likely to be swept up, crushed, or displaced. Traps designed for wall placement have reduced trap loss and damage.

Moisture

Traps may be exposed to moisture outdoors, or in damp places indoors. Plastic traps are weather resistant, and the use of plastic-coated papers protect other traps from moisture. The stored-product insects for which floor or surface-type traps are available are not likely to be found in damp areas, but moisture migration through brick walls and concrete floors, leaks, or spills can adversely affect traps with corrugated paper or cardboard parts.

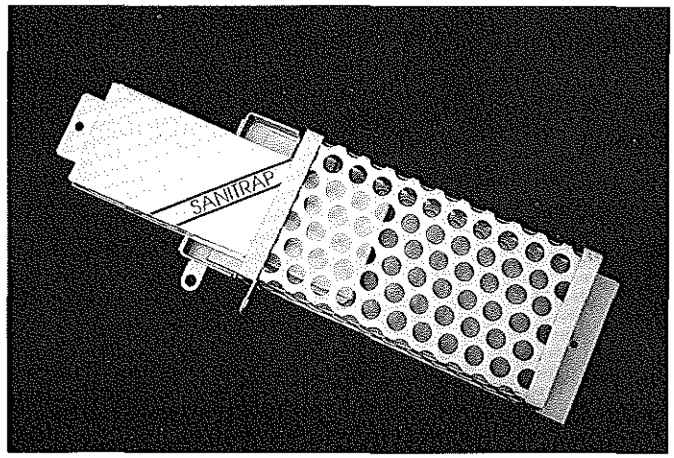

Figure 11. Perforated metal security cage for a cigarette beetle trap. (D. L. Faustini).

Interference

Curiosity may prompt unauthorized personnel to disturb traps and invites vandalism. Trap security has been improved by enclosing cigarette beetle traps within a perforated metal cage designed to let insects through, limit dust buildup within the cage, and yet not hinder inspection (Figure 11). Traps could be designed to be less conspicuous to unauthorized personnel. It has been suggested that traps be a bright, reflective color to help in locating traps, but this would be discouraged even though a clearly visible warning may be on the trap. Color is probably not too important in actual use. In tests in a feed mill, nearly all Indianmeal moths and Mediterranean flour moths were trapped at night in complete darkness. Warehouse environments are often dark.

Acceptance

Some workers in the food industry may object to the unsightly appearance of filled or dirty sticky traps, compared with the attractive plastic funnel trap used for moths. If used in public areas, traps should be visually pleasing to the consumer and should not become unsightly during use. In addition, consideration of materials used to construct a trap is important. Glues, plastics, and the breakdown products of these materials need to be considered as potentially harmful if used in food areas. The use of food-grade materials is desirable. If a trap were to inadvertently enter the mainstream of a process, it would be considered foreign material. If these components are hazardous, additional danger and potential liabilities may exist. Metal parts can be detected by metal detectors, but only ferrous metals may be removed by magnets. This is especially important for wire used to suspend traps, as small wires are difficult to detect, can pass through some sieves, and often cannot be magnetically removed.

A disadvantage with food traps is that traps which are lost or inadvertently shipped with a commodity may create or disperse an infestation.

Trap Loss

For use in areas with frequent, uncontrolled commodity movement, traps should be designed so that they may be used without being placed in or on the commodity. Traps should be designed as small as practicable and so that they can be readily affixed to walls or beams. Traps designed to be inserted into a commodity, such as perforated grain probe traps, should have provision for anchoring, such as lanyards, to avoid loss and to aid recovery.

In many environments, temperatures vary widely. As a result, sticky traps utilize adhesives that are functional within temperatures suitable for insect activity and flight. Sticky traps also are able to withstand high temperatures which may occur in grain bin headspace, warehouses, railcars, vans, or containers.

Use Influences Trap Design

Specific uses for a trap may require certain design features. A trap designed to remain in place with periodic servicing may have provisions for replacing glue surfaces, changing collection trays, or renewing attractants. However, such traps may be too elaborate and expensive to use where one-time use of disposable traps is adequate. In permanent pest control operations, some have found that more expensive plastic funnel traps eventually became cost effective. Traps also may be required to remain in place with only one servicing, and yet remain functional for an extended period. Therefore, a trap may need to have a large capacity, be made of durable materials, and be able to maintain trapped insects in a usable condition.

Insects that require minute examination for identification, such as khapra beetle, would be difficult to extract from sticky traps without solvent treatment. In food-type traps or other live traps, larval stages may cannibalize insects needed for identification or evidence (Figure 5). Funnel traps for moths may be more desirable than sticky traps if critical identification is required. Traps that allow insect movement, such as non-lethal pitfall or probe traps, may result in fragmented insects, thus making accurate counts or identifications difficult. Such traps may need to be serviced more frequently. Although insecticides, such as DDVP resin chips or insecticide-treated traps, have been used to kill trapped insects, traps using insecticides have not been favorably received by the U.S. food industry.

With different types of lures available (membranes, rubber septa, composites, and hollow fibers) for many different species, trap designs which could use different or multiple lures could have more utility. Trap designs could have multiple-species capability, variable release rates for different species, or different durations based on use needs. This may be important, for example, if a trap used for short-term monitoring is fitted with a long-duration lure and is lost. A lost trap may compete with placed traps or contaminate a commodity.

Summary

In summary, a wide array of traps and trapping systems have been designed. Traps have been designed to be utilized for single or multiple species either alone or simultaneously. Traps designed for one species have been fortuitously used for other species under different conditions or where different objectives are to be met. Conditions of the trapping environment, as well as use patterns, have led to specific design features. Trap designs should be based on knowledge of the insects' behavior and ecology. Important design features should be validated by laboratory and field data. To be successful, a trap should be reliable, commercially feasible, accepted in the marketplace, pose minimal environmental hazards, and meet government regulations.

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25

Identification of Common Dermestids

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Reviewed by Terry Seeno, California Department of Food and Agriculture

Beetles of the family Dermestidae comprise a relatively small number of omnivorous protein scavengers, several of which are pests of stored products. Dermestids can be very harmful and may be difficult to detect. As a result, pheromone and food trap monitoring of populations can be useful in early detection of a problem. Since the presence of larvae will give the first evidence of an infestation, larval as well as adult identification will be discussed. A complete taxonomic key for the Dermestidae is beyond the scope of this publication; therefore, these keys will apply only to those genera and species which are commonly encountered in a warehouse environment. A widefield dissecting scope (at least 45x) and, in some cases, a high-power (at least 440x) compound microscope is needed for correct identification.

The dermestids of greatest economic significance are represented by four genera.

1) *Dermestes* .... (hide, larder beetles)
2) *Attagenus* .... (black carpet beetle)
3) *Anthrenus* .... (varied, furniture carpet beetles)
4) *Trogoderma* .... (warehouse, khapra beetles)

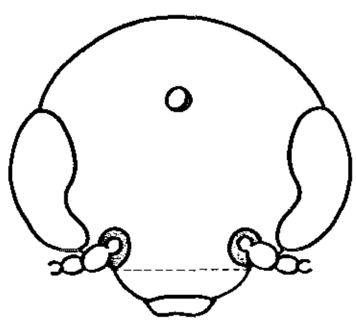

Figure 1. Position of the median ocellus between the compound eyes. In *T. inclusum,* the compound eyes are variably but distinctly emarginate, or notched at the middle of the inner margins as shown. (USDA)

The Adults

The commonly occurring adult dermestids can be placed in the correct genus based on gross characteristics. All dermestid adults, except the genus *Dermestes,* have a median ocellus, or small simple eye between the compound eyes (Figure 1). This is not difficult to see, but does require a widefield microscope with good top lighting. The *Dermestes* are large, up to 10mm long, whereas the others are much smaller, usually 2mm to 4mm.

Median ocellus absent; adults 7mm to 10mm .... *Dermestes*
Median ocellus present; adults 2mm to 4mm .... *Anthrenus*
Trogoderma
Attagenus

If the pronotum (thorax) has deep and conspicuous cavities as seen from a frontal view into which the antennae will fold, the genus is *Anthrenus* (Figure 2). In this

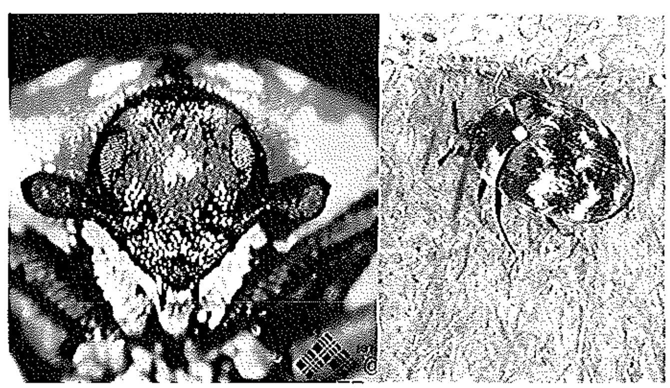

Figure 2. In the *Anthrenus,* the antennae fit into distinct cavities in the front of the pronotum (left). The varied carpet beetle with scale patterns (right). (Van Waters & Rogers, Inc.)

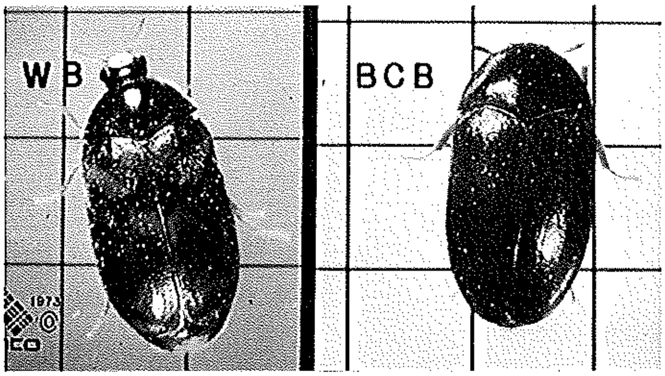

Figure 3. The warehouse beetle (left) has brownish elytral bands, while the black carpet beetle lacks bands and is shiny black (2mm grid). (Van Waters & Rogers, Inc.)

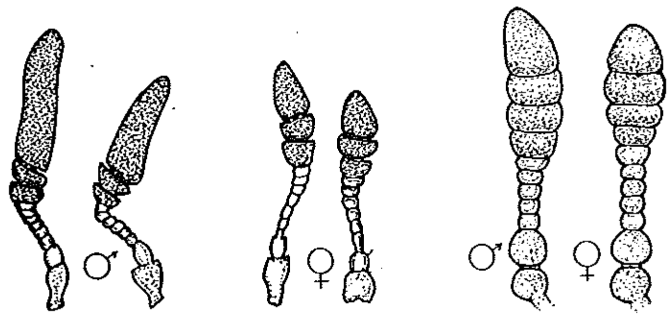

Figure 4. Dermestid antennae. Left, male *A. brunneus* (l) and black carpet beetle (r). Center, female *A. brunneus* (l) and black carpet beetle (r). Right, khapra beetle male (l) and female (r).

genus, the femora also fit into grooves, giving the adult a pill-like appearance when disturbed. In this genus, the adults are always covered in characteristic and colorful white, gold, or brown scales in variable patterns (Figure 2). If the antennae do not fit into a distinct frontal cavity, but instead fold tightly under the sharp front edge or carina of the pronotum into a cavity seen only from below, and the colorful scales are absent, and is not *Dermestes*, the adult may be *Attagenus* or *Trogoderma*.

Covered with colorful scales; antennae fit tightly into cavities on front edge of pronotum .... *Anthrenus*

Brownish to black; no colorful scales; antennae fold tightly under front edge of pronotum into a cavity visible only from below (and is not *Dermestes*) .... *Trogoderma, Attagenus*

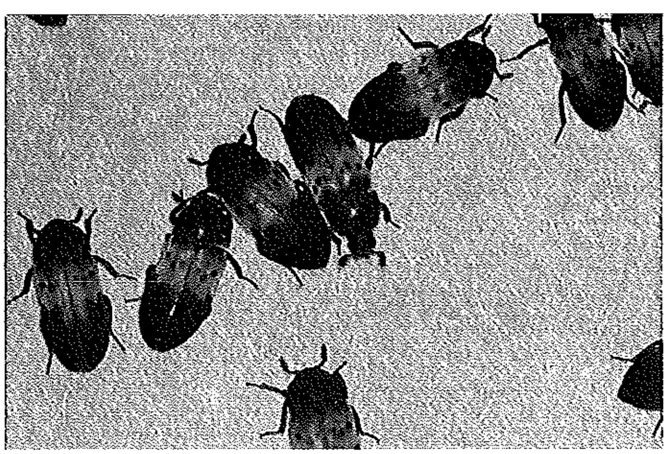

Figure 5. The larder beetle, showing cream-colored bands with dark patches. (Univ. of Minnesota)

Distinguishing the *Trogoderma* from the *Attagenus* is more difficult. The *Trogoderma* adults are characterized by faint to distinct patterns of fine brown and white setae and pigmentation which form bands or patterns across the elytra. In the khapra beetle, the bands can be very faint or nearly absent. The *Attagenus* have no banding, and appear shiny and rather uniformly black (Figure 3). However, old dead specimens may fade to shades of brown. In the *Attagenus*, the distal antennal club has three distinct segments and the male antennae have a long terminal segment as in Figure 4, while in the *Trogoderma*, the club is more gradual with four to seven segments of more similar length. In *Trogoderma*, the basal tarsal segment is twice as long as the second, while in *Attagenus*, the second is longer.

Adults oval, shiny black, covered with fine dark setae; elytra without patterns or bands; antennae with distinct, three-segmented, elongated club, with male terminal segment much longer than female; second tarsal segment twice as long as first .... *Attagenus*

Adults oval, brownish, but with faint to distinct patterns on elytra, covered with fine brown and sometimes scattered white setae; antennae with more gradual four- to seven-segmented terminal club; first tarsal segment twice as long as second .... *Trogoderma*

The *Dermestes*

In storage areas where dried or moist pet foods, animal skins, dried fish, or other similar proteinaceous animal products are stored, the two most common species that one is likely to encounter are the hide beetle, *Dermestes maculatus*, and the larder beetle, *Dermestes lardarius*. These two are easily separated. Adults of *D. lardarius* have a very distinct cream-colored band across the top third of the elytra (Figure 5). The band typically has three small black patches on each side. The hide beetle, *D. maculatus*, appears white on the underside, due to dense white setae which also extend partially along the margins of the pronotum (Figure 6). The hide beetle may be separated from less common but similar *Dermestes*, such as the incinerator beetle, *Dermestes ater*, by the elytra, which taper to a fine point at the tip in *D. maculatus*. Also, the males of *D. maculatus* have a small, round patch of setae clearly visible on the fourth abdominal sternite. But, in *D. ater*, *D. lardarius*, and some other less common species, these patches are found on both the third and fourth sternites (Figure 6). Setiferous patches are never found on females. Among the dermestids, the *Dermestes* are the only ones causing significant damage as adults.

The other genera of dermestids are commonly found on window sills in the spring and summer. Older adults fly to the light, and larvae are able to cannibalize dead insects on window sills and ledges. These adults have been observed to feed on pollen of ornamental shrubs, such as Spirea (bridal wreath), and may be found on the blooms in the spring and summer.

The *Anthrenus*

These carpet beetles are the most striking in appearance of all dermestids, and the colorful scale patterns are unique to this dermestid genus. Scale shape, not pattern, should be used to identify species. In *Anthrenus verbasci*, the varied carpet beetle (Figure 2), the scales are more narrow and 2.5 to 4 times as long as broad. In *Anthrenus flavipes*, the furniture carpet beetle (Figure 2), the scales are nearly oval and less than twice as long as broad.

The *Attagenus*

The black carpet beetle, *Attagenus unicolor* (= *A. megatoma*), is fairly common in warehouses, grain elevators, and homes. However, *Attagenus brunneus* (= *A. elongatulus*) is very similar and has been confused in the past with *A. megatoma* (Figure 7). In the male, the terminal segment of the antennal club of *A. unicolor* is about three times the length of the previous two segments combined, and in *A. brunneus*, it is about five times (Figure 4). In the females, the terminal segment is equal in length to the previous two combined for *A. unicolor*, and about one and a half times in length for *A. brunneus*.

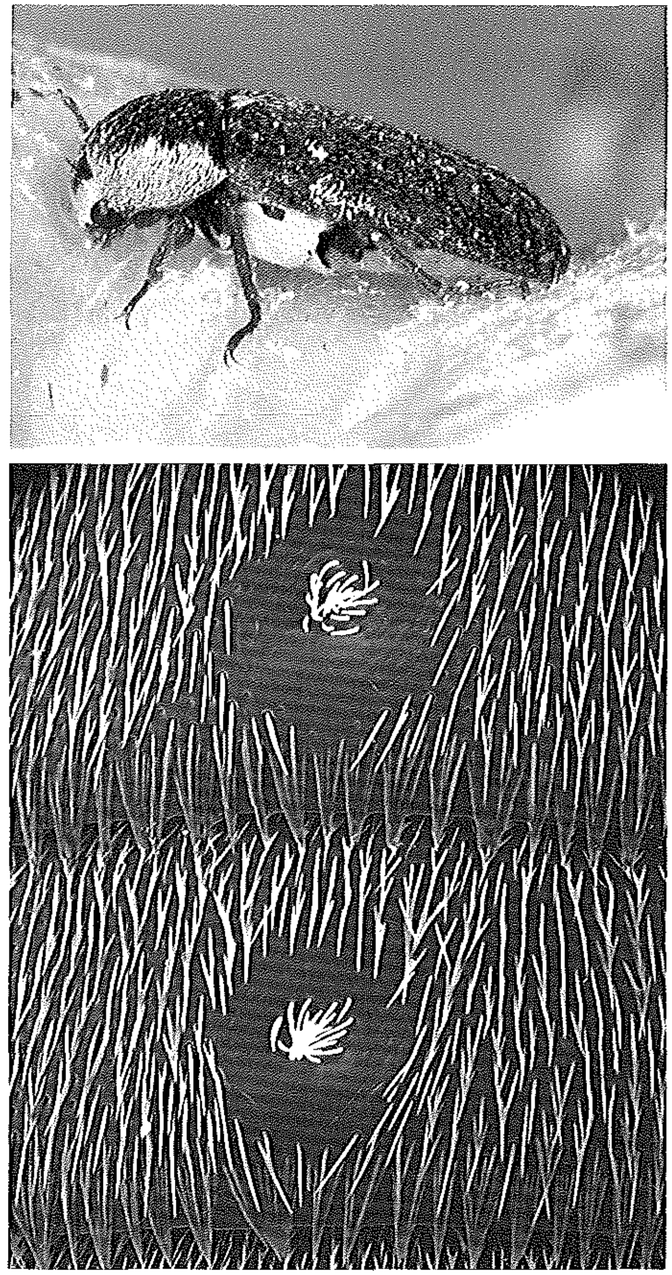

Figure 6. The hide beetle, on which the underside and sides of the pronotum are covered with silvery-white setae. (Van Waters & Rogers, Inc.) Lower, setiferous patches on the third and fourth abdominal segments of *D. ater* males. The patch is present on only the fourth segment of *D. maculatus* males. (Univ. of Wisconsin)

The *Trogoderma*

Only a few species are of economic significance in the U.S., one of which is a quarantine species. The possible occurrence of the khapra beetle, *Trogoderma granarium*, makes identification critical if the khapra beetle is suspected. Unfortunately, this can be difficult. *Trogoderma inclusum* can be separated from the others by looking at the inside margin of the eye which is moderately to deeply notched (Figure 1). *Trogoderma variabile*, *T. inclusum*, and several less common species, such as *Trogoderma simplex* and *Trogoderma sternale*, typically have light-

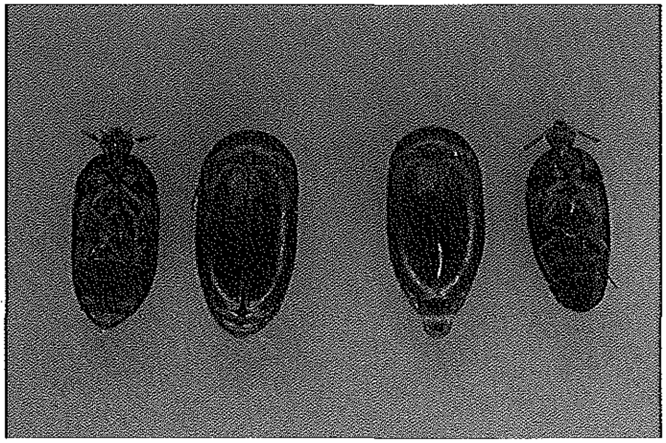

Figure 7. Male and female of black carpet beetle (left) and *A. brunneus* (right). The long terminal segment of the male antennal club identifies *A. brunneus.* (Univ. of Wisconsin)

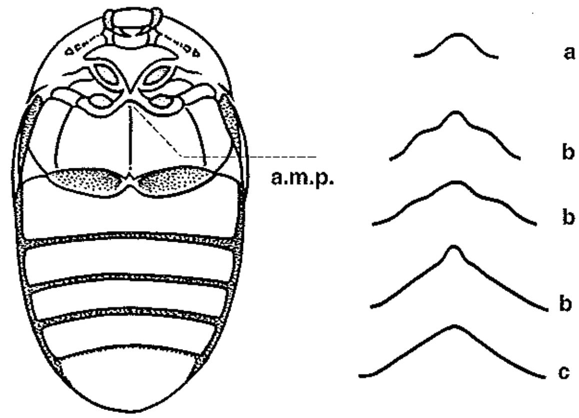

Figure 8. *Trogoderma granarium* female, ventral view. The anteromedial metasternal process of khapra beetle is compared with other *Trogoderma* spp. (G. T. Okumura)

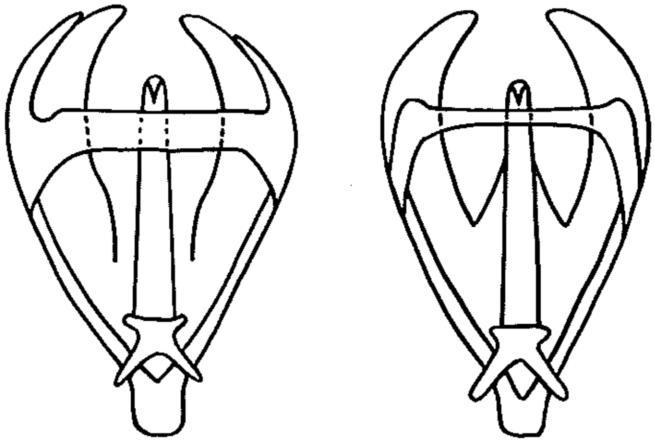

Figure 9. Male genitalia of khapra beetle (left) and warehouse beetle (right).

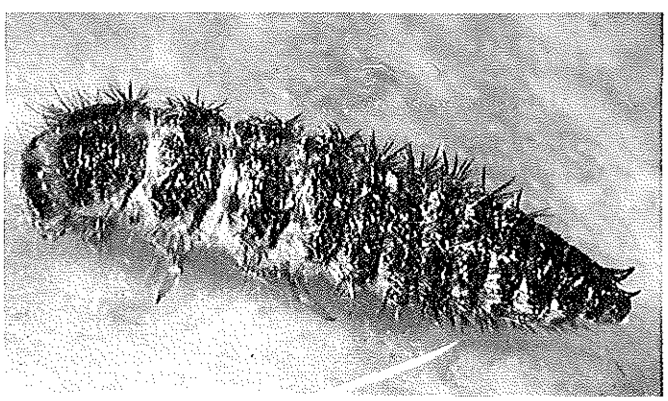

Figure 10. *Dermestes maculatus*, the hide beetle. Note the characteristic upward-curving urogomphi on the second to the last abdominal segment, and the pale, yellowish band down the back. (Van Waters & Rogers, Inc.)

colored patterns of banding on the elytra. The patterns are due to pigmentation, and are accentuated by light setae in the light areas and brown setae in the darker areas. The khapra beetle and *Trogoderma glabrum* have only slight patterning, if at all. In *T. glabrum*, which is rather black in appearance, there are sparse white setae which create faint patches or bands across the elytra, and patterns are due more to setae than pigmentation. Any *Trogoderma* in which patterns are nearly or completely absent should be carefully scrutinized. If adult *Trogoderma* are found which are very light or cream colored, they may not be fully sclerotized and should be held for a day so that cuticle can fully sclerotize, thus clarifying patterns and colors. Khapra beetle adults, especially the males, are small (males 2mm to 2.5mm) compared with *T. variabile* or *T. glabrum.* Males of *T. variabile* are commonly larger than khapra beetle females. *Trogoderma* males are smaller than females, and the sexual difference in antennal club (Figure 4) is not as apparent as in the *Attagenus.* The following method of identification is primarily to determine if khapra beetle is the *Trogoderma* present.

1. Inside margin of eye with deep to moderately deep notch; band patterns on elytra .... *T. inclusum*

   Eye without distinct notch; elytral bands may be present or absent 2
2. Elytra with conspicuous lighter patterns or bands..... .... probably *T. variabile*

   Elytral bands only faint, or absent 3
3. Generally blackish, may have scattered white setae in faint irregular patches across elytra .... *T. glabrum*

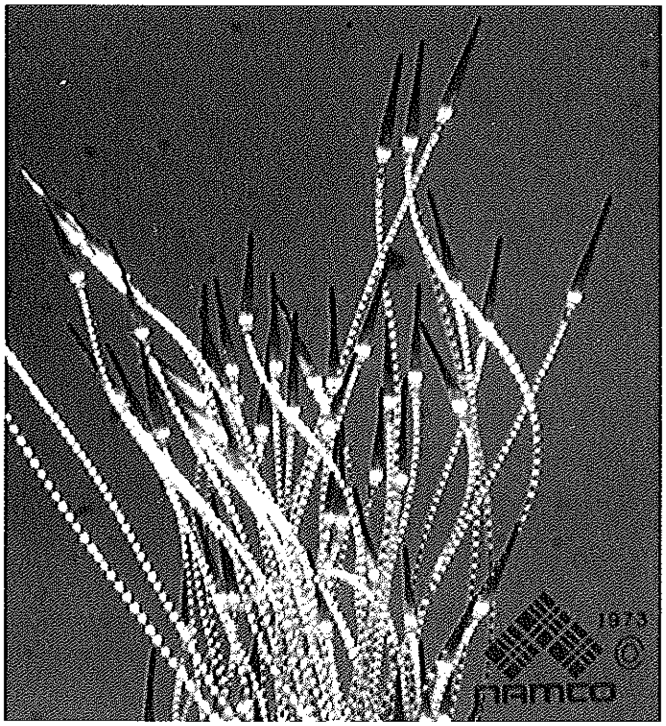

Figure 11. *Hastisetae.* These barbed and segmented setae are found in clumps or tufts on the terminal segments of larvae of only the *Anthrenus* and *Trogoderma.* (Van Waters & Rogers, Inc.)

Generally brown; elytral bands may be absent, or only faintly visible .... possible *T. granarium*

If khapra beetle is suspected, a supplementary character for males and females can be used. The khapra beetle is flightless, perhaps due in part to the shape of the anteromedial metasternal process. As in Figure 8, this process is smoothly rounded (a). But, in the other species, there may be a distinct nipple or notches (b), or is pyramidal (c). Khapra beetles will not be trapped in an aerial pheromone or light trap for flying insects.

A second character can be used for males. The genitalia must be extruded by squeezing a fresh male, or by soaking and dissecting an old, dried specimen. Representative male genitalia are shown in Figure 9. If the bridge across the genitalia is as wide or wider than the aedeagus at the point they cross, khapra beetle is confirmed.

The Larvae

As with adults, dermestid larvae have gross characteristics which allow placement within the correct genus. However, species identification may be much more diffi-

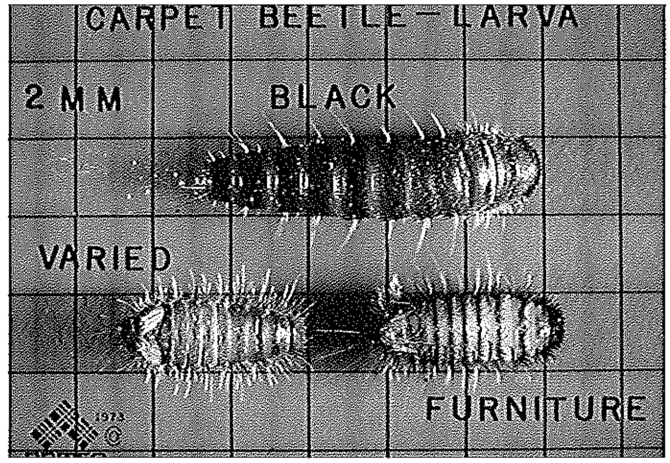

Figure 12. Characteristic shapes of carpet beetle larvae. The varied carpet beetle is wider at the rear compared with the furniture carpet beetle, which is wider toward the head. The *Attagenus* (black carpet beetle) are carrot-shaped. (Van Waters & Rogers, Inc.)

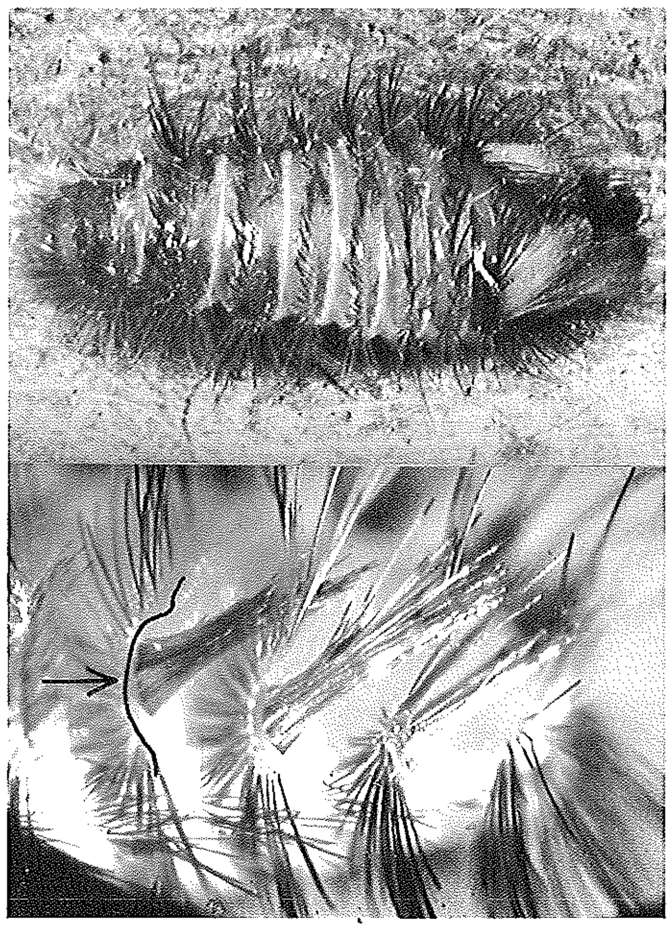

Figure 13. *Anthrenus verbasci*, the varied carpet beetle. Note the tufts of hastisetae which slant over the back. In the *Anthrenus* spp., the posterior margin of the segments is sinuate, curving around the tufts which arise from the intersegmental membrane (bottom). (Van Waters & Rogers, Inc.)

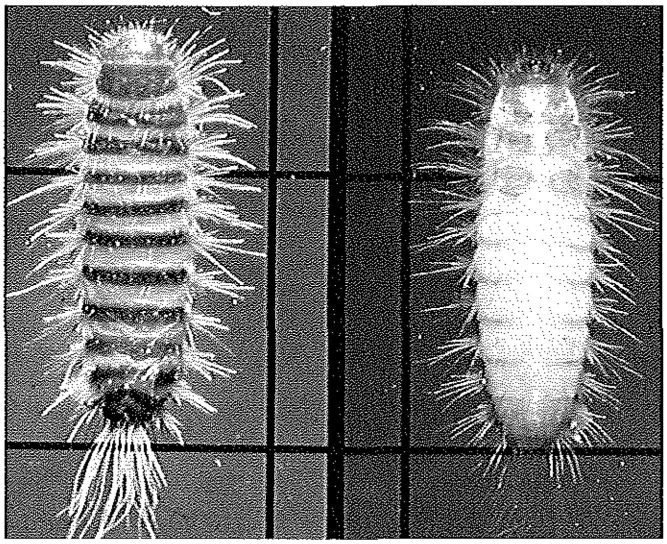

Figure 14. *Trogoderma variabile*, the warehouse beetle. In the *Trogoderma*, larvae have obvious segmentation, with hastisetae in dark clumps on the last abdominal segments. The larvae are very light on the underside (5mm grid). (Van Waters & Rogers, Inc.)

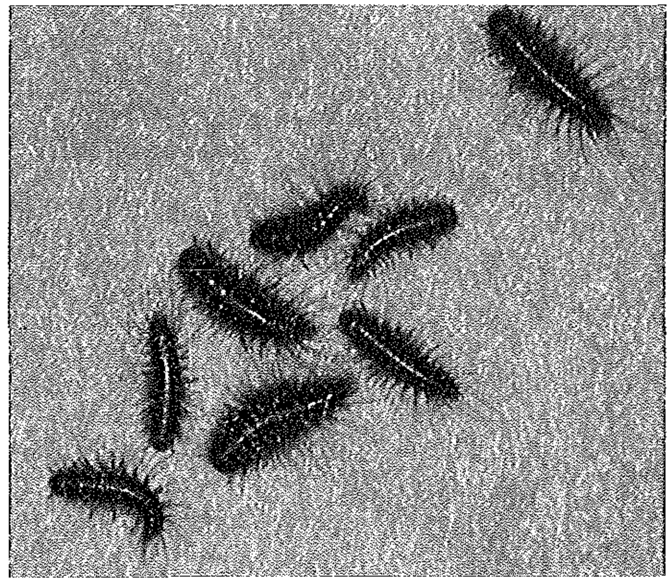

Figure 15. *Dermestes lardarius*, the larder beetle. A thin, white line down the back separates this species from the hide beetle. (Univ. of Minnesota)

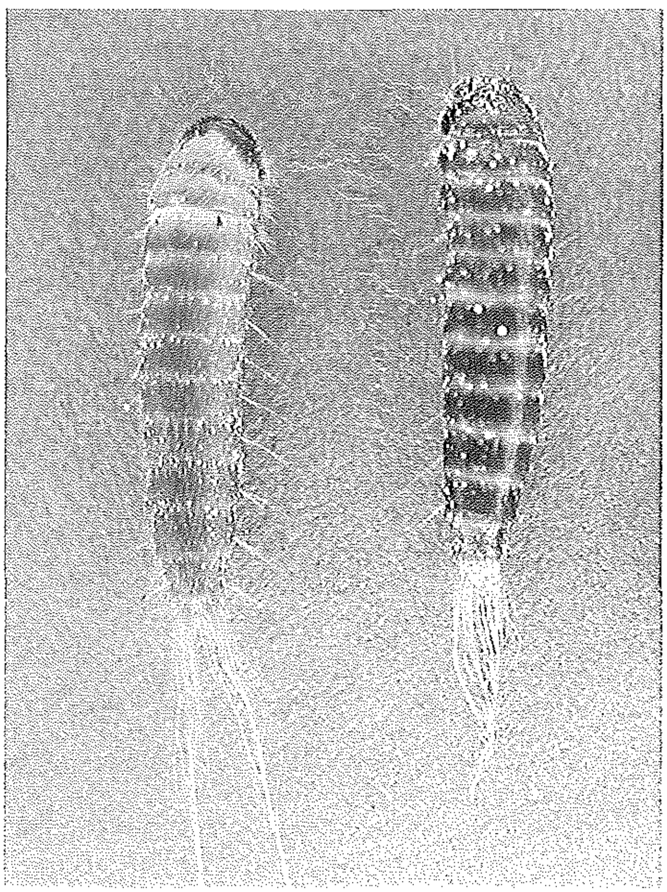

Figure 16. *Attagenus* larvae. The black carpet beetle, *A. unicolor* (right) is a darker chestnut brown, compared with the golden colored *A. brunneus* (left). (Univ. of Wisconsin)

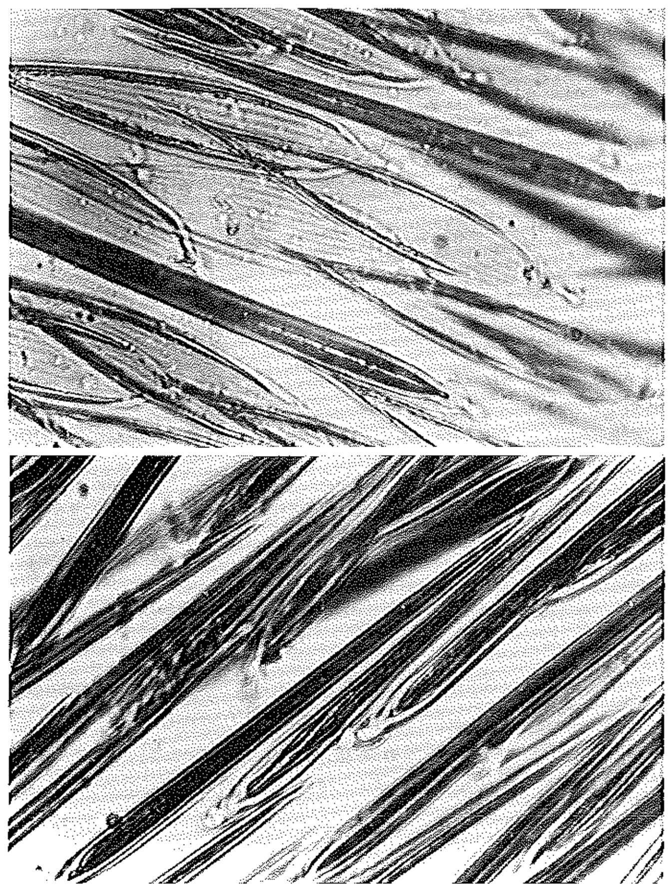

Figure 17. Broader, multiple-lined scales from the eighth abdominal sternites of *A. brunneus* (top), compared with the narrow three-lined scales of *A. unicolor* (bottom). (Univ. of Wisconsin)

cult. The dermestid larvae are all heavily to completely covered in setae, some of which are very characteristic and which give dermestid larvae a fuzzy look. The active and generally black *Dermestes* can be separated from other dermestid larvae by the presence of a pair of large, curved and conspicuous projections, called urogomphi, which arise dorsally from the second to the last segment on the more mature larvae (Figure 10). The *Dermestes* are the largest, up 15mm long, while larvae of the other genera are smaller and less robust, usually 5mm to 10mm when mature.

Urogomphi present .... *Dermestes*

Urogomphi absent ... *Anthrenus, Trogoderma, Attagenus*

Some larvae have specialized barbed and segmented setae, called hastisetae, in clumps or tufts on the dorsal, terminal segments of the larvae (Figure 11). If these setae are present, the larva is either *Anthrenus* or *Trogoderma*. Hastisetae are not found in *Attagenus* or *Dermestes*. The larvae of *Attagenus* (black carpet beetles) have a fan-shaped "tail" of caudal setae. The larvae are carrot-shaped, broader at the head and tapering towards the posterior. (Figure 12). Caution should be used, as caudal setae may be lost due to handling.

Hastisetae absent, (and not Dermestes) .... *Attagenus*

Hastisetae present .... *Anthrenus, Trogoderma*

If the hastisetae are present, the origin of the setae identifies the genus. When the setae are parallel and in tight tufts arising from the light-colored intersegmental region, the tufts point inwardly and may even overlap, and the posterior margin of the tergite is sinuate or curved around the region from which the setae arise (Figure 13), the larva is *Anthrenus* spp. In the *Trogoderma*, the setae are present in clumps clearly arising from the darker area of the sclerotized terminal abdominal tergites. *Trogoderma* larvae clearly have a segmented appearance (Figure 14).

Hastisetae in intersegmental tufts, margin of segment sinuate (curved) around tufts .... *Anthrenus*

Hastisetae in clumps on sclerotized dorsal tergites; posterior segmental margins not sinuate .... *Trogoderma*

With the larva in the proper genus we can now identify the correct species.

The *Dermestes*

In mature *D. lardarius*, the urogomphi curve downward toward the rear and a narrow, light-colored line runs down the center of the back (Figure 15). In mature *D. maculatus*, the urogomphi curve upwards (Figure 10), and the larva has a broad, pale-yellowish band extending down the back from the pronotum to the rear segments. In the less common *D. ater*, mature larva are similar to *D. maculatus*, with the broad, yellowish band down the back, except that the yellowish band begins at the mesonotum, not the larger pronotum as with *D. maculatus*, and the urogomphi are straight or only slightly curved upward.

Narrow, light line down back; urogomphi curve downward .... *D. lardarius*

Broad, yellowish band down back; band includes pronotum; urogomphi curve up .... *D. maculatus*

band begins at mesonotum; urogomphi straight .... *D. ater*

The *Attagenus*

Only two species are likely to be encountered—the black carpet beetle, *A. unicolor*, and the originally European *A. brunneus*. The larvae of *A. unicolor* are dark brown, while

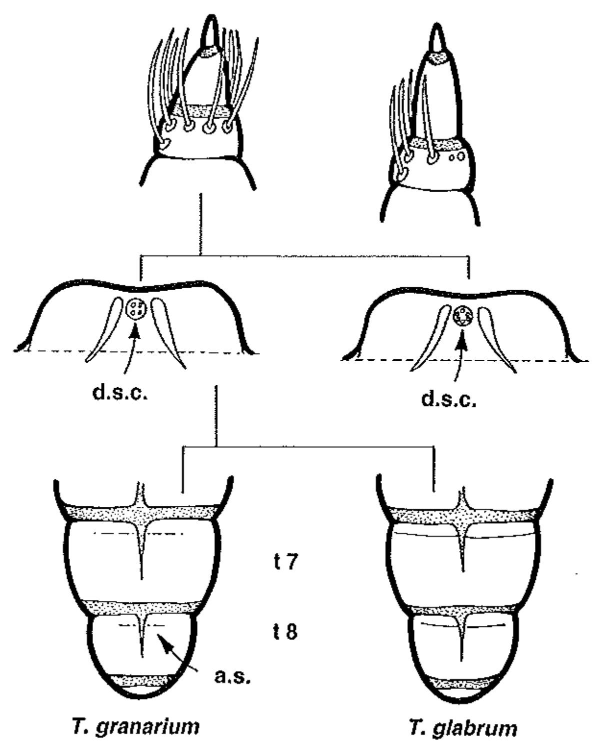

Figure 18. Schematic diagram of important characters used for separating larvae of *T. granarium*, the khapra beetle, from other species of *Trogoderma*. (USDA)

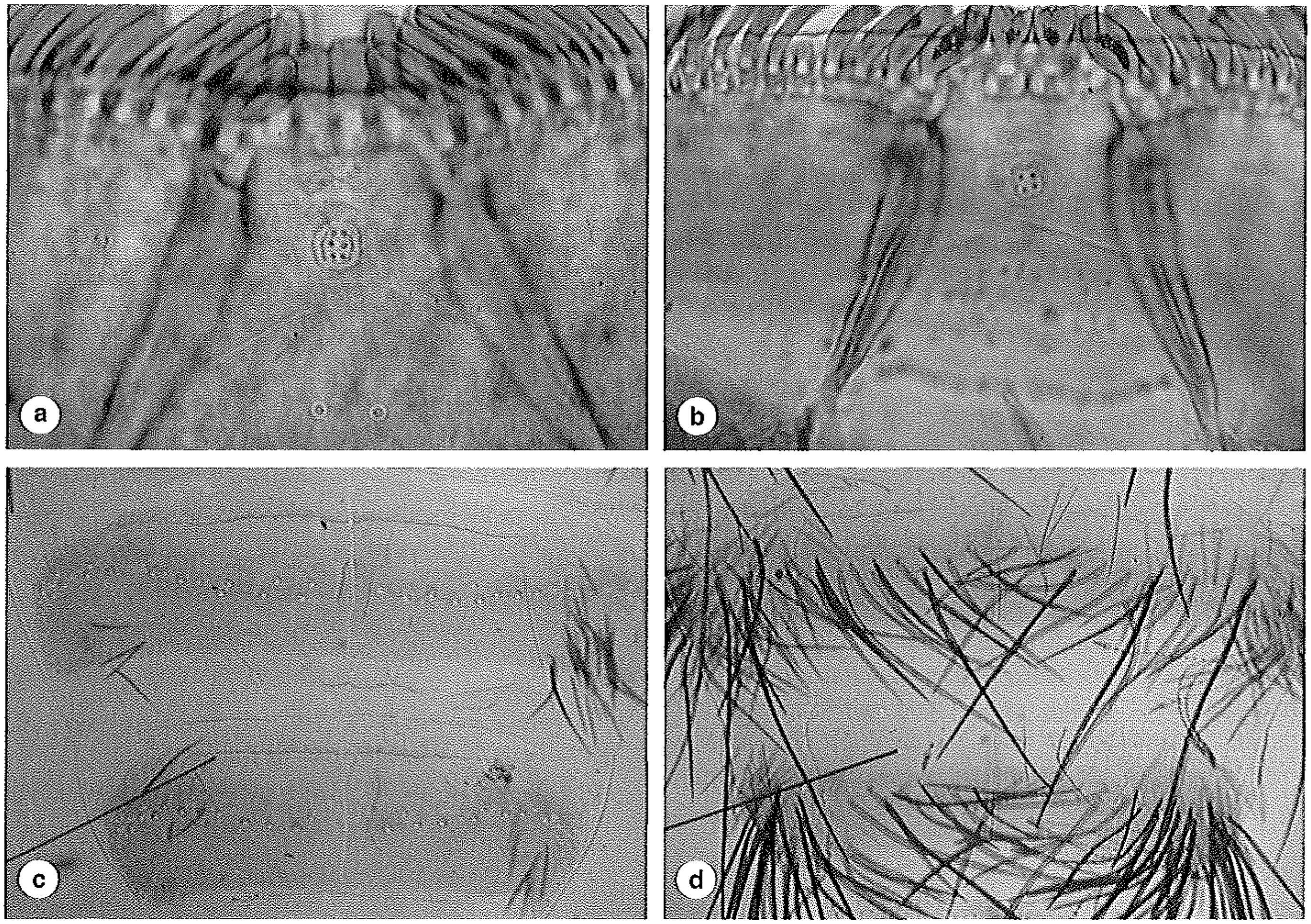

Figure 19. Photomicrographs used for the identification of *Trogoderma* larvae. Epipharynx of non-khapra-beetle larvae with six papillae in sensory cup (a), compared with four papillae in the khapra beetle (b). The antecostal suture is well-developed on the seventh and eighth abdominal tergites (pointer) in *T. glabrum* (c), compared with khapra beetle (d), where it is weak on the seventh tergite and absent or very faint on the eighth (pointer). (USDA)

in *A. brunneus,* the larvae are golden colored (Figure 16). Also, in *A. unicolor,* the scales are narrow with three longitudinal lines, while in *A. brunneus* the scales are broader with five longitudinal lines (Figure 17).

Dark chestnut brown, three-lined scales ....*A. unicolor*

Golden colored, broad five-lined scales ....*A. brunneus*

The *Anthrenus*

Two species are likely to be encountered in the warehouse. These are the varied carpet beetle, *A. verbasci,* and the furniture carpet beetle, *A. flavipes.* The larvae of this genus are rather stout and have hastisetae in definite posterior tufts (Figure 12). Larvae of the varied carpet beetle are rather wide and are broader at the rear than at the head. Larvae of the furniture carpet beetle are broader at the head and taper to the rear. If the tufts of setae are worn off, the sinuate posterior margin of the rear segments confirms the genus.

Broad at the rear, narrow at the head ....*A. verbasci*

Tapered to the rear, broader at the head........*A. flavipes*

The *Trogoderma*

These are common and abundant warehouse insects. The larvae can efficiently penetrate packages. This group contains the most destructive dermestids. If it were not for the occurrence of the khapra beetle, *T. granarium,* identification of species would not be so critical. Unfortunately, identification is very difficult. The khapra beetle is a quarantine species and is one of the most destructive stored-product species worldwide. If this species is found, eradication efforts are required. This key will serve the primary function of separating the khapra beetle from other common species. *T. glabrum* is a less common, generally outdoor, animal protein scavenging species, with *T. variabile*, and less so, *T. inclusum*, the most likely to be encountered in a storage environment. The main characteristics to be used are the arrangement of setae on the larval antenna, the number of papillae in the distal sensory cup of the epipharynx, and the extent of the antecostal suture of the seventh and eighth abdominal tergites (Figures 18 and 19). Only *T. granarium* and *T. glabrum* have four sensory papillae—all others have six. Preparation of specimens for examination is explained at the end of the chapter.

1) Setae arranged in a nearly complete whorl around basal antennal segment, extending to or beyond apex of second segment 2

   Setae of basal antennal segment bunched on mesal side of segment, one third or more of outside bare, and not reaching apex of second segment .... *T. variabile*

2) Distal sensory cup with four papillae; papillae may be grouped two and two, but always four total 3

   Distal sensory cup with six papillae; papillae may be grouped four and two, or three and three, but always six total .... *T. inclusum*

3) Tergum more darkly colored, antecostal suture of eighth abdominal tergum well developed .... *T. glabrum*

   Tergum uniformly light colored, antecostal suture of seventh abdominal tergum may be discontinuous, suture on eighth tergum may be weak, or even absent .... *T. granarium*

Specimen Preparation

Techniques for dissecting and mounting *Trogoderma* larvae for the purpose of identifying khapra beetle are given here. A microscope of 45x is needed to observe larval antennae and the antecostal suture. Magnification of about 440x is needed to count papillae in the distal sensory cup of the epipharynx.

Mounting media such as Hoyer's is best, but if not obtainable, PVA (polyvinyl alcohol) or glycerine will make a satisfactory media.

For Cast Skins

Cast skins are the easiest to work with, since no clearing is needed.

1) Place skin, ventral side up, in a watch glass containing media. Remove ventral mouthparts which interfere with observing the underside of the labrum.
2) Tease off hastisetae on dorsal surface of terminal abdominal segments.
3) Place skin on a slide in a few drops of media. Fold the skin over such that the ventral side of the head and the dorsal side of the abdomen are up.
4) Place coverslip over specimen without disturbing position.
5) Examine for number of papillae in sensory cup and presence of antecostal suture on seventh and eighth abdominal tergites.

   Note: The distal sensory cup may be divided into two or three parts, but the number of papillae will always be four or six as in the keys.

For Whole Larvae

Preserved larvae are best kept in 70 percent ethanol. Both preserved and fresh larvae must be cleared and dissected for use.

1) Puncture larva with fine insect pin (zero or one) just behind the legs, and place larva in warm 10 percent KOH for five minutes (two to three pellets in 15 ml water, 50°C).
2) With a fine insect pin with a bent tip, insert point through puncture, and hold down specimen. With a fine pin or micro-forceps, carefully pull away abdominal sternites.
3) Transfer larva to fresh water. Using a fine pin or brush, gently remove remaining tissues. Tease off hastisetae from terminal segments.
4) Place two drops of media (Hoyer's, PVA, or glycerine) on a clean, dry slide. Position larva dorsal side up. Remove and position head, ventral side up, near last abdominal sternite.
5) Carefully insert bent pin through occipital foramen (hole in back of capsule) to hold it down, and, with another pin, carefully remove mandibles from head, and gently pull away. Carefully remove labial and maxillary palpi, revealing the interior of the labrum.
6) Re-position specimen, if necessary, and drop coverslip over preparation. If done correctly, the antecostal suture of the seventh and eighth tergites, the sensory papillae, and the larval antennae should all be visible.

References

This material has been adapted from both published and unpublished material from numerous sources. The following list of references provided significant information and should be consulted if dermestids other than those discussed here are suspected.

The recent reference by Banks is an excellent key for the *Trogoderma* of quarantine significance to Australia, and includes khapra beetle and the economic species common in North America. This key utilizes excellent scanning electron photo micrographs as well as standard transmitted light photomicrographs of important characters, including male and female genitalia. All stages are discussed. Included are techniques for specimen preparation and examination.

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Rev. 1/95

Part V: Integrated Pest Management

26

Why Stored Product Integrated Pest Management is Needed

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Vera Krischik, USDA-FGIS and the Institute of Ecosystem Studies

The United States stores more than 15 billion bushels of grain each year. Damage caused by insects, molds, heat, and sprouting is common and results in annual losses totaling more than $1 billion. Both export buyers and flour mills emphasize the need for high-quality U.S. grain. Storing grain increases risks of storage problems and may result in weight loss, loss of germination, nutrient loss, lower market value, contamination, costs of treatment, and heat and stress damage. These losses also threaten the U.S. export markets.

Integrated Pest Management is a multi-disciplinary approach which integrates all biotic and abiotic components within the system to help grain managers make sound management decisions. The grain mass is a living, breathing, dynamic ecosystem. Grain quality can depreciate over time without proper storage and management. Grain storability or "risk" is determined primarily by: 1) grain temperature, 2) grain moisture, 3) the ability to sample the grain and estimate its condition, and 4) time in storage. The critical variables are temperature and moisture—the higher the grain temperature and moisture, the greater the risk.

Successful storage is accomplished by starting with clean, whole, insect-free grain in the storage facility and by maintaining moisture and temperature at low levels. Grain moisture and temperature must be monitored since they are associated with the development rate of insect and mold populations.

Producers, elevator operators, processors, and distributors must understand the marketing system, storage problems encountered, management options available, and cost:benefit analysis for these options. This storage situation is complex, and components cannot be managed independently. High-risk grain that enters the grain marketing system at any position will put other grain stored with it at risk. If loads of infested grain are not detected, the infestation will move throughout the remainder of the storage facility and reduce quality, profitability, and future marketability of the entire grain mass. The grain storage system is illustrated in Figure 1 and shows the flow of the grain through the system to the eventual consumer. An integrated management approach is necessary to develop economically- and environmentally-sound stored-grain programs. □

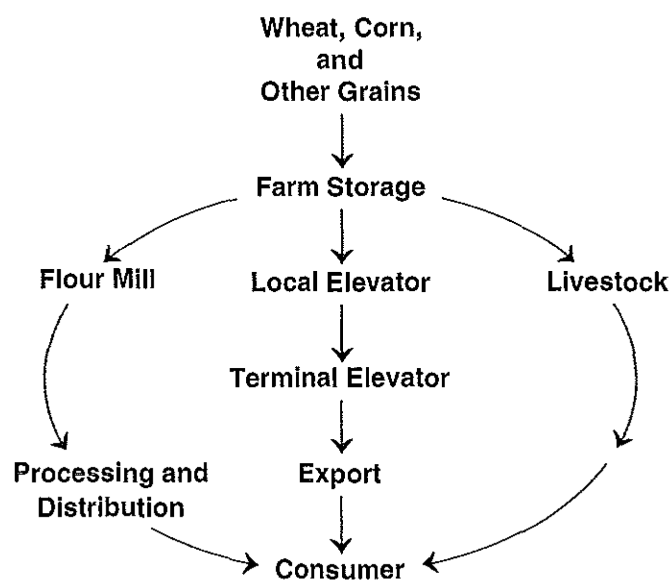

Figure 1. Flow of grain through marketing system.

27

IPM in Grain Storage and Bulk Commodities

David Hagstrum, USDA-ARS, U. S. Grain Marketing Research Laboratory
Paul Flinn, USDA-ARS, U. S. Grain Marketing Research Laboratory

Introduction

Integrated pest management (IPM) is a comprehensive approach to pest control that involves insect sampling, risk:benefit analysis, and use of multiple control tactics. IPM is a concept that is well established in crop protection, and one that must be more widely understood and used by stored-grain managers.

The economic injury level (EIL) is defined as the insect density that causes reductions in market value greater than the cost of the control. A critical concept in IPM is the economic threshold (ET), an insect density at which control measures should be applied to prevent insect populations from exceeding the EIL (Figure 1). Onstad (1987) provides a detailed discussion of the economic threshold. Current grain standards are actually EILs.

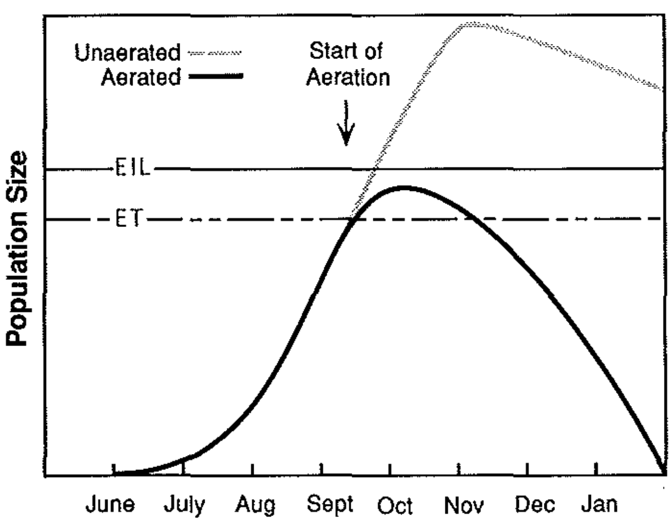

Figure 1. Economic threshold concept.

Stored-grain IPM programs would be improved by the development of better insect sampling programs. Sampling of insect populations is critical to an IPM program, because without it the manager would not know if the population is approaching or had exceeded the economic threshold. IPM programs use risk:benefit analysis to maximize profit and reduce economic losses. IPM programs are based on an understanding of the ecology of insect pests and allow for a variety of control measures, such as sanitation, parasites, and aeration, to be substituted for some or all insecticide applications.

IPM involves consideration of both the timing and choice of control methods. Non-chemical control methods are generally more dependent on an understanding of insect ecology than are chemical control methods. In IPM programs, control measures are applied only when the sampling program shows that insect populations have reached the economic threshold. This chapter describes the fundamental concepts of an IPM program for stored-product insects, and will hopefully facilitate and encourage the use of IPM on stored-product insect pests.

Insect Population Growth in Relation to Temperature and Moisture

When proper sanitation practices are used and infestations are initiated by small numbers of insects, grain temperature and moisture can be the most important factors determining if and when insect populations will multiply to reach economic injury levels. Simulation models can be used to examine the effects of insect species, grain storage period, grain moisture, temperature, and pest control practices on insect population growth (Flinn and Hagstrum 1990, Hagstrum and Flinn 1990). These simulated population trends are used here instead of actual field data

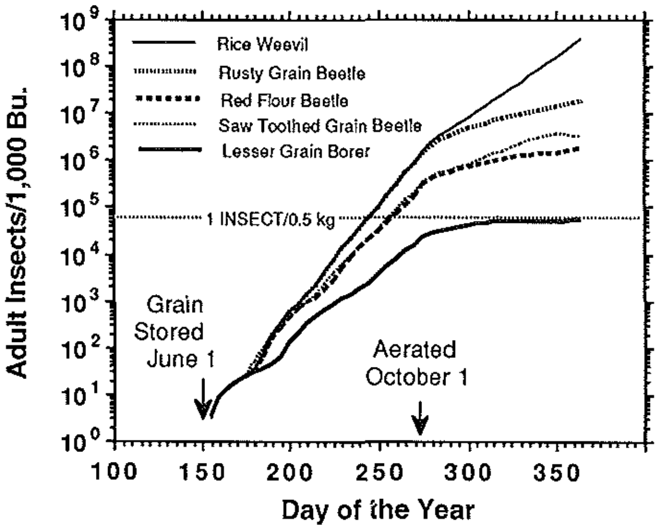

Figure 2. Population growth of different species on wheat stored at 32°C and 14 percent moisture content. (Redrawn from Hagstrum and Flinn, 1990.)

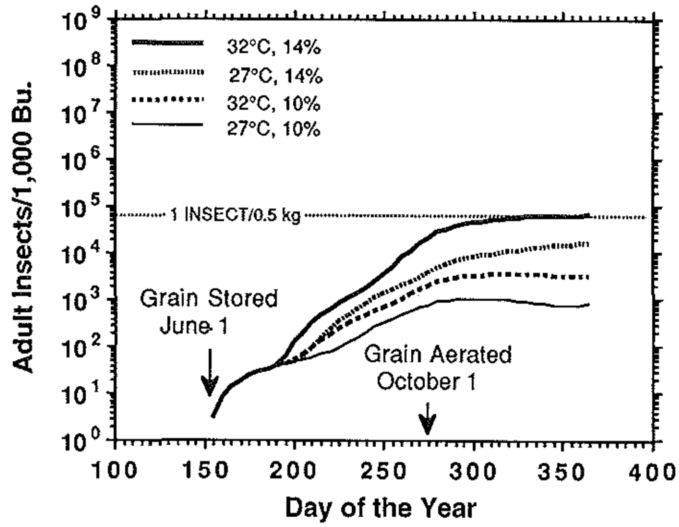

Figure 3. Growth of lesser grain borer populations under different conditions. (Redrawn from Flinn and Hagstrum, 1990a.)

because they can better illustrate the effects of a single temperature-moisture combination. Of the five major beetle pests, the rice weevil and the rusty grain beetle have the highest population growth rates, and the lesser grain borer has the lowest (Figure 2). A longer generation time for the lesser grain borer than for the other species is mainly responsible for the slower population growth. At 32°C, increasing moisture from 10 to 14 percent increases population density at year-end by 20-fold (Figure 3). The effects of moisture on population growth are greater at 32°C than at 27°C. At 14 percent moisture content, a 5°C change in grain temperature results in a four-fold increase in population density.

Aeration

Aeration involves blowing air through grain to change grain temperature or moisture content. Without aeration, grain cools from the outside to the center in the fall, and warms from the outside to the center in the spring. The temperature of the grain generally changes by only 1°C to 2°C per week. In the fall, conditions for insect population growth remain favorable longer in large bins than in small bins. Aeration can make grain temperature less suitable for insect population growth (Cuperus et al. 1986). Because grain temperature is one of the most important factors determining if and when insect populations will reach economic injury levels, aeration is an extremely effective control measure. Below 20°C, population growth rates are low for all of the major pests of stored grain. The timing of fall aeration can have a strong effect on the predicted population growth of the lesser grain borer (Figure 4). Population densities increase exponentially before aeration, but their densities generally begin to level off soon after beginning aeration. The earlier aeration begins, the less likely insect populations are to reach the economic injury level.

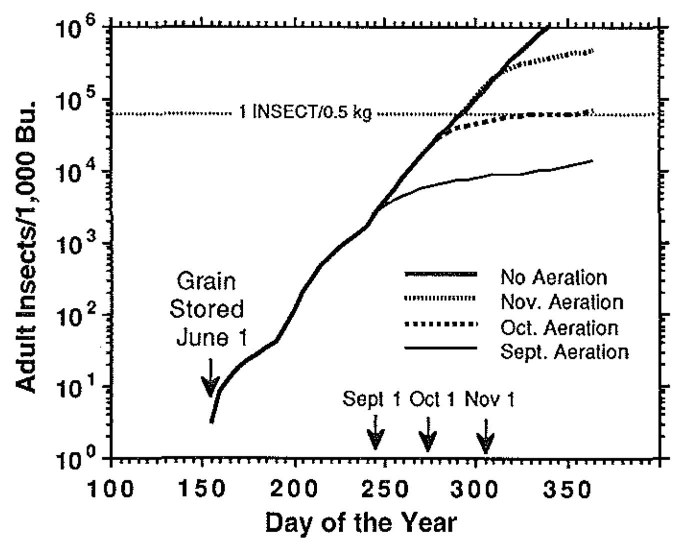

Figure 4. Time of aeration and growth of lesser grain borer populations on wheat stored at 32°C and 14 percent moisture content. (Redrawn from Flinn and Hagstrum, 1990a.)

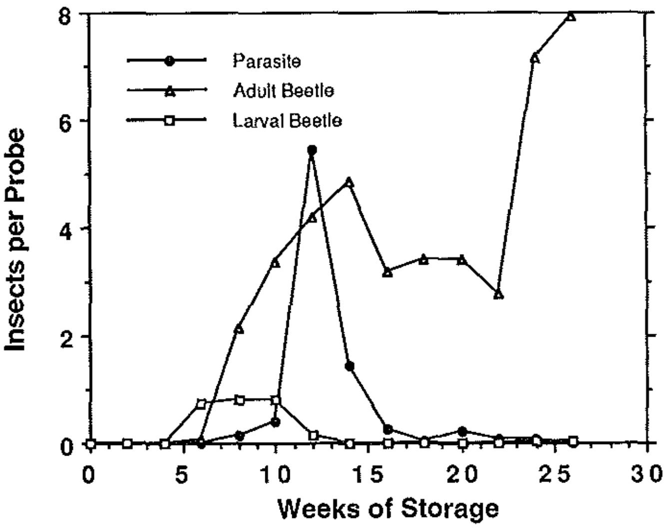

Figure 5. Growth of parasite, *Cephalonomia waterstoni*, and rusty grain beetle populations. (Redrawn from Hagstrum, 1987.)

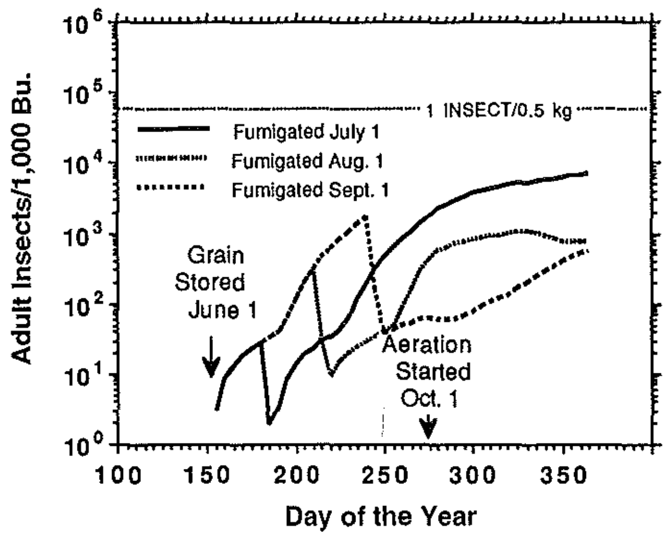

Figure 6. Time of fumigation and growth of lesser grain borer populations on wheat stored at 32°C and 14 percent moisture content. (Redrawn from Flinn and Hagstrum, 1990a.)

Biological Control

Parasites are reported to attack most of the major grain pests and are frequently found in stored grain (Hagstrum and Flinn 1991). The parasite, *Cephalonomia waterstoni* Gahan, can reduce rusty grain beetle population growth by more than 50 percent and prevent them from reaching economic injury levels (Figure 5). Parasites can reduce pest populations early in the storage period, before aeration can lower the temperature enough to stop insect population growth. Unlike chemical control which kills parasites along with hosts, aeration is compatible with parasites. Some parasites can overwinter in the grain and reduce the growth of pest populations as the grain warms in the spring. Parasites can be effective even without the expense of rearing and large-scale commercial releases, and their preservation can be an important consideration in a stored-grain pest management program.

Sanitation

Sanitation is one of the most important and widely used control methods. Infestation of wheat harvested with a clean combine and stored in clean bins is generally initiated by small numbers of insects entering the bins throughout the summer and early fall (Schwitzgebel and Walkden 1944). Cleaning bins is quite effective in increasing the time required for populations to reach the EIL. Removing old grain from inside and around bins reduces breeding sites and the number of insects available to infest newly harvested grain, or to reinfest grain after fumigation. Treating the sides and the floor of a bin with insecticide after cleaning can further reduce insect populations.

Chemical Control

Fumigants have no residual effect; consequently, only the insects present in the grain at the time of fumigation are killed. Insects can reinfest the bin soon after fumigation because they can continue to enter the grain bin until cool fall temperatures reduce flight activity. Simulation studies indicate that waiting to fumigate in August or September, instead of fumigating in July, results in an approximately 20-fold decrease in population densities of the lesser grain borer at year-end (Figure 6). Decrease occurs because delaying fumigation reduces the time available for population growth after fumigation and before the beginning of cool fall temperatures. Thus, delaying fumigation until August may result in better population control, provided that insects do not exceed the economic injury level before August.

Chemical insecticides applied to grain as grain protectants can substantially reduce insect populations, but they are generally applied as grain is first augered into the bin—a time when it is difficult to know whether insect populations will reach the economic injury level. In simulation studies, the predicted numbers of internal feeding species,

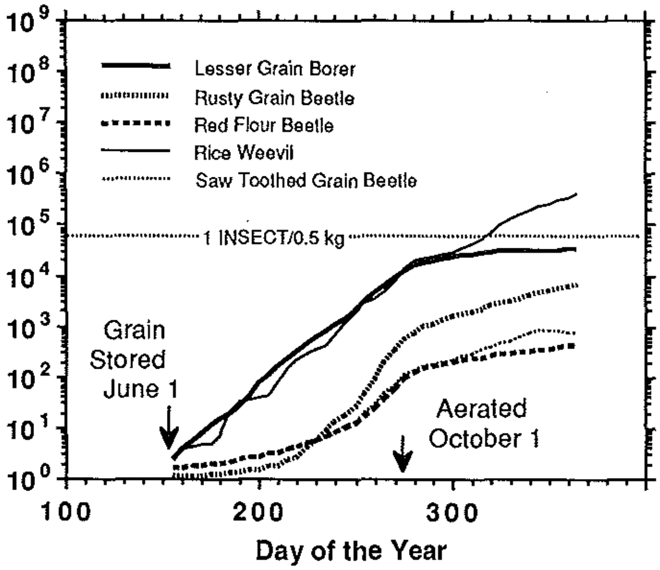

Figure 7. Insecticide application and population growth of different species on wheat stored at 32°C and 14 percent moisture content. (Redrawn from Hagstrum and Flinn, 1990).

lesser grain borer and rice weevil, are much less affected by malathion than are the three external feeding species (Figure 7). Of the two internal feeders, the population size of the rice weevil is more affected by malathion than that of the lesser grain borer.

Area-wide Control

Area-wide management programs seek to reduce insect pest populations in a region over time, and thus reduce the costs of pest control (Bellows 1987). Such programs may be particularly important for stored-grain insect pests, because these pests are moved through the marketing system with the grain (Smith and Loschiavo 1978). This allows management decisions made at any point in the system to affect decisions made elsewhere.

With stored grain, the simplest area-wide management program might include all of the bins on a farm and spillage outside bins (Sinclair and Alder 1985). Such area-wide control is important because stored-grain insects can readily move from bin to bin or from spillage to bin.

In the United States, the wheat harvest begins in the south in June and ends in the north in August (Hagstrum and Heid 1988). This means that wheat is generally stored two months longer in the south than in the north, before cool fall weather reduces insect population growth rates. An optimal area-wide pest management program would be to store wheat longer in the north than the south. This occurs naturally to some extent. Prices are higher in June when wheat is harvested in the southern states than in July when wheat is harvested in the middle states, thus promoting the earlier sale of southern wheat.

An optimal pest control program would detect and control insects before combining wheat lots with different insect infestation levels. Because the cost of control is greater for treating larger quantities of grain, control costs are increased when uninfested and infested grain are mixed.

IPM Program

Grain storage date, grain moisture, sanitation, and aeration are important considerations in designing an IPM program (Table 1). Managers usually do not have control over the grain storage date, but they can decide to use proper sanitation and aeration.

Initial grain moisture at harvest can also be lowered by harvesting the grain as dry as possible. Mature grain should be given enough time to dry before harvest begins. Harvesting should begin late enough in the day so that grain is not wet from dew, and harvesting should not resume too soon after a rain.

Setting the combine to minimize grain breakage, foreign material, and chaff will ensure that a build-up of this

Table 1. Low-risk storage period during which insect densities are likely to be below detectable levels (two insects per kilogram of wheat), as predicted by simulation models.

Moisture	Sanitation[a]	Aeration[b]	Low-risk Period When Wheat Is Stored in: June	July	August
14 %	Yes	Yes	90 days	90 days	through winter
14 %	No	Yes	65 days	65 days	75 days
14 %	Yes	No	90 days	90 days	90 days
14 %	No	No	65 days	65 days	65 days
12 %	Yes	Yes	110 days	through winter	through winter
12 %	No	Yes	80 days	80 days	through winter
12 %	Yes	No	110 days	110 days	120 days
12 %	No	No	80 days	80 days	85 days
10 %	Yes	Yes	through winter	through winter	through winter
10 %	No	Yes	85 days	through winter	through winter
10 %	Yes	No	160 days	165 days	through winter
10 %	No	No	115 days	115 days	125 days

[a]Proper bin sanitation is followed, and bin is not located next to an infested bin.
[b]Assumes aeration begins in September or early October, grain is uniformly cooled to below 20°C, and bin size is 3,000 to 5,000 bushels.

material in the spout line does not result in areas that are difficult to cool by aeration. Cleaning grain before storage and using a spreader to load grain into a bin will further minimize aeration problems.

Grain stored in June often has a shorter low-risk storage period (during which insects are unlikely to be detected) than grain stored in August, and thus is more likely to be fumigated (Table 1). An alternative would be to sell the grain within the low-risk storage period, which would save the cost of fumigation. The low-risk storage periods are much longer for grain stored at 10 percent moisture than grain stored at 14 percent moisture.

Sanitation generally extends the low-risk storage period by four to six weeks. Early fall aeration can extend the low-risk storage period even more than sanitation. Although low-risk storage periods can be used in planning an IPM program, sampling grain for insects will still be necessary to be certain that insect infestation will not reach unacceptable levels. For example, sampling is important when seasonal changes in grain moisture content occur during storage, and when nearby sources of insect infestation are overlooked during cleaning.

New Technologies

In the future, expert systems may assist managers in making pest management decisions. Expert systems are computer programs that attempt to mimic the ability of an expert to make relatively complicated decisions. Table 1 is an adaptation of some of the rules used in the expert system, Stored Grain Advisor (Flinn and Hagstrum 1990b).

This expert system can obtain information on insect density by directly accessing acoustical sensors that are placed in the grain. Early in the storage period, acoustical sensors can provide information on insect densities to the expert system so that it can predict future population growth and the need for control. This expert system could even automatically control some pest management actions, such as aeration. While expert systems and acoustical detection technologies represent the future of stored-grain IPM systems, sufficient information and sampling technology exists today for stored-grain managers to benefit from using IPM principles.

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28

Automatic Sample Inspection and In-Bin Monitoring of Stored-Grain Insects using Acoustical Sensors

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Dennis Shuman, USDA-ARS, Insect Attractants, Behavior and Basic Biology Laboratory

Insects produce sounds as they move through stored grain and feed on or inside kernels of grain. The idea of detecting insects in fruits and grains by amplifying their feeding and movement sounds was conceived as early as the mid-1920s (Brain 1924). However, technical difficulties prevented early workers (Street 1971) from developing practical systems.

Acoustical detection is now practical as a result of the development of inexpensive computers, better band-pass filters, and high-gain, low-noise amplifiers. Webb et al. (1988) described a system which detects these sounds in grain samples and converts them to electrical signals (Figure 1). Substitution of a piezoelectric sensor (Hagstrum et al. 1990) for the microphone used in the Webb et al. (1988) system provides a less expensive and more durable system. Hagstrum et al. (1991) developed and demonstrated the effectiveness of an automatic, in-bin insect monitoring system in five bushel (0.135 ton) lots of wheat. Because the number of times that sounds are detected increases as the number of insects infesting grain increases (Figure 2), insect infestation levels can be estimated from the number of times that insect sounds are detected. The number of times that insects are detected also depends upon insect size (Hagstrum and Flinn 1993). Large insects evidently produce more powerful sounds, can be detected from further away, and are thus detected more often than small insects. Rice weevil and red flour beetle were detected almost twice as often as lesser grain borer. Rusty grain beetle and sawtoothed grain beetle are much smaller and more difficult to detect.

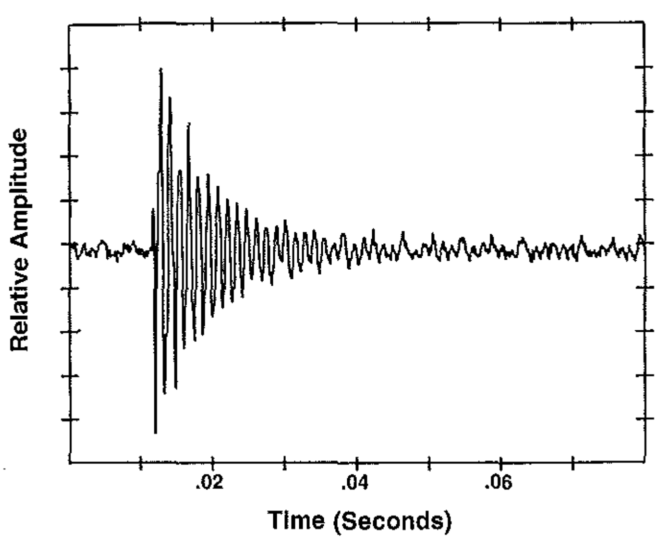

Figure 1. Amplified sound signal of a rice weevil larva feeding in a kernel of wheat.

The grain industry currently checks grain for insect infestations by removing samples either from a storage bin or from the grain stream as a bin is loaded or unloaded. The insects sieved from these grain samples are then counted. This procedure limits detection to externally feeding larvae and adults, since internal feeding larvae are not visible. An acoustical inspection method can determine the number of insects, including internal feeding larvae, in grain samples. Stored grain can also be continuously and automatically monitored for insect infestations without removing samples by using acoustical sensors permanently installed in storage structures.

Acoustical methods are well suited to the grain storage and milling industries' need for routine inspection of grain samples for insects. The most accurate inspection system determines the number of insects in a sample by counting the number of locations emitting sound (Shuman et al. 1993). A computerized system determines the number of locations from the relative arrival times of each sound at several sensors (Figure 3). When coupled with an automatic grain sampling device, this equipment could signifi-

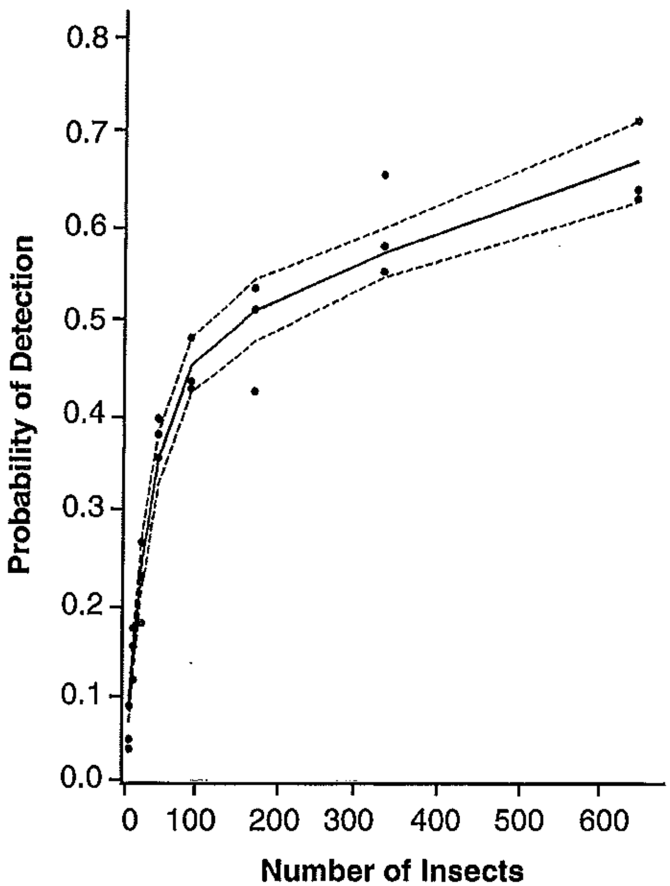

Figure 2. Relationship between insect density per five bushels of wheat and the probability of detecting insects with an acoustical sensor (from Hagstrum et al. 1991). The dashed lines show the 95 percent confidence intervals.,

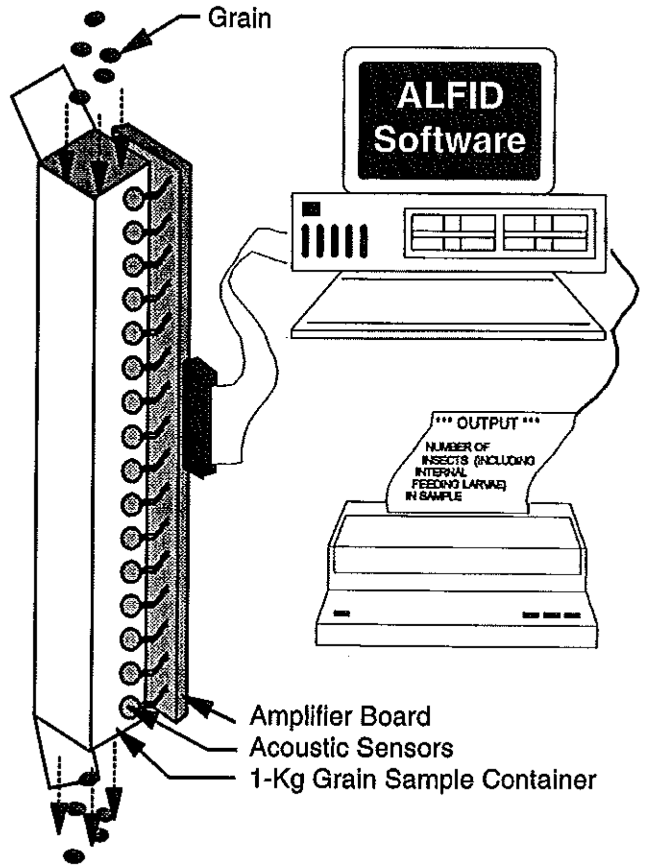

Figure 3. User's view of the acoustic location fixing insect detector (ALFID) system for determining the number of insects in grain samples (from Shuman et al. 1993).

cantly reduce the labor required for insect detection, as well as quantify previously undetectable larval infestation.

An automatic, in-bin insect monitoring system can provide farmers or elevator managers with accurate and up-to-date information on the infestation levels in each grain bin (Figure 4). This system is currently being tested in bins storing 2,400 to 4,000 bushels (65 to 110 tons) of wheat (Hagstrum et al. 1994). Acoustical sensors are mounted on cables similar to the thermocouple cables currently being used. Computer software estimates the number of insects from the number of times each sensor detects insect sounds. The number of times that insect sounds were detected increased by one each time insect density increased by 0.3 insects per kilogram of grain. The acoustical sensors detected insects 16 to 31 days earlier than grain trier samples. With the automated system, a computer in the main office could provide a list of the insect infestation levels in each bin. Insect population growth models can use this information to forecast which bins will need insect control, when control will be needed, and the expected effectiveness of a number of different control measures (Hagstrum and Flinn 1990). This information could be useful in deciding which grain to sell first or in making sure that grain with different insect infestation levels is not combined to fill an order. By networking computers, individual lots of grain could be followed as they moved through the marketing system, and insect control measures could be applied at the most appropriate time.

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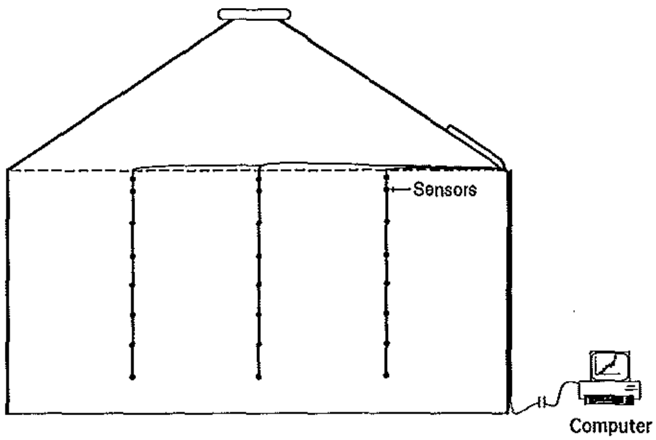

Figure 4. Schematic representation of an automatic in-bin insect monitoring system that uses acoustical sensors.

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29

Ecology of Insect Pests of Stored Wheat

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Insect ecology is the study of factors that regulate insect distribution and abundance. With an understanding of the ecology of insects in the wheat marketing system, we should be able to more effectively use pest control measures, such as grain turning and aeration, based upon natural population regulating factors. With mathematical models that predict insect population growth, managers can forecast when insect control will be needed. Some of the studies done in the United States and Canada are reviewed to provide an overview of the ecology of insect pests in these wheat marketing systems. Much of this discussion should apply to insects infesting other grains.

Insect Species

The flat and rusty grain beetles are the most common species that infest stored wheat, and the lesser grain borer and rice weevil are the most damaging. The rice weevil is more likely to be found in wheat stored at the elevator than in wheat stored on the farm. The red flour beetle and sawtoothed grain beetle are found less frequently, but they can reach high densities. Large numbers of hairy fungus beetles and foreign grain beetles are commonly found soon after grain is stored, but these species often disappear. Indianmeal moth adults are commonly seen flying in the bin headspace and larvae spin silk that is visible on the surface of the grain, but this species generally is not detected when grain is sold. More information about these stored-product insects is available in Chapter 13.

Initial Infestation

Insects are generally not found in newly harvested wheat when it is stored on the farm (Hagstrum 1989) or delivered to the elevator (Chao et al. 1953). Insect flight activity in the vicinity of grain bins on the farm is extensive and small numbers of insects enter bins each day (Schwitzgebel and Walkden 1944). Grain is more likely to become heavily infested if a bin is close to other bins storing infested grain. The dispersal of rusty grain beetles (Hagstrum 1989) and red flour beetles (Figure 1) into the grain mass results in an exponential decrease in the number of insects from top to bottom. Unpublished data from this study showed that lesser grain borer is less mobile and remained near the surface in the center of the bin. In one case, a rusty grain beetle infestation also started at the bottom of the bin, probably as a result of a residual infestation that had not

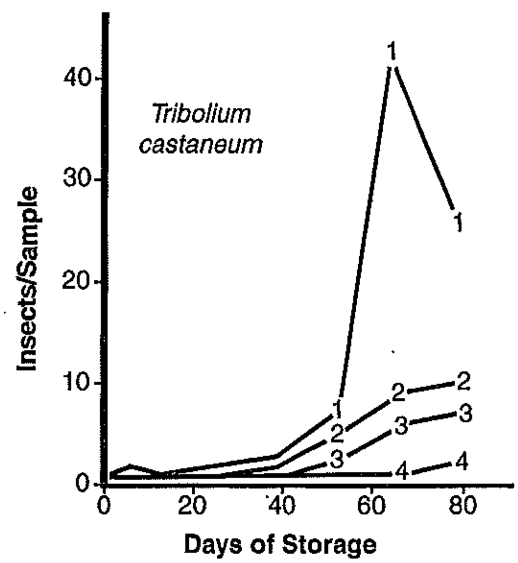

Figure 1. Distribution of red flour beetle adults from top (1) to bottom (4) one-meter layers of wheat in a 3,000 bushel bin on farm based on unpublished data from Hagstrum (1989) study.

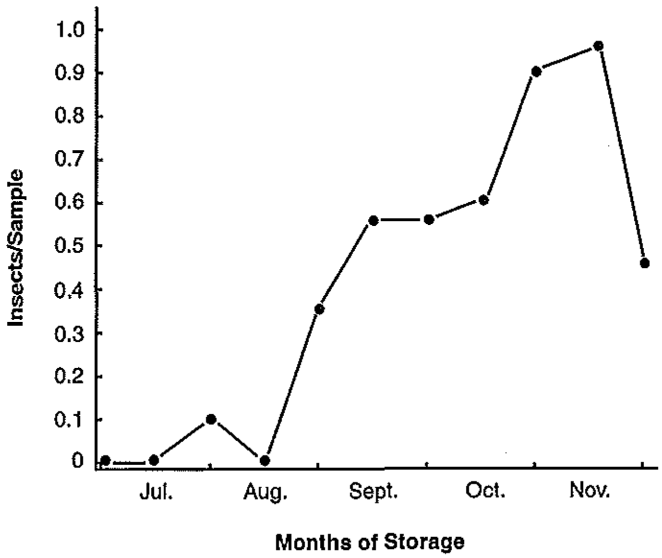

Figure 2. Seasonal trends for rusty grain beetle adults in 3,000 bushels of wheat stored on farm. (Redrawn from Hagstrum 1987.)

been cleaned out prior to storage. The grain residues left in bins are often infested by small numbers of insects (Barker and Smith 1987).

Population Growth Rate

Insect population growth is most rapid when grain is warm and moist. Managers can forecast when insect control will be needed by using mathematical models to predict when insect populations will grow to unacceptable levels. Models predicting insect population growth rates over a broad range of grain temperature and moisture conditions are available for five of the most important pest species (Hagstrum and Throne 1989, Hagstrum and Flinn 1990). These models predict insect population growth by calculating the effects of grain temperature and moisture on insect developmental time and egg production.

Insect numbers are reduced by grain handling. Muir et al. (1977) found that 61 percent of rusty grain beetle larvae and 83 percent of adults were killed when grain was moved with an auger. Bahr (1975) found that more than 90 percent of granary weevils, rice weevils, rusty grain beetles, lesser grain borers, red flour beetles, and sawtoothed grain beetles in grain were often killed by pneumatic conveying.

Seasonal Trends

Insect populations infesting grain stored on farms (Figure 2) or at elevators (Smith 1985) and grain received at ports (Figure 3) increase steadily over the summer until the grain begins to cool in the fall. The time during which temperatures are suitable for population growth is shorter for wheat harvested in Canada in August than for wheat harvested in Texas in May. During summer, grain temperature does not vary much, and bin to bin variation in population growth rates may be determined primarily by grain moisture. In the fall, the grain mass cools from the outside to the center, population growth rates begin to decrease, and temperature gradients across the grain mass are as large as 20°C (Hagstrum 1987). In the fall, population growth rates are influenced more by temperature and vary between locations in the grain mass (Flinn et al. 1992). Without aeration, temperatures will remain suitable for insect population growth for a longer time in large grain masses than in small.

Population Age Structure

The changes in the proportion of the insects in different developmental stages can be important to pest management. Figure 4 shows the changes in the stage structure of a rusty grain beetle population over time. After several generations, populations approach a stable age distribution, with a ratio of 15 immatures for every adult. Because

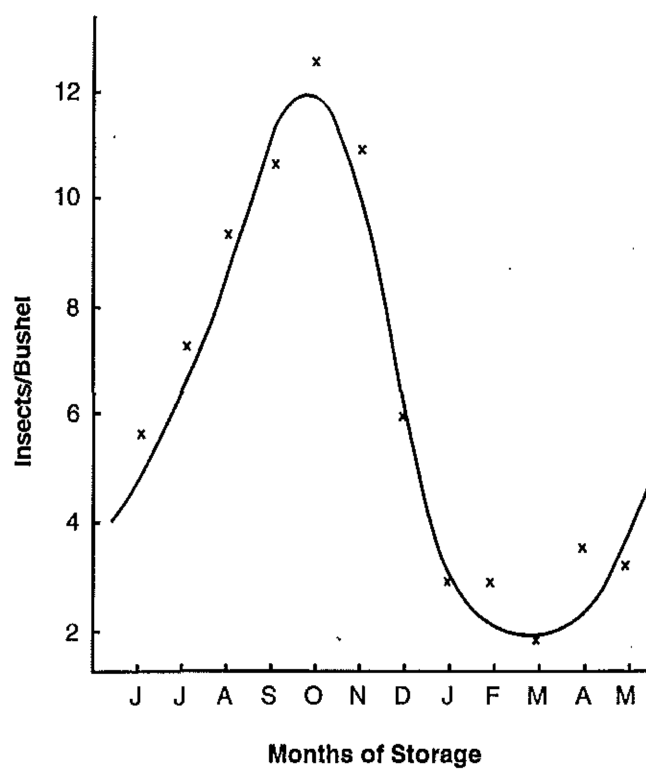

Figure 3. Seasonal trends for lesser grain borers in wheat received at ports. (Redrawn from Hagstrum and Heid 1988.)

only the adults in grain samples are generally counted, actual insect population densities are often underestimated. Fumigating when egg and larval stages are lowest would also be beneficial, because these are the stages that are most resistant to fumigant.

Grain Marketing System

The rate at which grain flows through the marketing system is important because insects are moved along with the grain. In the United States, the elevator system can be considered a pipeline that is filled as farmers sell grain and is emptied through the milling and export of grain (Hagstrum and Heid 1988). The time that it takes to move grain through the system is the time available for insect population growth. Growth rates will vary with seasonal changes in grain temperature and the numbers of insects are reduced by handling each time grain is moved to a new location. The seasonal changes in air temperature in the fall are similar throughout the wheat belt and this results in similar changes in grain temperature. Also, average grain moistures do not change as grain moves from farms to ports, although the range of grain moistures is narrowed by the mixing of grain as it moves through the system. As a result of these similarities in grain environments, seasonal trends in insect population growth rates will tend to be similar throughout the marketing system.

Other factors will result in local differences in insect populations (Hagstrum and Heid 1988). The moisture content of grain is lower for wheat grown under irrigation on the West Coast and higher for soft wheat grown in the Midwest. Earlier harvest in Texas than Canada results in more time for insect population growth before grain begins to cool in the fall. Differences between locations in the marketing system in the sizes of grain masses, the numbers of times that grain is moved, and the use of pest control will further contribute to regional variation in insect densities.

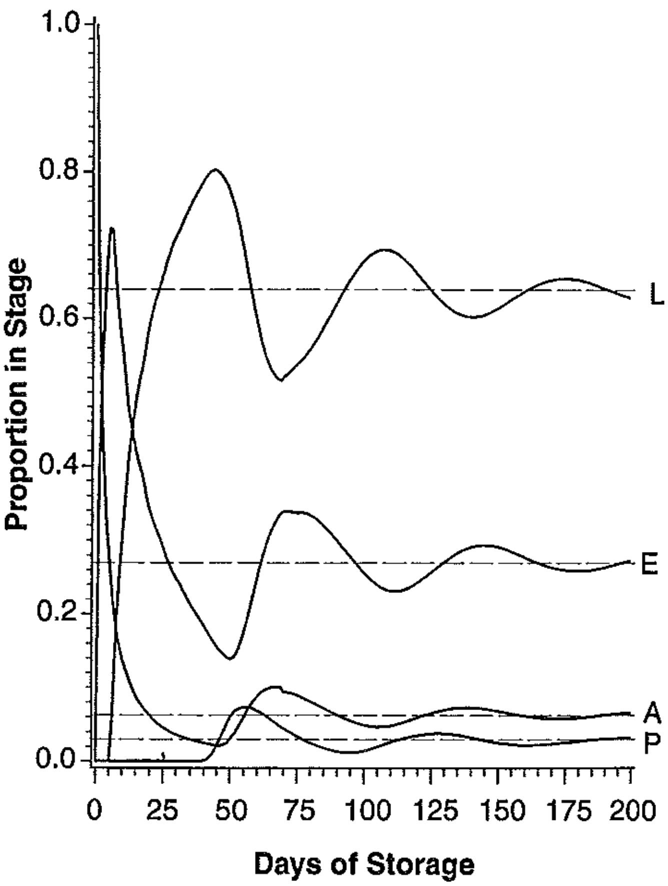

Figure 4. Stage structure of rusty grain beetle eggs (E), larvae (L), pupae (P), and adults (A) predicted from model of Hagstrum and Throne (1989).

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Rev. 1/95

30

Modified Atmospheres: An Alternative to Chemical Fumigants

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Modified atmosphere treatments involve alteration of the proportions of the normal gaseous constituents of air (oxygen, nitrogen, carbon dioxide, and trace gases) to provide an insecticidal atmosphere. Because only the basic components of air are involved and no other chemicals are added, the U.S. Environmental Protection Agency established an exemption from the requirement of a tolerance for modified atmospheres on all raw and processed agriculture commodities (Anonymous 1980 and 1981).

The three most common types of atmospheres used for the disinfestation of stored commodities are:

1) Nitrogen atmospheres in which the concentration of nitrogen is increased to a level that virtually excludes oxygen.
2) Carbon dioxide atmospheres in which the fractional levels of carbon dioxide typically found in air are increased to levels exceeding 60 percent, generally at the expense nitrogen and oxygen normally present.
3) Combustion product gases that result from the burning of a fuel gas (propane or natural gas) under a controlled process which provides an exhaust gas composed of less that one percent oxygen, 10 to 11 percent carbon dioxide, with the balance principally nitrogen.

Carbon dioxide is generally delivered by tanker truck and transferred to an on-site receiver from which the liquid CO_2 is vaporized and passed as a gas through the stored commodity. One pound of liquid carbon dioxide produces 8.7 cubic feet of gas, and about 5 kW of power is required to vaporize 1,000 cubic feet per hour of gas.

Liquid nitrogen may also be vaporized on-site for introduction into stored commodities with one pound of liquid nitrogen producing 13.8 cubic feet of gas. A more common source of high-nitrogen/low-oxygen atmospheres is the use of on-site devices to physically separate nitrogen present in normal air from oxygen and the other trace gases. Two types of devices are used. Pressure swing adsorption (PSA) systems separate nitrogen from compressed air using a carbon molecular sieve which preferentially adsorbs oxygen, moisture, and other trace gases and passes the unadsorbed nitrogen for use as product gas. As the sieve bed becomes saturated with oxygen and other trace gases, the pressure on the sieve material is released, allowing the adsorbed oxygen and water vapor to escape. The PSA system is composed of two identical sieve beds which alternate or "swing" between pressure and release cycles. The other nitrogen separation device uses bundles of semi-permeable membranes formed into tiny hollow fibers. As pressurized air flows through the hollow fibers, oxygen, water vapor, and the trace gases permeate through the fiber walls and the remaining nitrogen passes through the hollow fibers where it is collected for use.

Combustion product gases are produced by exothermic gas generators which provide a low-oxygen exhaust atmosphere through the ignition of a fuel gas and air (at a ratio of about 10 parts air to 1 part fuel) under a controlled combustion process. Combustion takes place in a water-cooled, refractory-lined chamber from which the exhaust product gas is cooled and dried before use. Composition of the product gas is typically less than one percent oxygen, with about 11 percent carbon dioxide and the balance principally nitrogen. Safety overrides automatically shut down the system if any abnormalities develop during operation.

Each of these various modified atmospheres are lethal to all life stages of the common insect species that infest stored grain and processed commodities. The lethal effect, however, is both temperature and time dependent, and varies between insect species and their specific stage/ age of development. In general, pupae are the most tolerant and early larval stages the most susceptible. Eggs which are often highly resistant to chemical fumigants are more readily susceptible to modified atmospheres. When grain temperatures are near 80°F (27°C), most insect species that live outside of the grain kernel will be killed following exposures of four to five days. Internally developing insects, such as the weevils (*Sitophilus* spp.), require longer exposure periods of 10 to 14 days to be effective. At temperatures exceeding 90°F (32°C), the exposure period may be correspondingly reduced. When grain temperatures fall below 70°F (21°C), much longer exposures are required to achieve control, and treatments below 60°F (15°C) may require a treatment time for some insect species beyond practical time limits.

Immobilization of insects occurs rapidly after exposure to modified atmospheres and all activity (feeding, mating, and dispersal) is suspended during the period of exposure. Severe physiological damage has been observed among insects surviving sublethal exposures to modified atmospheres, with immature stages often failing to develop normal adult characteristics and adults producing nonviable eggs.

Modified atmospheres have been used extensively to create storage environments to maintain the keeping qualities and growth characteristics of several types of fruits, feeds, seeds, vegetables, and ornamental plants. Studies have also examined the possible long-term effects of modified atmospheres on functional and end-use processes, such as flour yield, bread making, cooking, and brewing, as well as other changes which might affect taste, texture, or germinative capability. These studies have shown that neither low-oxygen nor CO_2-rich atmospheres have any significant detrimental effects on the overall storability of cereal grains (Banks 1981, White and Jayas 1992). It has also been observed that the storage of high-moisture grain under modified atmospheres has shown positive effects by slowing germination loss, maintaining quality longer than normal air storage, and inhibiting (but not preventing) fungal growth.

Modified atmosphere treatments of bulk stored commodities is essentially a two phase process. In the first (displacement) phase, a sufficient gas volume is introduced (generally at the base of the storage) to push out the lighter, normal air within the grain mass and from the overhead space above the grain surface. This process is often referred to as plug-flow displacement. Typically, about 35 to 45 percent of the area occupied by stored grain is air. Once displacement of the existing air is achieved, the volume of modified atmospheres released into the storage is reduced to a maintenance or second phase, which sets the rate of input at a level sufficient to sustain displacement by offsetting leakage and preventing the ingress of outside air.

A modified atmosphere "system" design matches output of the system to the type of commodity and storage structures being treated, and provides operational flexibility and safety requirements necessary for its use in both grain handling and food processing operations. The most critical factors affecting the successful utilization of modified atmosphere systems are the relative gastightness of storage structures and the temperature of the commodity under treatment. Grain structures do not have to be "hermetically sealed" to be effectively treated with modified atmosphere systems, but bin walls, drawoffs, fill-spouts, and vent openings must be adequately sealed to permit the plug-flow passage of the modified atmosphere through the grain mass in an efficient displacement manner. Displacement of existing normal air typically requires an input of about one and a half times the existing air volume within the bin. Once the existing air has been displaced, the principal cost factor in the operation of the system is the rate of maintenance input required to sustain displacement throughout the exposure period. In moderately sealed structures, maintenance displacement has been sustained with hourly inputs of less than two percent of the existing air within the structure. After an effective maintenance input rate has been established for a particular bin, the remaining output capacity of the modified atmosphere system becomes available for subsequent treatment/maintenance of other bins in the storage complex. The most important considerations in sizing a modified atmosphere system to a particular storage location is to ensure that all the modified atmosphere being produced is effectively utilized in either the displacement or maintenance phases, and that sufficient output capacity is available to meet the time constraints and varying storage volumes typical of grain handling operations.

Retrofitting existing grain structures to a higher level of gastightness is a key cost factor in the adoption of modified atmosphere technology. However, improved gas retention may also become a necessary prerequisite for the continued authorized use of aluminum phosphide, if future restrictions are placed on the uncontrolled release of phosphine gas either during or after completion of a fumigation.

The "cost" of modified atmosphere technology has yet to be fully determined. Cost evaluations for conventional chemical materials are typically based on the weight or dilution volume required for treatment of a prescribed volume/weight of commodity. Cost associated with modified atmospheres will involve a much wider range of factors, all of which must be assessed in the final cost analysis. For example, Jay and D'Orazio (1984) reported an average treatment cost for carbon dioxide of 30 cents per ton of grain (about 0.9 cents per bushel), based on delivery costs of liquid CO_2 to various treatment sites. However, when other necessary costs such as rental or ownership of an on-site receiver for storage of the liquid CO_2 and energy costs for vaporization of the CO_2 are factored-in, the total cost package makes carbon dioxide treatments more expensive than conventional chemical fumigants. Similarly, modified atmosphere systems based on devices such as PSA units, diffusion membranes, or gas generators require a substantial capital investment, in addition to the cost of consumables (electricity and/or fuel) and maintenance required for their operation. Soderstrom et al. (1984) placed projected costs for insect control in bulk stored raisins using a low-oxygen, inert atmosphere generator at a point between industry reported costs for methyl bromide and those reported for phosphine treatments. Their analysis included fixed costs on the purchase of a generator and estimated variable cost on its operation and maintenance. However, actual cost data on day to day operations of modified atmosphere devices, especially over an extended period of time, are not available. Overall experiences with modified atmospheres is still extremely limited, and those industries who are operating modified atmosphere equipment in their pest management programs generally consider such information proprietary to their specific operations.

It should also be recognized that for most industrial gas suppliers and equipment manufacturers, movement into the pest management market represents a significant departure from the traditional industrial gas uses in petrochemical production, metallurgical processes, and other food preservation activities. As their experiences in the pest management area increases, equipment designs together with operational methodologies specific to pest control practices will likely become more efficient and cost effective.

Realistically, industries looking for immediate insect treatments that are more cost effective than simply flooding grain stocks with conventional chemical pesticides will not find them among any of the possible alternatives for bulk grain disinfestation (heat, cold, irradiation, or modified atmospheres). However, in today's environmentally conscious world, neither cost nor treatment efficiency are the sole considerations they once were in pest management when a wider variety of chemical options were available. Regulatory actions adversely affecting the continued use of conventional chemical pesticides are moving forward at an alarming rate, and the public perception of chemical pesticide use has become increasingly negative. Yet, the economic consequences of allowing stored commodities to become infested remains unchanged. There are no direct substitutes for chemical fumigants, only possible alternatives. Grain or processed commodity handlers who must rely on fumigations should begin considering what control procedures may be required in the future to make their commodities acceptable to buyers and still be the changes ahead in regulatory requirements. Clearly, alternative insect control procedures such as modified atmospheres will have to be considered by the grain and food processing industries in the years ahead. There simply aren't many choices left.

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Biologicals: Insect Diseases, Insect Parasites, and Predators

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Introduction

Characteristically, stored-product pest control heavily depends on chemicals. Restrictions on pesticide residues in food, increasing costs of chemicals, and development of resistance to insecticides by storage pests have stimulated new interest in the potential of biological control. Parasites (synonymous with parasitoids), predators, or diseases have often been observed to greatly reduce pest populations in stored commodities, but these occurrences are sporadic. Parasites and predators are limited by the use of protectants and fumigants in commodity storage. Pathogens should be unaffected.

Advantages of Biological Control

Biological control in commodity storages offers unique advantages. Biological agents leave no harmful chemical residues on the commodities, are harmless to humans, and can be applied by relatively unskilled workers. An additional long-term advantage is that stored-product pests (hosts) are not known to develop resistance to parasites or predators. Biological control agents for storage pests usually are small, have short life cycles and high reproductive potentials, and populations can be self-perpetuating. Pathogens are probably compatible with beneficial insects and may even be spread by the activities of parasitic insects.

Disadvantages of Biological Control

Parasites of stored-product pests may be too host-specific to eliminate multi-species infestations. Predators are more general feeders and probably would enhance parasite releases. Biological agents are slower-acting than most chemicals. Effective use of biological agents may require frequent releases. At present, biological control may be more expensive than traditional chemical controls. This situation may change with mass-rearing, development of artificial diets, and availability of commercial suppliers. Most biological agents are incompatible with chemical protectants, so both methods cannot be used simultaneously. However, fumigation could be synchronized with biological releases, if necessary.

At present, candidate parasites and predators are sensitive to pesticides, but resistant strains exist in nature and could be colonized commercially (Baker 1994, Baker and Weaver 1993). A potential disadvantage is increased contamination of the commodity by insect fragments from large numbers of released beneficial arthropods. This might preclude releases of beneficial insects in or around manufactured food products that are not well packaged. In farm-stored or bulk-stored agricultural commodities, cleaning before processing could eliminate the contamination.

Application Techniques

Application of biological control for stored-product pests is a preventive treatment. Application techniques include inundation, inoculation, and augmentation. Of these, inundative release of large numbers of beneficials at frequent intervals is most likely to be effective. Inundative releases should begin in the empty storages before the commodity is placed inside and should continue through the storage season. If some biological control agents are already present, these can be augmented by releases of the same or complementary species. Inoculation involving release of relatively small numbers of beneficial species early in the storage season may provide an adequate level of pest control in some storage situations (Wen and Brower 1994).

Use of Pathogens for Insect Control

Application of insect pathogens is similar in theory and practice to the use of grain protectants. Pathogens formulated as dusts or wettable powders are applied to the grain as it is placed into the storage, or used as a top-layer treatment to grain already in storage. In either case, pathogens are most effective when applied at the time grain is first placed into storage. Many pathogens, including viruses, bacteria, protozoa, and fungi, infect stored-product insects (Arbogast 1984). Some organisms, especially the protozoa, adversely affect the developmental success, the fecundity, or the longevity of infected hosts. A few are highly pathogenic. Most developmental work has involved viruses and bacteria.

Bacteria

One product, Dipel®, has been registered for commercial use against moth larvae. This product contains a rod-shaped, spore-forming bacterium, *Bacillus thuringiensis* (*B.t.*). The preparation is applied in water into the grain stream as the last four-inch layer of grain is augured into the bin, or the mixture is applied to the grain surface and mixed with a scoop or rake to a depth of four inches. *B.t.* is most effective when applied to newly harvested grain before large moth populations can build up. The treatment persists for at least one year in storage (Kinsinger and McGaughey 1976). Good control was observed in laboratory and pilot scale tests, but control was more difficult to achieve in full-sized grain bins (McGaughey 1976). This treatment is effective against all pyralid (phycitid) moth larvae, less effective against the interval larvae of the Angoumois grain moth, *Sitotroga cerealella*, and not at all effective against stored-product beetles. An intensive search is in progress to find strains of *B.t.* that are effective against beetles.

Unfortunately, as with chemical pesticides, resistance to *B.t.* has appeared in at least two species of moths—the Indianmeal moth, *Plodia interpunctella*, and the almond moth, *Cadra cautella* (McGaughey and Beeman 1988). In some populations, resistance develops after only a few generations and can reach levels that result in control failures. Users should be alert to the possibility of resistance and its potential impact on control programs. *B.t.* formulations are apparently compatible with most chemical control practices used in the grain industry and with parasites and predators, since these beneficials are less affected by Dipel.

Viruses

Among viruses which infect storage insects, the granulosis and nuclear polyhedrosis groups appear to have the most potential (Arbogast 1984). There is commercial interest in developing a granulosis virus for use against the Indianmeal moth in dried fruits and nuts (Vail and Tebbets 1990), but researchers caution that various Indianmeal moth strains differ in their susceptibility to this virus. Aqueous and dust formulations of this virus effectively controlled the Indianmeal moth in stored corn and wheat (McGaughey 1975). The virus was compatible with malathion and most fumigants, and the efficacy was little reduced after one year of storage (Kinsinger and McGaughey 1976).

Nuclear polyhedrosis viruses are often cross-infective between moth species, and they have been isolated from both the almond moth and the Indianmeal moth. They are effective against both species in laboratory tests, but little developmental work has been done (Arbogast 1984).

Parasites as Biological Control Agents

Note: Photographs of insects are located in Chapter 13.

The concept of using parasites for the control of stored-product insects is not a new one. In 1911, parasites were sold in Britain for moth control in flour mills (Brower 1990). There was considerable interest in this approach until the development of synthetic insecticides during the 1940s. Little more was done until the 1970s, when the Agricultural Research Service of the USDA initiated a research program that continues today.

Recently, the Federal Register (Anonymous 1992) published the final rule that allows the release of parasites and predators into stored grain, stored legumes, and structures such as warehouses. The rule makes the use of beneficials subject to regulation by the Federal Insecticide Fungicide and Rodenticide Act (FIFRA) and exempt from the requirement of a tolerance in food products. The Food and Drug Administration (FDA) will continue to use its criteria for enforcement of insect fragments in food, and the Federal Grain Inspection Service (FGIS) is still responsible for inspecting and grading the grain.

Moths

Much of the research to date has focused on the efficacy of parasites for control of stored-product moth pests (family Pyralidae) because 1) they are the most destructive pests, and 2) effective parasites of the moths were available. Many laboratory tests have been conducted, but few field-scale tests have been evaluated. For example, *Trichogramma pretiosum*, egg parasites of stored-product moths, released at a rate of 3,000 each week for 14 weeks into small metal buildings containing infested peanuts, suppressed almond moths by 41.7 percent and Indianmeal moths by 57.4 percent. Damage to peanuts was reduced 50 percent (Brower 1988).

The braconid wasp, *Bracon hebetor*, parasitizes late-stage larvae of all stored-product pyralid moths. *B. hebetor* released into a warehouse room containing infested food debris reduced the almond moth population by 97 percent (Press et al. 1982). Keever et al. (1986) released 324,000 *B. hebetor* bimonthly from October through January into two commercial warehouses containing farmers' stock peanuts. Reduction of moth infestation was 69 percent greater in the biocontrol warehouse than in a similar warehouse treated with malathion. Peanuts protected by the *B. hebetor* had 25 to 50 percent less damage than those in the malathion treatment.

Ideally, an egg parasite should be combined with a larval parasite or a predator. *B. hebetor* complements *Trichogramma* sp. because they compete only indirectly for hosts. When *B. hebetor*, *T. pretiosum*, or both parasites were released in small peanut warehouses infested with Indianmeal moths and almond moths (Brower and Press 1990), Indianmeal moths were reduced by 37.3 percent by *T. pretiosum* alone, 66.1 percent by *B. hebetor* alone, and 84.3 percent by the combination. Almond moths were reduced 96.7 percent, 97.3 percent, and 98.0 percent for the same treatments, respectively. Insect feeding damage to the peanuts was reduced to less than 0.4 percent by the two parasites, compared to 15.8 percent in the untreated checks.

Beetles

Biological control of stored-product beetles is a much greater challenge, since many different species of beetles infest stored products. Parasites tend to be host specific, at least to a genus or to a single family of beetles. Thus, different species of parasites must be reared and released to control the different pests encountered. Fortunately, in any given agricultural commodity, only a few pests directly attack the commodity if it is in good condition. Thus, these pests are targeted for biological control. Beetles are the primary pests of sound bulk grain; therefore, recent research has been directed toward them. Many laboratory studies have yielded promising results, but only a few tests of larger size have been conducted.

M. A. Ryabov (1926) suggested that the artificial propagation and release of a small pteromalid parasite, *Lariophagus distinguendus*, might be used to control weevils in stored grain. In 1955, two independent studies of another pteromalid, *Anisopteromalus calandrae*, a parasite of *Sitophilus* weevils and other stored-product beetles, examined the biology of this parasite with the objective of evaluating its possible use for biological control of pest species (Chatterji 1955, Ghani and Sweetman 1955). Chatterji (1955) speculated that this species might be important in the natural suppression of the rice weevil (*Sitophilus oryzae*); but, due to highly variable results, Ghani and Sweetman (1955) concluded that *A. calandrae* was incapable of controlling granary weevil cultures in quart jars. Williams and Floyd (1971) surveyed corn storages in Louisiana and found that *A. calandrae* occurred frequently in dry corn ears still in the field and in shelled corn in farm storages, but the maize weevil, *Sitophilus zeamais*, was not eliminated by it. They studied the control attainable with single parasite releases under laboratory and semi-natural conditions. The parasite reduced maize weevil populations by up to 95 percent under laboratory conditions and 55 percent under natural conditions from January through June. Recently, serious consideration has been given to the use of *A. calandrae* as a biocontrol agent (Wen and Brower 1994, Smith 1992). In simulated warehouse rooms that contained wheat debris with rice weevils, release of 30 to 50 pairs of *A. calandrae* reduced the weevil population by more than 90 percent, and release of only five pairs reduced the pest population by about 50 percent (Press et al. 1984). In a similar test with larger quantities of infested grain (18 pounds) and grain in small fabric bags, *A. calandrae* significantly suppressed the weevil population (Cline et al. 1985). Suppression of the rice weevil was 76 percent in the loose grain, and uninfested grain in fabric bags was almost completely protected.

Commercial Tests

The first commercial-scale test using biocontrol agents to protect stored grain sorghum was conducted in 1990 (Parker and Nilakhe). A total of 62.2 metric tons of grain sorghum was stored in metal bins (capacity 90.7 metric tons) in September 1988, and three chemical treatments (pirimiphos-methyl, chlorpyriphos-methyl + methoprene, and malathion), parasites and predators, and an untreated check were evaluated for one year. The chemical treatments were applied as the grain was loaded into bins and six times later as a surface treatment during the one-year test period. Parasites and predators were released about every nine days. A total of 12,700 *A. calandrae*, 1,900 *B. hebetor*, 400 *Choetospila elegans*, 1,675,000 *T. pretiosum*, 17,083 warehouse pirate bugs, and some straw itch mites (October and November only) were released during the test. The biocontrol bins tended to have more weevils (two *Sitophilus* species) than the insecticide bins. The biocontrol and malathion bins had significantly greater numbers of the rusty grain beetle, *Cryptolestes ferrugineus*, and the flat grain beetle, *Cryptolestes pusillus*, than the chlorpyriphos-methyl + methoprene, and pirimiphos-methyl bins. The numbers of lesser grain borer, *Rhyzopertha dominica* (perhaps the most destructive pest in the test), per quart of sorghum taken from the top layer of grain were three in pirimiphos-methyl bins, four in the biocontrol, seven in chlorpyriphos-methyl + methoprene, 22 in check, and 23 in malathion bins. A similar trend was observed in samples taken deeper. The percent grain loss was the lowest in the biocontrol bins (2.3 percent), followed by 2.4 percent in chlorpyriphos-methyl + methoprene bins, 2.7 percent in pirimiphos-methyl bins, 3.7 percent in check, and 3.8 percent in malathion bins. The check and the malathion bins had significantly greater grain loss than in the remaining two insecticide and biocontrol bins.

Between April 1988 and December 1989, in a test of integrated biological control applied to commercial-sized bins containing long-grain, rough rice (paddy) (Cogburn and Brower, In Press), *A. calandrae*, *B. hebetor*, and *T. pretiosum* initially did not control rice weevils, lesser grain borers, flat grain beetles, red flour beetles, or Angoumois grain moths. After the bins were sealed, the same parasites, with the addition of the warehouse pirate bug, inhibited populations of these pests, but not the Angoumois grain moth. Grain samples showed population reductions of 89 percent for lesser grain borers, 67 percent for rice weevils, and 97 percent for flat grain beetles. This "integrated system" would probably benefit from the addition of a parasite specific for the Angoumois grain moth, such as *Pteromalus cerealellae* (Brower 1991).

Several other parasites have been identified from stored-product beetle hosts (Brower 1990), but none have been studied adequately. Some of the more promising candidates are:

- *Lariophagus distinguendus*—a parasite of several beetle species that feed internally within grain,
- *Choetospila elegans*—an especially good parasite of lesser grain borers,
- *Sitophilus* weevils,
- cigarette beetles (*Lasioderma serricorne*),
- drugstore beetles (*Stegobium paniceum*), and
- *Dibrachys cavus*—a parasite of a wide range of stored-product beetles.

D. cavus has not been studied to any great extent. Unfortunately, it also attacks many of the primary parasites of stored-product pests.

Several species of parasitic wasps in the family Bethylidae are promising agents for biological control in stored products because of their small size and ability to penetrate the grain mass. Several species associated primarily with stored products may have a rather wide host range. Some species are especially effective against larvae of secondary pests, such as the flat grain beetle, sawtoothed grain beetle (*Oryzaephilus surinamensis*), flour beetles, cigarette beetle, and dermestids. Most studies have concentrated on their biology, but their efficacy as biocontrol agents remains unclear (Flinn 1991).

Predators as Biological Control Agents

Predators differ from parasites in several respects. Both the adult and young of a predator feed on the same prey species, usually killing them in the process, and a number of prey are required for a young predator to complete its development. A wide variety of predators attack stored-product pests, but many of them seem minor in regulating host populations. However, little experimental evidence is available on which to base this opinion. The one exception, the warehouse pirate bug, *Xylocoris flavipes*, has been studied for more than 20 years.

Warehouse Pirate Bug

The warehouse pirate bug will attack almost any small stage of both beetles and moths (Jay et al. 1968). The smaller species of beetles appear to be the preferred prey, but eggs and larvae of most species are utilized as well. The internal grain feeders are not particularly subject to predation because of their protected location.

When 35-quart lots of shelled corn were infested with 20 pairs of sawtoothed grain beetles and predators were added in different ratios, pest populations were reduced by 97 to 99 percent compared to the untreated control (Arbogast 1976). The level of reduction depended on the predator:host ratio. Red flour beetles were suppressed by warehouse pirate bugs in a simulated warehouse (Press et al. 1975). LeCato et al. (1977) showed that populations of the almond moth and of two beetle species did not increase in a room containing grain debris when warehouse pirate bugs were released in small numbers. All three pest populations increased greatly in the room when no predators were released.

Brower and Mullen (1990) released large numbers of the warehouse pirate bug into small peanut warehouses infested with almond moths and Indianmeal moths. Populations of the moths were suppressed 70 to 80 percent during the fall storage season, and no moths were present in the biocontrol treatments during the spring. In a recently completed test (Brower and Press 1992), populations of stored-grain pests infesting grain residues in empty corn bins were affected differently by the release of 50 pairs of the warehouse pirate bug, depending on their size and niche. Large insects, such as late instar pyralid moth larvae and adults, were apparently unaffected. Species such as the *Sitophilus* weevils and the lesser grain borer developing within grain kernels were much less affected than small external feeders. However, small beetle species, including both direct grain feeders and secondary feeders, were reduced by 70 to 100 percent. Thus, the predator shows considerable promise for control of residual populations of several species of small beetles in empty grain bins. If specific parasites were also released for moths and the primary pests, then the whole pest complex might be greatly reduced or eliminated before new grain is placed in storage.

Other Predators

Predaceous beetles in the family Histeridae have been recently examined (Rees 1985, 1987). They decreased populations of the larger grain borer, *Prostephanus truncatus*, by 92.5 to 96.5 percent, depending upon initial pest density (Rees 1985). In a further study, Rees (1987) reported that this predator was most effective against the greater grain borer, less effective against the red flour beetle, and not effective against the maize weevil. The latter finding shows that although predators are usually more universal in their choice of prey than parasites, it is still important to know the relative acceptability of the various target pests to a given predator.

Stored-product Mites

This area of biological control is a relatively new one and most of the published work is of foreign origin (Brower 1990). In general, the most likely candidates for biocontrol of pest mites will be predaceous mites and not insects. The most important predators are mites in the family Cheyletidae. Several studies have demonstrated their ability to control infestations of pest mites, such as *Acarus siro*. Pulpan and Verner (1965) showed the predaceous mite, *Cheyletus eruditus*, often controlled pest mites under natural conditions in Czechoslovakia. Most trials where this predator was introduced into infested grain storages were successful, and these authors formulated specific recommendations for the use of predaceous mites as biocontrol agents.

Conclusions

Biological control will become an increasingly important part of integrated pest management programs to control stored-product insects. Much information is accumulating on the basic biology of stored-product parasites and predators and interactions with their hosts. As yet, little data is available on the efficacy of natural agents in the commercial stored-product environment. Basic research on integrated systems and alternative pest control strategies is urgently needed. Biological control is not a panacea, but the opportunity exists for its application in some commercial storage situations. New developments should make biological control attractive, not only from a philosophical point of view, but from an economic one as well.

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Vertebrate Pest Management in Grain Storage Facilities

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Several vertebrate species can cause problems in grain storage facilities. In particular, house mice (*Mus musculus*), pigeons (*Columbia livia*), house sparrows (*Passer domesticus*) and Norway rats (*Rattus norvegicus*) are common and serious economic pests in Nebraska (Table 1). These species are often called "commensal" because of their close association with humans. Not one of the four species is native to North America—they were imported into the United States from Europe and Asia by colonists in the late 1700s and 1800s. All four species are now found throughout the North American continent. They are not protected by state or federal regulations, as are most other species of wildlife, because of their non-native status and the significant problems they cause. State and local laws should be consulted, however, before any control measures are taken. The following is a brief discussion of the primary vertebrate pests in grain storage facilities and recommended methods for controlling the damage they cause.

Table 1. Percentage of Nebraska Feed and Grain Association respondents who reported experiencing problems with specific pests in 1988 ($n = 102$).

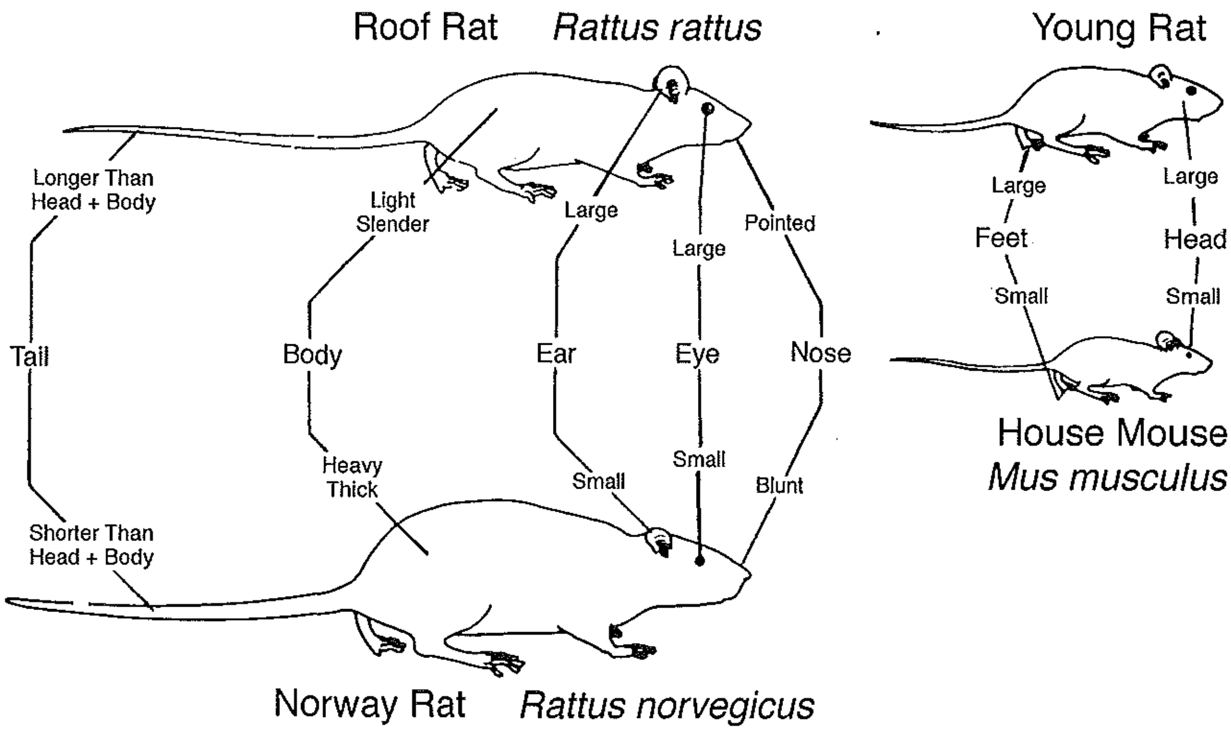
Pest	%
Indian meal moths	82
Granary weevils	65
House mice	**42**
Pigeons	**42**
House sparrows	**30**
Norway rats	**29**
Red flour beetles	27
Sawtooth grain beetles	25
Lesser grain borers	16
Flat grain beetles	15
Starlings	10
Rice weevils	9
Maize weevils	5
Common bean weevils	2
Bats	2
Bran bug	1
Owls	1
Raccoons	1

Mice and Rats

Rodent Biology

House mice are quite small (Figure 1). Adults weigh about one-half ounce and are about five to seven inches long, including a three- to four-inch tail. They are usually light brown to light gray in color and have beady little black eyes. They are excellent climbers and can run up any rough vertical surface. They will run horizontally along wire cables or ropes. Mice can squeeze through openings slightly larger than one-fourth inch across. In a single year, a female house mouse may have five to 10 litters of usually five or six young each. Young are born 19 to 21 days after mating and they reach reproductive maturity in six to 10 weeks. Individuals usually live about nine to 12 months.

Norway rats are medium-sized rodents (Figure 1). Adults weigh about 11 ounces and are about 13 to 18 inches long, including a six- to eight-inch, scale-covered tail. They are light to dark brown in color and somewhat stocky in appearance. Rats have keen senses of taste, hearing, and smell. They will climb to find food or shelter and they can gain entrance to buildings through any opening larger than one-half inch across. Rats have litters



Source:
U.S. Dept. of Health, Education, and Welfare
Centers for Disease Control

Figure 1. Characteristics of commensal rodents.

of six to 12 young, which are born 21 to 23 days after mating. Young rats reach reproductive maturity in about three months. Breeding is usually most active in spring and fall. The average female has four to six litters per year. Individuals usually live 12 to 18 months.

The presence of mice and rats can be determined by droppings, fresh gnawing, and tracks in areas where they are active. Rat runways and burrows may be found next to buildings, along fences, under low vegetation, and among debris and stored materials. Rub marks are often found on walls near holes and active runways. Nests are usually found in sheltered locations and are made of finely shredded paper or other fibrous material. House mice have a characteristic musky odor that identifies their presence. Mice are occasionally seen during daylight hours, whereas rats are seldom seen.

Rodent Damage

Mice and rats consume and contaminate an estimated $8.4 million worth of stored grain each year in Nebraska. One rat can eat about one-half pound of feed per week, but it is the contamination of grain that is perhaps the greatest concern. Rodents contaminate about 10 times the amount of feed and grain that they consume. In one year, a pair of house mice will shed approximately 10,000 droppings and two pints of urine. Mice and rats spread several diseases that affect humans and livestock (i.e., leptospirosis, salmonellosis, swine dysentery) through their feces and urine. The USDA and FDA enforce a threshold of two rodent pellets, hairs, or parts per 1,000-gram sample of grain. Samples that are identified as contaminated by the USDA may be inspected by the FDA and by report quality standards reduced to Sample grade.

Commensal rodents also damage an estimated $8 million worth of farm buildings, equipment, and machinery by their gnawing, burrowing, and nest-building activities. Damage to insulation in environmentally controlled facilities is cause for serious concern. Resultant increased energy costs and reinsulation costs can amount to several thousand dollars lost in only a few years. Rodents also gnaw on electrical wires and plumbing, which can lead to excessive losses due to fire and flooding.

Rodent Damage Prevention and Control

Effective control in grain storage facilities requires an integrated approach that involves three aspects—sanitation, rodent-proof construction, and population reduction. The first two are useful as preventative measures. When a mouse or rat infestation already exists, some form of population reduction is almost always necessary.

Sanitation. All animals need food, water, and shelter to survive. Through good sanitation practices, the availability of these resources can be reduced and the number of rodents that inhabit an area effectively eliminated. It is almost impossible, however, to eliminate all rodents through sanitation. Mice can survive in very small areas with limited amounts of food, shelter, and water. Still, poor sanitation is sure to attract rodents and will permit them to thrive in greater abundance.

Sanitation can be as simple as cleaning up spilled grain around augers, elevators, and bins. Store grain or products in rodent-proof buildings, rooms, or containers whenever possible. Stack sacks of grain or products on pallets with adequate space left around and under stored articles to allow for inspection for signs of rodents. It is difficult to remove all food that rodents can use around grain storage and handling facilities. Therefore, pay particular attention to eliminating places where mice and rats can find shelter.

Remove as much shelter as possible that can be used for hiding, resting, and nesting. Properly dispose of accumulated debris. Mow vegetation around elevators and storage bins. Store lumber, pipes, and miscellaneous equipment on racks, one to two feet above ground.

Mice do not require free water, but rats do if they are feeding on dried grain or feed. Repair any leaky faucets, pipes, or fixtures that provide a source of water. Proper drainage around buildings will limit the amount of standing water available to rodents.

Rodent-proof Construction. The most successful and permanent form of rodent control is to "build them out" by eliminating all openings through which they can enter a structure. It is important to understand the physical abilities of mice and rats to be successful in rodent-proofing. Mice can enter buildings through any openings larger than one-fourth inch across. By gnawing, rats can gain entry through any opening greater than one-half inch across. Therefore, it is important to seal up buildings and bins tightly. Mice and rats can also gnaw through a wide variety of materials, including lead and aluminum sheeting, wood, rubber, vinyl, and concrete block. Use appropriate materials when trying to build rodents out (Table 2). Rodent-proofing techniques discussed here apply both to the construction of new buildings and the modification of existing ones. Rodent-proofing is a good investment. It is less expensive to design a rodent-proof structure than to add rodent-proofing later.

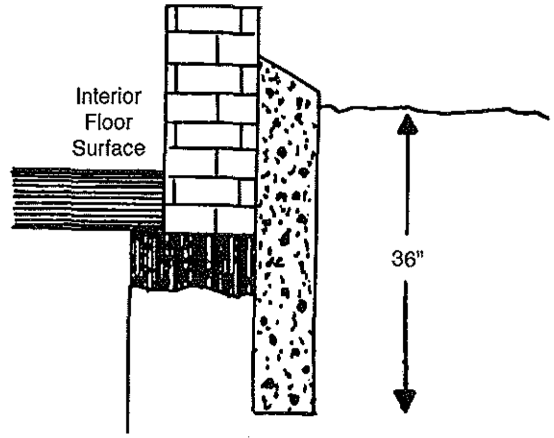


Figure 2. A concrete curtain wall will prevent rats from burrowing under foundations to gain access to buildings.

Table 2. Recommended materials for rodent-proofing.

Concrete: reinforced—minimum thickness of 2 inches; not reinforced—3 3/4 inches.

Galvanized sheet metal: 24 gauge or heavier. Perforated sheet metal grills should be 14 gauge.

Brick: 3 3/4 inches thick with mortar-filled joints.

Hardware cloth (wire mesh): 19 gauge 1/2 x 1/2-inch mesh to exclude rats; 24 gauge 1/4 x 1/4-inch mesh to exclude mice.

Aluminum: 22 gauge for frames and flashing; 20 gauge for kick plates; 18 gauge for guards.

Rodents can burrow beneath the floors or foundations of buildings that rest on pilings or shallow foundation walls. Norway rats can burrow straight down into the ground at least 36 inches. To prevent rat entry by this route, extend foundation or curtain walls below ground at least 36 inches (Figure 2). This also reduces damage from frost. Avoid the use of slab-on-grade construction techniques for grain storage facilities. Rats frequently seek shelter under concrete floors and slabs, where they burrow to find protection.

Rats and mice can climb almost any rough vertical surface, such as wood, concrete, brick, and weathered sheet metal. Rats can jump up to 36 inches vertically and as far as 48 inches horizontally, while house mice can jump as high as 18 inches. A sheet metal band attached to a wall will prevent climbing by rodents, particularly in corners. Rodent guards should be 12 to 18 inches wide, and located 36 inches above ground or floor level. Inspect storage rooms, closets, or other areas where construction may be poorly finished. A common entry point for mice into buildings is through the unprotected end of corrugated metal siding. Cap the ends or install the siding snugly to the sill plate to seal off these openings.

Ventilation openings and windows should be screened with 1/2 x 1/2-inch galvanized hardware cloth. Smaller mesh screen can significantly reduce air flow, become clogged with dust, or freeze over. The use of 1/2 x 1/2-inch mesh is a reasonable compromise between ventilation requirements and rodent control.

All doors should fit tightly. The distance between the bottom of the door and the threshold should not exceed one-fourth inch. Steel pipes make good rodent-proof thresholds and allow doors to swing freely. Install metal flashing on the lower edge of doors. Mechanical door-closing devices save time and help overcome human negligence. Doors that are left open for ventilation should be equipped with rodent-proof screen doors, or the existing door should be modified so the upper half can be left open for ventilation.

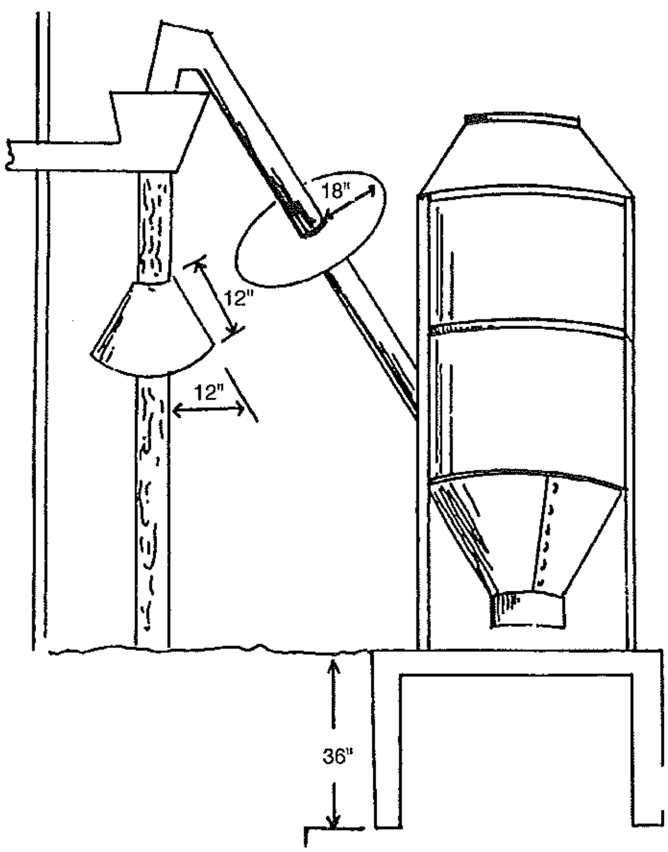


Figure 3. Guards used to prevent rodents from climbing augers, pipes, or wires leading to buildings.

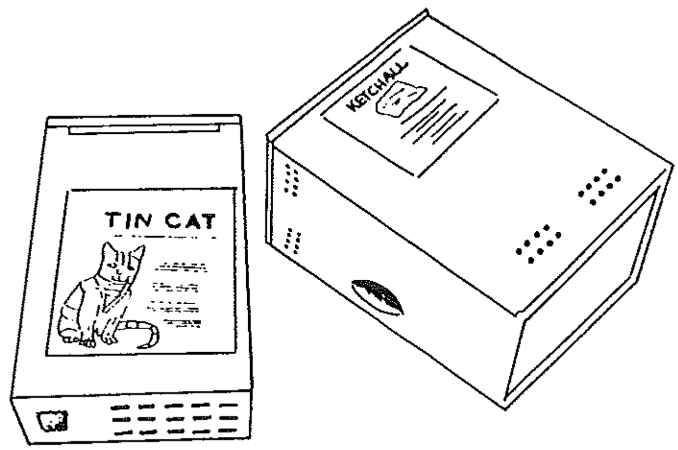


Figure 4. Examples of multiple-catch mouse traps.

Rodent-proofing must also include protective devices on pipes, wires, drains, and other equipment along which rodents can travel. Guards must be wide enough and positioned to keep rodents from reaching the outer margins by climbing or jumping. Cones or discs act as rodent guards on suspended cables, ropes, augers, or pipes (Figure 3). With some ingenuity, you can design rodent guards to fit any given situation. Shields or wire guards made of one-fourth-inch wire mesh are useful in excluding rodents from the interior of feed augers, fan housings, and similar openings. Openings where utilities enter buildings should be sealed tightly with metal or concrete.

Trapping. Although time-consuming, trapping is an effective control method, especially for house mice. Trapping has several advantages: 1) it does not rely on inherently hazardous rodenticides; 2) it permits the users to view their success; and 3) it allows for disposal of the rodent carcasses, thereby eliminating odors that may occur when toxicants kill rodents within buildings.

Wood-based snap traps are simple, inexpensive, and effective. Bait traps with peanut butter if permissible, or set them without bait close to walls, in dark corners, near entryways, and in places where there is evidence of mouse activity. The effectiveness of unbaited traps can be increased by enlarging the trap's trigger. Non-food baits such as cotton balls, which mice will use for nesting material, may increase snap trap success. Traps should be spaced no more than about 10 feet apart in areas where mice are active, since mice seldom venture far from their shelter and food supply.

More common in industry than snap traps are multiple-catch box traps (Figure 4). These are enclosed traps that are capable of catching several rodents in a 24-hour

Table 3. Non-anticoagulant rodenticides commonly used for commensal rodent control.

Common Name	Chemical Name	Percent Active Ingredient Used in Food Bait
Bromethalin (Assault®, Trounce®)	*N*-methyl-2,4-dinitro-*N*-(2,4,6-tribromophenyl)-6-triflouromethyl) benzenamine	0.005 - 0.01
Cholecalciferol, Vitamin D_3 (Quintox®, Rampage®)	9,10-Seocholesta-5,7,10(19)-trein-3-betaol	0.075
Zinc phosphide (ZP®)	zinc phosphide	1.0 - 2.0

Table 4. Anticoagulant rodenticides commonly used for rodent control.

Common Name	Chemical Name	Percent Active Ingredient Used in Food Bait
Brodifacoum (Havoc®, Talon-G®)	3-{3-[4'-bromo(1,1'-biphenyl)-4-yl]-1,2,3,4-tetrahydro-1-naphthalenyl}-4-hydroxy-2H-1-benzopyran-2-one	0.005
Bromadiolone (Maki®, Contrac®)	3-{3-[4'-bromo(1,1'-biphenyl)-4-yl]-3-hydroxy-1-phenylpropyl}-4-hydroxy-2H-1-benzopyran-2-one	0.005
Chlorophacinone (RoZol®, AC 90)	2-{(*p*-chlorophenyl)phenylacetyl}-1,3-indandione	0.005
Diphacinone (Ramik®, Bait Blocks®)	2-diphenylacetyl-1,3-indandione	0.005
Pivalyl, Pindone (Pival®, Pivalyn®)	2-pivalyl-1,3-indandione	0.025
Warfarin (d-Con®)	3-(α-acetonylbenzyl)-4-hydroxycoumarin	0.025
Warfarin + sulfaquinoxaline (Proline®)	3-(α-acetonylbenzyl)-4-hydroxycoumarin + quinoxalinyl sulfanilamide	0.025

period. Place the trap against the wall with the openings parallel to the wall. Mice are inherently curious and readily step through a one-way door or on a treadle and are brushed into an escape-proof chamber.

An alternative to traps is glue boards. Place glue boards along walls where mice and rats travel. Do not use them where children, pets, or desirable wildlife can contact them.

The location and number of traps or glueboards should be mapped and recorded. By keeping records, effectiveness of trapping and location of problem areas can be determined. Traps should be checked at least weekly and dead rodents removed carefully because of disease and ectoparasites. Wear rubber gloves when handling rodents and seal them in plastic bags for disposal.

Rodenticides. Rodenticides should be used to control mice and rats when populations exceed tolerable levels or when attempting to maintain low population levels. Follow all pesticide label recommendations carefully to minimize hazards to humans, livestock, pets, and other non-target animals. Always wear gloves and use protective clothing and equipment as specified by the pesticide label. Store unused bait and concentrates in locked cabinets out of the reach of children or animals. Some rodenticides are Restricted Use Pesticides and can only be purchased and used by individuals who are certified by the Environmental Protection Agency. Contact your local Extension agent for information on pesticide applicator training programs in your area.

There are two types of rodenticides with which to be familiar: non-anticoagulant and anticoagulant (Tables 3 and 4). Non-anticoagulant rodenticides, such as zinc phosphide, bromethalin, and others, provide a quick knockdown of rodent populations and are preferred where rats or mice are abundant. They are also useful where it is difficult to get mice to accept a bait for several days in succession because of competing food items.

When using a non-anticoagulant rodenticide, "prebait" by applying untreated bait for three to four days before applying toxic bait. This will help increase the acceptance of the poison bait. If acceptance of prebait is poor, do not apply toxic bait. Poor acceptance may be corrected by changing bait material or its placement. Remove and destroy all uneaten bait at the end of the poisoning program. Non-anticoagulant rodenticides are more hazardous than anticoagulant rodenticides. When possible, use commercially prepared baits to simplify handling procedures.

Anticoagulant rodenticides, such as warfarin, chlorophacinone, and others, are generally much safer than non-anticoagulant rodenticides. They are used at very low dose rates and they cause death by internal bleeding. Vitamin K is a commonly available antidote for several products. Active ingredients are at very low levels, so "bait shyness" usually does not occur and prebaiting is not necessary. Fresh bait should be provided as long as active feeding continues, which may last more than two weeks. Most of these baits cause death only after they are fed upon for several days. Anticoagulant rodenticides are very useful as an initial control measure, as a follow-up to non-anticoagulant rodenticides, and as a preventative measure.

There are several different formulations of rodenticides that are commercially available or that can be prepared by individuals. Non-anticoagulant rodenticides are usually available as treated grain baits, pellets, tracking powders, or concentrates. Anticoagulant baits are often available as sealed "place packs," which keep baits fresh and make it easy to place baits in burrows, walls, or other locations. Extruded or paraffinized bait blocks are useful in damp locations where loose grain baits would spoil quickly. Some anticoagulants can be prepared as water solutions. Since rats require water daily, they can be drawn to water stations in some situations. Water baits are particularly effective in grain storage structures, warehouses, and other locations where water is scarce.

Bait placement is just as important as bait selection. Where possible, place baits between the rodents' sources of food and shelter. Place baits near burrows, against walls, or along runways. Rodents usually will not go out of their way to find baits. House mice seldom venture more than a few feet from their nests or food sources, so place bait stations no more than 10 to 12 feet apart in areas where mice are active. Rats maintain much larger home ranges, thus, baits can be placed up to 50 feet apart. Rats are often

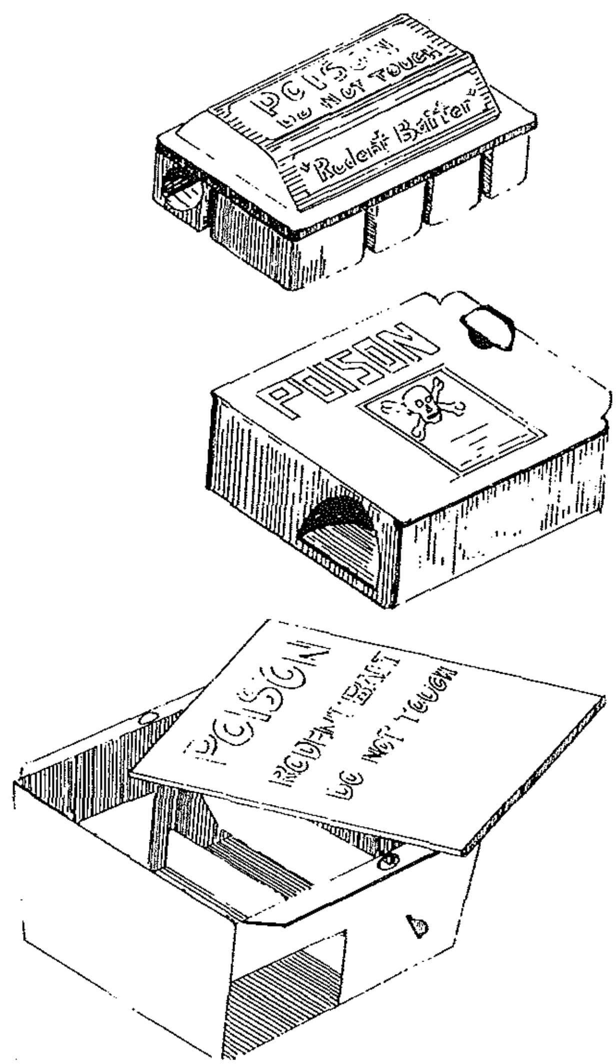


Figure 5. Examples of commercially manufactured rodent bait stations.

suspicious of new or unfamiliar objects. It may take several days for rats to feed on new baits.

Bait boxes or stations can be used to protect rodenticides from weather, and they provide a safeguard to people, pets, and other animals (Figure 5). Bait stations should have at least two openings about one inch in diameter for mice, and they should be large enough to accommodate several mice at one time. For rats, the two openings should be about two and a half inches in diameter. Place bait boxes next to walls with the openings close to the wall, or in other places where mice or rats are active. Clearly label all bait boxes "Caution—Poison Bait" as a safety precaution. Some bait stations are completely enclosed and can contain liquid as well as solid rodent baits. A hinged lid with a child-proof latch can be used for convenience in inspecting permanent stations. Where buildings are not rodent-proof, permanent bait stations can be placed inside buildings, along the outside of building foundations, or around the perimeter of the area. When maintained regularly with fresh anticoagulant bait, these bait stations will help keep rodent numbers at a low level. Rodents moving in from nearby areas will be controlled before they can reproduce and cause serious damage.

The use of rodenticides may be limited to exterior use. If used inside, they must be restricted to nonfood areas only. Pellet or bait blocks should not be used indoors, due to the potential to be carried away from a bait station. Further, treated grain baits should not be used when similarities exist between the bait and any raw materials or finished product.

Fumigants. Aluminum phosphide, methyl bromide, and chloropicrin are often used to fumigate grain bins, railway cars, food processing plants, and other enclosed areas. When practical, fumigation is a very quick way to achieve 100 percent rodent control. The three fumigants noted above are all Restricted Use Pesticides, registered for insect and rodent control in grain storage facilities. Because of their high toxicity to humans and livestock, they must not be used in any situation where the occupants of structures might be exposed. Only licensed structural pest control operators should use fumigants in situations involving grain storage facilities, buildings, or other structural enclosures. Grain storage facilities are usually fumigated two to four times annually to control insects. These fumigations also eliminate rodent populations and, therefore, provide an excellent opportunity to reestablish a rodent control program emphasizing sanitation and trapping.

Sound and Electronic Devices. Although mice and rats are easily frightened by strange or unfamiliar noises, they quickly become accustomed to regularly repeated sounds and are often found living in grain mills and factories. Sonic, subsonic, ultrasonic, magnetic, and vibrational devices have very limited use in rodent control. The energy forms that they emit typically are not directional, do not penetrate behind objects, and lose their intensity quickly with distance. In addition, rodents typically acclimate very quickly to environmental disturbances. There is little evidence that electronic devices of any type will drive established mice or rats from buildings.

Predators. Although cats, dogs, and other predators may kill mice, they do not provide effective control in most situations.

Pigeons and Sparrows

Bird Biology

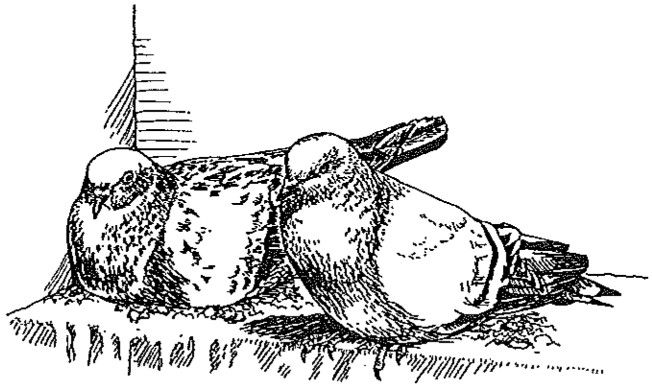
Feral pigeons typically have a gray body with a whitish rump, two black bars on the secondary wing feathers, a broad black band on the tail, and red feet (Figure 6). Body color and markings can vary from gray to white, tan, red, and black. The average weight is 13 ounces and the average length is 11 inches. When pigeons take off, their wing tips touch, making a characteristic clicking sound. When they glide, their wings are raised at an angle.

Pigeons are highly dependent on humans to provide them with food and sites for roosting, loafing, and nesting. Pigeons are primarily grain and seed eaters and can subsist on spilled or improperly stored grain. They require about one ounce of water daily.

Pigeons are monogamous. Eight to 12 days after mating, the females lay one or two eggs which hatch after 18 days. The young are fed pigeon milk, a liquid-solid substance that is regurgitated from the crops of the adults. The young leave the nest at four to six weeks of age. By this time the female is already incubating the next clutch. Breeding may occur at all seasons, but peak reproduction occurs in the spring and fall.

The house or English sparrow (Figure 6) is a brown, chunky bird about five and three-fourths inches long, and very common in human-made habitats. The male has a distinctive black bib, white cheeks, a chestnut mantle around the gray crown, and chestnut-colored feathers on the upper wings. The female and young are difficult to distinguish from some native sparrows. They have a plain, dingy-gray breast, a distinct, buffy eye stripe, and a streaked back.

Breeding can occur in any month, but it is most common from March through August. The male usually selects a nest site and controls a territory centered around it. Nests are bulky, roofed affairs, built haphazardly, and without the good workmanship displayed by other weaver



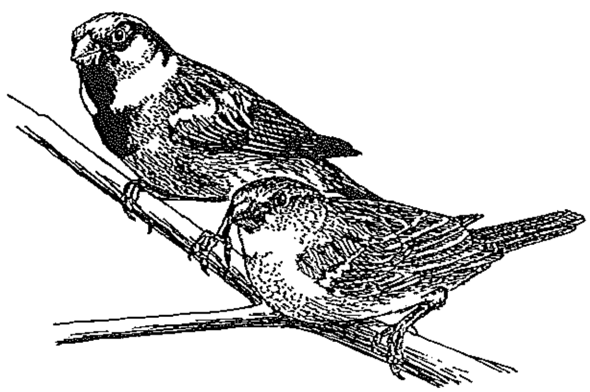


Figure 6. Feral pigeons (top) and house sparrows (bottom).

finches—the group to which the house sparrow belongs. Sparrows are loosely monogamous. Both sexes feed and take care of the young, although the female does most of the brooding. Three to seven eggs are laid and incubation takes 10 to 14 days.

Bird Damage

The presence of pigeons, sparrows, and their associated droppings at grain handling facilities are aesthetically displeasing and suggest unsanitary conditions. Pigeon droppings deface and accelerate the deterioration of buildings and increase the cost of maintenance. Around grain handling facilities, pigeons consume and contaminate large quantities of food destined for human or livestock consumption.

House sparrows consume grains in fields and in storage. They interfere with livestock production, particularly poultry, by consuming and contaminating feed. In grain storage facilities, fecal contamination probably results in as much monetary loss as does the actual consumption of grain. House sparrow droppings create unsanitary conditions inside and outside of buildings and on sidewalks under roosting areas.

Pigeons and sparrows can transmit diseases to humans and livestock through their droppings. Specific diseases include ornithosis, coccidiosis, encephalitis, Newcastle disease, toxoplasmosis, and salmonellosis. Under the right conditions, pigeon manure can also harbor airborne spores of the fungus that causes histoplasmosis, a systemic disease that affects humans. Birds and their nests also can harbor a variety of fleas, lice, and mites—some of which readily bite people.

Bird Damage Prevention and Control

Habitat Modification/Sanitation. Elimination of feeding, watering, roosting, and nesting sites is important in long-term pigeon and sparrow control. Clean up spilled grain around elevators, mills, and railcar clean-out areas. Eliminate pools of standing water that birds could use for watering. Examine ventilators, vents, air conditioners, building signs, ledges, eaves, and overhangs for potential and existing bird usage and eliminate those sites where practical. Modify structures, buildings, and architectural designs to make them less attractive to perching, nesting, or roosting birds.

Exclusion. Pigeons and sparrows can be excluded from buildings by blocking access to indoor roosts and nesting areas. Close all openings larger than three-fourths inch to exclude house sparrows from buildings. Openings to lofts, steeples, vents, and eaves should be blocked with wood, metal, glass, masonry, one-fourth-inch rust-proofed wire mesh, or plastic or nylon netting. Doorways that must accommodate human or vehicle traffic can sometimes be effectively blocked by hanging a flexible wall of four- to six-inch plastic strips in front of the opening. These will not seriously impede human movements, yet they present an impassable barrier to sparrows.

Roosting on ledges can be discouraged by changing the angle to 45° or more. Sheet metal, wood, styrofoam blocks, stone, and other materials can be formed and fastened to ledges to accomplish the desired angle. Access to rafters or ceiling joists in drive-through areas can be permanently prevented by screening the underside of the rafters or joists with netting. Panels can be cut into the netting and velcro fasteners can allow access to the rafter area to service equipment or lights. The life span of this netting can be as long as 10 years.

Porcupine wires are mechanical repellents that can be used to exclude problem birds. They are composed of several spring-tempered, stainless steel prongs with sharp

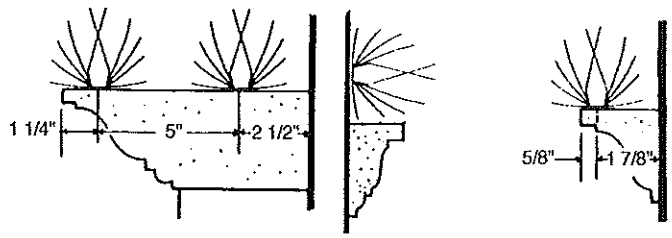


Figure 7. Porcupine wires are a relatively permanent method of discouraging birds from roosting on structures.

points extending outward at all angles. The sharp points of these wires inflict temporary discomfort and deter birds from landing. The prongs are fastened to a solid base that can be installed on window sills, ledges, eaves, roof peaks, or wherever birds are prone to roost (Figure 7). Sometimes, pigeons and sparrows cover the wires with nesting material or droppings, which requires occasional removal.

Tightly stretched parallel strands of 16- to 18-gauge steel wire or 80-pound+ test monofilament line can be used to keep birds off support cables, narrow ledges, conduit, and similar areas. Attach L-brackets at each end of the area to be protected and fasten the wire to the L-brackets with turnbuckles. On heavily used structures, it may be necessary to stretch three lines at two, five, and seven inches above the surface.

Electric shock bird control systems are available for repelling pigeons and sparrows. The systems consist of a cable embedded in plastic with two electrical conductors. Mounting and grounding hardware and a control unit are included. The conductors carry a pulsating electrical charge. When birds make contact with the conductors and the cable, they receive a shock that repels but does not kill them. Although these devices and their installation are usually labor intensive and expensive, their effectiveness in some cases justifies the investment.

Frightening. Frightening devices (fireworks, shell crackers, acetylene exploders, and cymbals) will move pigeons and sparrows from an area for a short period. The commensal species, however, adapt quickly to frightening devices and will not be repelled by sounds for any great length of time, unless the sounds are diversified and their locations shifted periodically. High-frequency (ultrasonic) sound, inaudible to humans, is not effective on pigeons. Revolving lights, waving colored flags, balloons, rubber snakes, owl models, and other devices likewise have little or no effect.

Nesting sites can be sprayed with streams of water to disperse pigeons, but this must be done persistently until the birds have established themselves elsewhere.

Avitrol® (4-aminopyridine) is a chemical frightening agent that is available in a variety of grain bait formulations. Birds that consume sufficient amounts of the treated bait usually die. The dying birds exhibit distress behavior that frightens other members of the flock away. In order to minimize the mortality and maximize the flock-alarming reactions, the treated bait must be diluted with clean, untreated grain. In urban areas where high bird mortality may cause adverse public reactions, a blend ratio of 1:19 or 1:29 will produce low mortality, but requires more time to achieve control. Where high mortality is acceptable, a blend ratio of 1:9 will produce quicker population reduction. Prebaiting for at least 10 to 14 days is critical for a successful program. See the section on toxicants below for information on prebaiting and baiting.

Repellents. Tactile repellents (polybutenes) are available in the form of liquids, aerosols, nondrying films, and pastes. These substances are not toxic to pigeons or sparrows. Rather, they produce a sticky surface that the birds dislike, forcing them to find loafing or roosting sites elsewhere. Applications should be made about one-half inch thick in rows spaced no farther than three to four inches apart. To be effective, all roosting and loafing surfaces in a problem area must be treated, or the pigeons will move to untreated surfaces. The effectiveness of sticky repellents is usually lost over time, especially in dusty areas. An application may remain effective for six months to two years. Tactile repellents are most appropriate for small- and medium-sized jobs. For large commercial situations requiring significant amounts of labor and expensive equipment, the use of repellents may be economically shortsighted because it is expensive to frequently reapply them.

Toxicants. DRC-1339 (3-chloro-p-toluidine hydrochloride) is a Restricted Use Pesticide registered for the control of pigeons. It can only be used by employees of the United States Department of Agriculture-Animal and Plant Health Inspection Service-Animal Damage Control (USDA-APHIS-ADC) or persons working under their direct supervision. DRC-1339 is slow-acting and apparently painless. It takes from several hours to three days for death to occur. Death is caused by uremic poisoning and occurs without convulsions or spasms. DRC-1339 is metabolized within two and a half hours after ingestion. Normally, there is little chance of undigested bait remaining in the crop or gut of a dead or dying pigeon. The excreta and the flesh of pigeons poisoned with DRC-1339 are nontoxic to predators or scavengers. Prebaiting is the single most important element of a successful toxicant program. The birds must be trained to feed on a specific bait at specific sites before the toxicant is introduced. If the prebaiting is not done correctly, the results will likely be less than desirable.

In urban areas, flat rooftops make excellent bait sites, even though pigeons do not normally feed on them. They do normally frequent rooftops, however, and it is possible to control access to them. All prebait must be removed before the toxic bait is applied. When the toxic bait is put out, the feeding birds should not be disturbed but should be observed from a hidden location.

The Rid-A-Bird™ perch contains 11 percent fenthion, a Restricted Use Pesticide, and is registered for pigeon and sparrow control. These perches are hollow tubes that hold about one ounce of the toxicant within a wick. When a bird lands on the perch, the toxicant is absorbed through the feet in a short period of time. Death usually takes place within 24 to 72 hours. Rid-A-Bird™ perches are restricted for use at farm buildings, loading docks, rooftops, nonfood storage warehouses, and bridges. They are prohibited inside food processing, handling, or storage buildings.

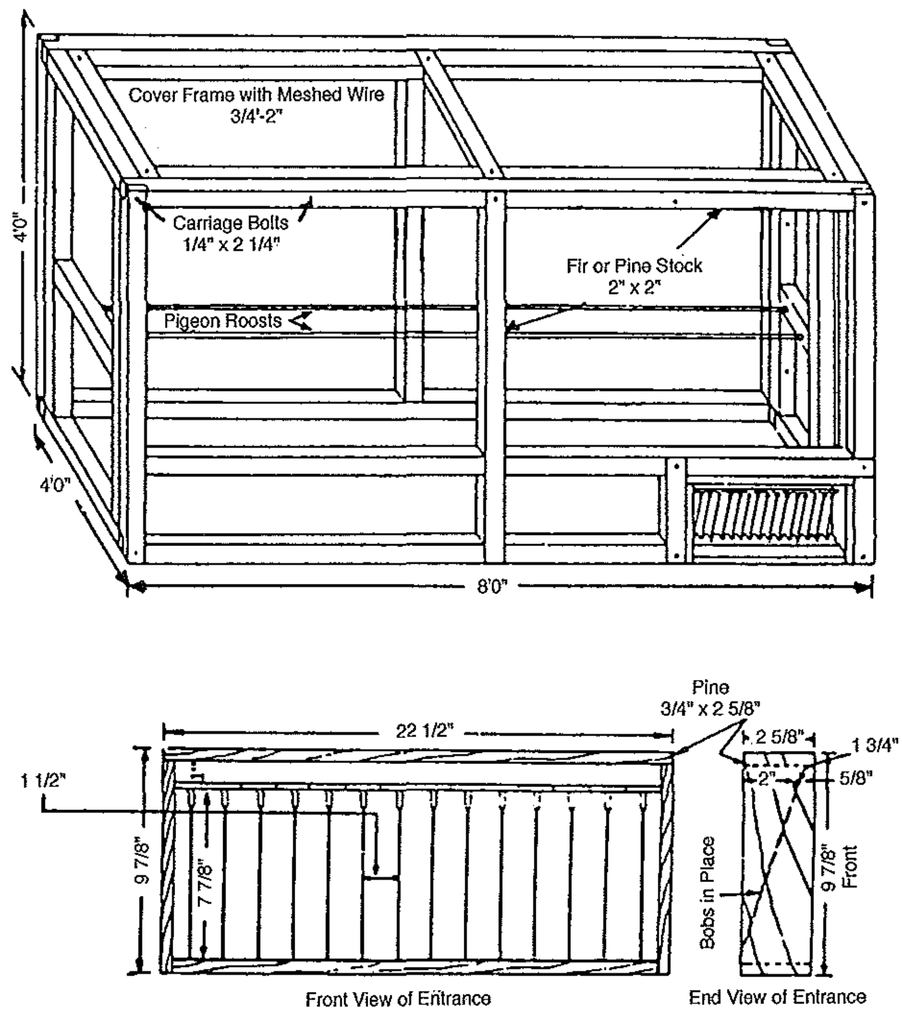


Figure 8. A bob-type trap for pigeons.

Perches are available in a number of configurations for both indoor and limited outdoor applications. The wide perch, 1 x 24 inches, is used to accommodate the sitting (non-grasping) habit of pigeons. Ten to 12 perches will solve most problems, but large jobs may require as many as 30 perches. For example, in a drive-through, most birds can be eliminated by placing one or two perches in each heavily used area. Effective places to install perches around structures can be determined if the area is observed for preferred perching areas for 48 hours before placement.

Toxic perches should be used only by certified persons experienced with their use, because they can be hazardous to other birds, animals, and people if used incorrectly. Label instructions must be rigidly followed. Use extreme care to avoid spillage of fenthion. It can be absorbed through the skin, so applicators must be aware of the toxicity hazards. Fenthion may present a secondary hazard to birds of prey, small carnivores, and scavengers.

Trapping. Pigeons can be effectively controlled by capturing them in traps placed near their roosting, loafing, or feeding sites. Some bob-type traps are more than six feet tall, while low-profile traps measure only nine inches high and 24 inches in width and length (Figure 8). Generally, the larger the population of birds to be trapped, the larger the trap should be. Although larger traps hold many birds, they can be cumbersome in situations such as rooftop trapping programs. In these instances, it may be more convenient to use several low-profile traps that are more portable and easier to deploy.

The best locations for traps are major pigeon loafing areas. During the heat of the summer, place traps near pigeon watering sites, such as rooftop cooling condensers. Also consider prebaiting areas for several days before beginning the actual trapping. To prebait, place attractive baits, such as corn or milo, around the outside of the traps.

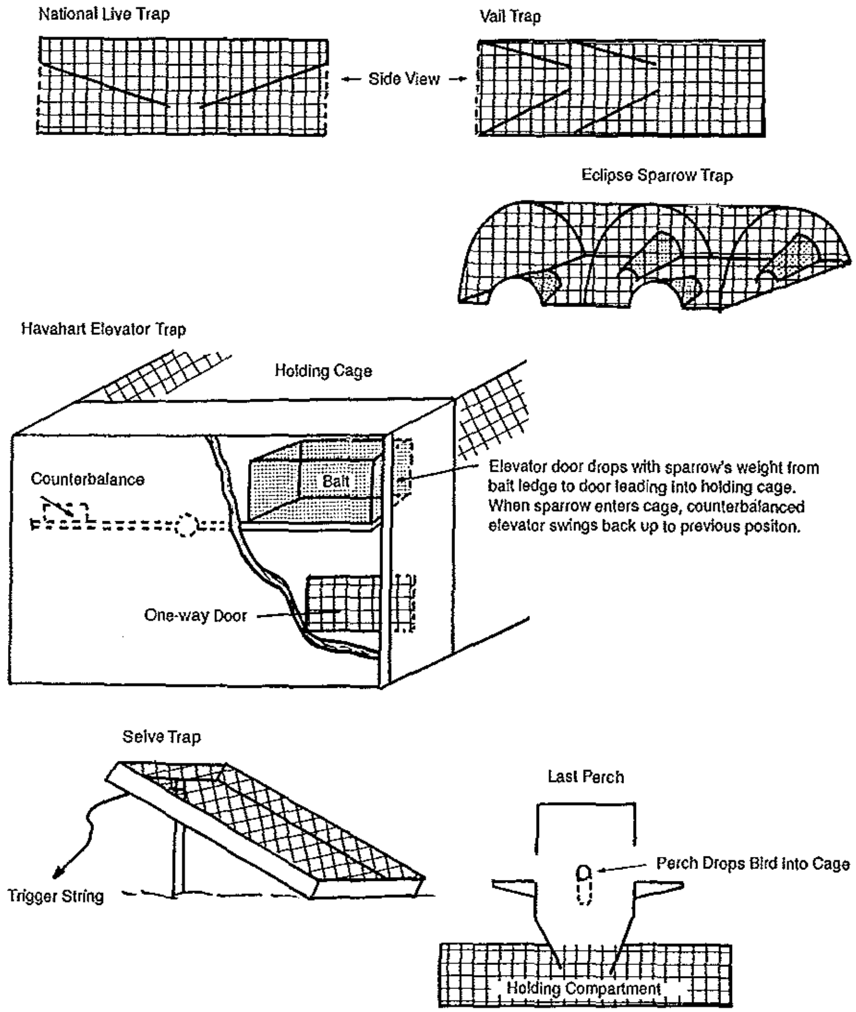


Figure 9. Several types of sparrow traps are available.

After three to four days, the baits can be placed inside the trap (in both compartments of the low-profile trap). Four or five decoy birds should be left in the trap to lure in more pigeons.

The disposal of trapped birds should be quick and humane. For large-scale pigeon control projects, the most cost-effective and humane method is to use a carbon dioxide (CO_2) gas chamber. The chambers can be purchased commercially or be constructed by modifying a garbage can or 55-gallon drum with a tight-fitting lid having a hole for a gas supply line. Compressed CO_2 is commercially available in cylinders. Releasing pigeons back to the "wild" is impractical. Pigeons are likely to return, even when released 50 or more miles from the problem site, or become pests in other communities.

Trapping is probably the most widely used method in attempting to reduce house sparrow populations in small areas. There are more types of traps available for sparrows than for any other bird (Figure 9). While funnel traps are probably the most easily entered of any trap, sparrows can also escape from them with relative ease. Thus, they should be checked frequently and the birds removed. Where possible, decoy individuals should be penned in separate compartments inside these traps.

Shooting. Where permissible, persistent shooting with .22 caliber rifles (preferably using ammunition loaded with bird shot or short-range pellets), .410 gauge shotguns, or high-powered air rifles can eliminate small flocks of pigeons or sparrows. Shooting at night can be an effective technique to remove the few problem birds that may persist around farm or grain elevators after a reduction program has been terminated.

Most towns and cities have ordinances prohibiting the discharge of firearms within corporate limits. Check local laws before employing a shooting program.

Other Control Methods. Alpha-chloralose is an immobilizing agent that depresses the cortical centers of the brain. Pigeons fed about 60 mg/kg of alpha-chloralose become comatose in 45 to 90 minutes. The pigeons can then be captured to be relocated or euthanized. Full recovery occurs four to 24 hours later. Only USDA-APHIS-ADC personnel certified in its use or individuals under their supervision are allowed to use alpha-chloralose.

Pigeons and house sparrows can be discouraged from using an area by persistent harassment, removing nests, and destroying the eggs and/or young. House sparrows are especially persistent, so nest destruction must be repeated at two-week intervals throughout the breeding season. Use a long, insulated pole with a hook attached to one end to remove nests that are located in high places. The nesting materials should be collected and removed to make it harder for the birds to find materials for new nests.

Acknowledgments

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Copies of the 850-page reference *Prevention and Control of Wildlife Damage* are available for purchase. Please specify book ($45), CD-ROM ($43), or book and CD-ROM ($65). Checks, money orders, and purchase orders are payable to the University of Nebraska. Mail requests to Wildlife Damage Handbook, 202 Natural Resources Hall, University of Nebraska, Lincoln, Nebraska 68583-0819, or phone 402-472-2188 for more information. ❑

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