

Pest Management Strategic Plan
Stored Hard Red Winter Wheat
Oklahoma

Contents

- I. Executive Summary
 - II. Research, Education, and Regulatory Priorities
 - III. Background
 - A. *General Production Information*
 - B. *Critical Pest Information*
 - C. *Critical IPM and Pesticide Information*
 - 1. Sanitation
 - 2. Monitoring
 - 3. Aeration
 - 4. Biological Control
 - 5. Chemical Treatments
 - a) Empty bin treatments
 - b) Grain protectants
 - c) Fumigants
 - d) Rodenticides
 - e) Avicides
 - D. *Resistance Management*
 - E. *Consumer Education*
 - F. *Import/Export Issues*
 - IV. References
 - V. Appendices
 - Appendix A. Workshop participants
 - Appendix B. Document Editors
 - Appendix C. Fumigation Certification Requirements in Oklahoma
 - Appendix D. Glossary
 - Appendix E. Pest Management Timeline of Hard Red Winter Wheat in Oklahoma
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I. Executive Summary

The primary crop production enterprise in Oklahoma is the production of hard red winter wheat, with an average annual value of \$378,568,600; Oklahoma ranks 2nd or 3rd in the nation for the production of this crop. Storage of harvested wheat averages 148,853,000 bushels per year, predominantly in commercial facilities versus on-farm. Because of hot, dry summertime conditions, Oklahoma is at high risk for stored wheat insect pests, which can cause significant damage and reduction in wheat value. The most damaging insect types are those that feed within the kernel itself, causing Insect Damaged Kernels (IDK). Wheat is discounted based on the number of IDK as well as the presence of live insects and other grain quality factors, at the time of sale. Several cultural practices to manage pests are used by commercial facilities. Those that minimize pest invasion into storage structures include cleaning bins and equipment prior to harvest and after bin emptying, applying “empty-bin” insecticides to the inside of the structures, sealing structures, cleaning up grain spills on the grounds, and removing weeds close to structures. Additional management techniques include storing dry wheat (< 13% moisture content), since moisture can encourage mold and insect development, aerating the stored grain with fans to cool the wheat and thus slow insect development, and close monitoring of grain temperature and insect populations. There are limited chemical options for managing insects in the grain itself. Grain protectants are expensive, and thus are usually used only for seed wheat protection. Diatomaceous earth should only be used on the top and bottom of the grain mass, as the dust decreases the test weight and thus value of the grain. Biological control agents, such as predatory and parasitic insects, are rarely used in stored wheat management due to inadequate availability and limited efficacy. Fumigants are the most commonly used type of insecticide for stored grain insects in Oklahoma. Chloropicrin is restricted by label for use in empty bins only; methyl bromide, besides being phased out of use in the United States, is expensive and can damage the wheat germ. Phosphine is the most commonly used fumigant currently registered for use in stored wheat. Phosphine is highly effective, remedial, relatively inexpensive, leaves no residual product, and when used correctly, is safe around workers and the environment.

A draft version of this document was prepared in advance of the strategic planning session conducted October 3, 2003, in Oklahoma City, OK. Invitees (Appendix A) represented multiple interests in the stored wheat industry, including commercial elevator managers (large terminal elevators and local farmer-owned cooperatives), seed storage managers, flour milling companies, wheat producers, and commodity organizations, plus representatives from USDA, EPA, and the state department of agriculture. During the planning meeting, the group first critiqued and clarified the draft document to create an accurate representation of stored wheat management in Oklahoma. The group then identified critical research, education, and regulatory needs, which are summarized on page three. The next draft of the document was re-submitted to the meeting invitees for review and additional comments. The final version of this document is presented here.

II. Research, Education, and Regulatory Priorities

Research Priorities

- Test new insecticides for insect management, focusing on economics, efficacy, and safety
- Verify the safety of phosphine fumigation, particularly in residues and application techniques
- Investigate phosphine gas-releasing devices from external sources and related application methods
- Research Profume gas characteristics and application methods for stored grain
- Research Storcide II efficacy and residual activity
- Research the efficacy of using diatomaceous earth for top- and bottom-bin applications
- Research the efficacy of diatomaceous earth in combination with other insecticides
- Define and clarify the sources and speed of bin re-infestation by insects
- Research the use of barrier (top/bottom) treatments
- Research the residual activity of grain protectants

Education Priorities

- Training on regulatory requirements of the new phosphine label, including the Fumigation Management Plan
- Educate elevator managers and wheat producers on effective grain management, especially on the value of regular monitoring of grain, for example grain temperature, presence of insects, moisture content, levels of damage and dockage
- Develop fact sheets on rodent and bird management in stored grain
- Proper use of phosphine: effective application methods, worker safety, and resistance management

Regulatory Priorities

- Preserve the uses of phosphine fumigant
- Enforce Oklahoma restrictions on phosphine sales and use by certified applicators (see Appendix C for certification requirements)
- Expand the phosphine labels to include the use of pellets and tablets in external chambers
- Rapid registration of new chemistries for insect management

III. Background

A. General Production Information

- Wheat is Oklahoma's most important crop by value and acreage.
- Winter wheat in Oklahoma is planted in the fall from late September through November.
- Harvest of Oklahoma winter wheat starts in the southern counties around late May and is mostly completed by the first week of July. The majority of acres will be harvested in June, weather permitting.
- Hard red winter (HRW) is the dominant wheat class in Oklahoma. Oklahoma typically ranks second or third in the nation in winter wheat production and fourth or fifth in the nation in overall wheat production. Winter wheat is used for breads, rolls and, to a lesser extent, sweet goods and all-purpose flour.
- Winter wheat planted acreage has held steady over the past five years (1998-2002) with an average of 6,160,000 acres planted. In 2002 there were 6,100,000 acres planted and in 2003 there were 6,600,000 acres planted in Oklahoma.
- Harvested acreage over the past five years (1998-2002) averaged 4,180,000 acres. In 2002 the harvested acreage was 3,600,000 acres and 4,600,000 acres were harvested in 2003 with a record-tying yield of 39.0 bushels per acre.
- Production over the past five years (1998-2002) averaged 143,020,000 bushels, and in 2003 production totaled 179,400,000 bushels.
- The five year average (1998-2002) value of production in Oklahoma was \$378,568,600, with an average price of \$2.72/Bushel.
- In 2002 the value of production of wheat was \$343,000,000, with an average price of \$3.50/Bushel.
- Oklahoma averaged 148,853,000 bushels in storage at the end of the past five years (1998-2002). Commercial storage averaged 133,253,000 bushels and farm storage averaged 15,600,000 bushels the past five years in September. A total of 98,182,000 bushels were stored in September 2002, of which 88,182,000 bushels were commercially stored and 10,000,000 bushels were stored on farm.
- The following numbers represent September 2003 National Agricultural Statistics Service and Oklahoma Agricultural Statistics Service data: wheat stocks were up 40 percent from 2002 according to OASS, with 137,079,000 bushels stored, 89% of the total stocks (122,079,000 bushels) were commercially stored and 15,000,000 bushels were stored on farm.

B. Critical Pest Overview

The predominant pests in Oklahoma stored wheat are insects, with birds and rodents considered to be less serious. Mold (various species) can also contaminate wheat, but is the consequence of high-moisture that is managed with cultural practices only.

Oklahoma stored wheat contains a broad spectrum of insect species. Low moisture of the stored grain is an unfavorable environment for most of the stored insects, except for the lesser grain borer that has been found in grain with moisture as low as 8%. Warm grain temperatures at harvest and during storage, combined with grain moisture content of 12-13%, are conducive to growth of insect populations. Insect populations increase during the summer, peak during October and November, and reproduction declines through the remainder of winter.

Wheat is tested and graded when it is sold; the price received for grain is dependant upon the standards of the buyer. Government standards are set by the Grain Inspection, Packers and Stockyard

Administration. Grain contaminated with high levels of insect damaged kernels (IDK), mycotoxins, or pesticides, or commodities contaminated with animal or insect filth or fragments above established tolerances can be condemned. Grain is assigned a U.S. Grade, from No. 1 to 5, with an additional Sample Grade status. The premium grade is U.S. No. 1, and requires that a bushel of hard red winter wheat weigh a minimum of 60 pounds and have less than 2% damaged kernels; there can also be no more than one live insect injurious to grain in a 1-kg sample. Wheat that contains 32 or more IDK per 100 gram sample is classified as sample grade and cannot be sold for human consumption. Sample-grade wheat is difficult to sell and will suffer considerable price discount. Flour millers strive to minimize insect fragments in their finished product and thus often have high quality standards for grain purchased (Kenkel et al. 1994). Millers will typically not accept grain with any live insects, and prefer grain with few or no IDK per sample.

For export contracts, some countries may specify a specific grain treatment to eliminate insect pests, whereas another country will not accept grain on which any pesticide was used. Approximately 80% of Oklahoma wheat is exported (Hodges, personal communication).

All pest management decisions are based on minimizing discounts at the time of sale. Table 1 includes an example of a discount schedule.

Table 1. Example of discount schedule for hard red winter wheat at time of sale.

Factor	Amount of discount (per bushel)	Factor	Amount of discount (per bushel)
<i>Grade Discounts</i>		<i>Damage Discounts</i>	
No. 2	- ½ cent	3.1% - 5.0%	- 1 cent each ½%
No. 3	- 3 cents	5.1% - 10.0%	- 5 cents each 1%
No. 4	- 6 cents	Over 10.0%	Subject to rejection
No. 5	- 9 cents		
Sample grade	- 12 cents		
Infested	- 5 cents	<i>IDK Discount</i>	
Musty	- 5 cents	1 to 5	No discount
Sour	- 8 cents	6 to 20	1 cent each kernel
		21 to 31	2 cents each kernel
		32 and above	Rejected
<i>Test Wt. Discounts</i>			
57.9 lbs to 55.0 lbs	- 2 cents for each ½ lb		
54.9 lbs to 54.0 lbs	- 4 cents for each ½ lb		
53.9 lbs and below	Subject to rejection		

Critical Pests

Insects are managed based on the type of damage they cause, and are consequently grouped based on that type of damage. **Internal Grain Feeders** are those insects (beetles) that feed inside kernels; larvae bore tunnels inside the kernel and adults chew holes. These species contribute to the IDK (insect damaged kernel) grade and thus are considered serious pests. **External Grain Feeders** and **Mold Feeders** are pests (beetles, booklice, moths, and mites) that are unable to penetrate the whole grain, so they feed and live on broken kernels, grain dust, fungi, and milled products, causing less direct damage than primary insects. Although they do not contribute to IDK, they contaminate the grain with their body parts. If two or more live insects, regardless of feeding habits, are found in a sample, the grain is referred to as “infested grain” and sold at a significant discount. The **Indianmeal**

Moth infesting grain causes damage when the larvae spin massive amounts of silk over the grain surface, which blocks off aeration, causes grain heating and molding, and prevents efficient fumigation. Additional pests of concern are **Birds**, **Rodents**, and **Molds**.

Internal Grain Feeding Insects

- **Lesser Grain Borer** (*Rhyzopertha dominica*) is the most destructive insect pest of stored wheat in Oklahoma. This insect is a strong flier that can tolerate high temperatures and dry grain (moisture content less than 12%). The insect feeds and destroys the whole grain causing IDK of wheat. The female can deposit up to 500 eggs on the grain surface. After hatching, larvae burrow into the kernel to feed and develop to adult stage. During development, the larvae push dust out of the grains. The adults chew their way out of the grain and continue to feed on the whole kernel. Adults and larvae have powerful jaws that are used to riddle the grain, creating large, irregular-shaped holes. Heavy infestation with lesser grain borers can be identified by a sweetish, musty odor in the storage.



Resistance - Lesser Grain Borer has shown high resistance to malathion and moderate resistance to Reldan; thus the insect is not listed on the Reldan label. A light to moderate resistance has been found to phosphine gas. Alternative protectants and fumigants will slow the development of resistance.

- **Rice Weevil** (*Sitophilus oryzae*) is less common than lesser grain borer, but is another important internal grain feeding insect. Adults can fly in warm conditions and cause serious damage to wheat. The insect is usually found in whole grain of stored wheat and is not a problem in milled products. Rice weevils require higher moisture (>12%) grain than does the lesser grain borer. The adult chews a hole in the kernel, deposits eggs, and seals the hole with gelatinous material. After hatching, larvae feed and develop to adult stage inside the kernel before they chew their way out and continue to feed on the grain.



External Grain Feeding Insects

- **Rusty Grain Beetle** (*Cryptolestes ferrugineus*) is the most common external feeding grain insect in Oklahoma. Eggs are deposited loosely between kernels and in the cracks or furrows on the grain surface. After hatching, larvae feed in the germ layer of the wheat kernel and also feed on broken kernels and grain dust.
- **Red Flour Beetle** (*Tribolium castaneum*) is another external feeding insect in Oklahoma. It is mostly found in grain and milled products. The insects reproduce faster when some fine material is



present in the stored grain especially if grain moisture is more than 12%. Beetles cannot grow and reproduce on undamaged grain. A pungent, bad odor in the grain is a sign of high infestations with red flour beetles. Red flour beetles have shown resistance to malathion and other insecticides.

- **Sawtoothed Grain Beetle** (*Oryzaephilus surinamensis*) is a common insect in stored grain, cereals, and milled products. The larvae develop in flour, cereal products, and many other dried products. Eggs are deposited on cracks in the kernels and adults and larvae feed on damaged kernels, fines, and occasionally the germ of the intact grain.



- **Flat Grain Beetle** (*Cryptolestes pusillus*) is one of the smallest beetles commonly found in the grain and closely resembles the rusty grain beetle. It does not attack the whole grain but feeds upon broken kernels and the dust resulting from attacks of other grain-feeding insects.

Mold Feeders

- **Hairy Fungus Beetle** (*Typhaea stercorea*) and **Foreign Grain Beetle** (*Ahasverus advena*) do not feed on the grain itself, but on fungi that grow on high moisture grain. Their presence is an indication of moldy grain, and is more likely seen following rain. Adult beetles feed on molds growing on stored grains, where females deposit their eggs. Adults may be introduced into the grain bins on newly harvested grain. These beetles do not damage stored grain. Their presence in a bin indicates mold growth on the grain or introduction of moldy field grain during harvest. Well-managed grain is typically not infested with these beetles. Populations are kept under control if proper sanitation techniques are used and the grain moisture level is maintained at less than 13%.
- **Booklice** (Psocids) These tiny insects are often found in very large numbers in stored wheat. They are not known to damage wheat nor to feed on the kernels or broken kernels. State warehouse inspectors and buyers may require treatment due to the large number of booklice. However presence of booklice in a grain sample during grading should not result in the classification “infested” grain.
- **Mites** These minute insect relatives are occasionally found in stored wheat. They are not known to damage wheat, but will feed on wheat germ, broken kernels or mold. Some mites are predators of insects and other mites. Presence of mites in a grain sample during grading should not result in the classification “infested” grain.

Moth Pests

- **Indianmeal Moth** (*Plodia interpunctella*) is a serious pest that attacks stored grain and cereal products. It is capable of infesting any cereal grains or milled products. Damage occurs when the larvae feed on kernels and spin massive amounts of silk over the grain surface. This webbing impedes air movement, which can cause grain heating and mold growth, and decreases fumigation effectiveness. Adult moths are short lived and do not feed.



Rodents

Several vertebrate species can cause problems in grain storage facilities. In particular, house mice (*Mus musculus*) and Norway rats (*Rattus norvegicus*) are the most common of these pests. While both rats and mice can consume large amounts of grain, it is the contamination of grain that is perhaps the greatest concern. Two droppings per sample will decrease the grade factor significantly. In addition, rodents can damage buildings, equipment, and machinery by their gnawing, burrowing, and nest-building activities.

Resistance- Many of the older Rodenticides have similar modes of action. It is necessary to rotate Rodenticides to avoid possible resistant development.

Birds

Numerous bird species are common pests of stored grain facilities. Birds consume and contaminate grain with their droppings and feathers.

Mold

Any condition that increases moisture in the grain storage can allow for the growth of mold. Examples are condensation, leakage above the grain mass, or wheat harvested high in moisture (>13%). Mold can spread over the kernel surfaces and result in caking near the surface. The mold itself produces heat and additional moisture, thus maintaining or increasing the relative humidity, and resulting in further mold growth. Mold production can decrease grain quality and support insect growth; grain surface caking can decrease the effectiveness of fumigation and interfere with bin emptying.

C. Critical Pesticide Information and IPM Issues

The integrated pest management (IPM) approach that protects stored grain includes sanitation, frequent monitoring, aeration, biological control, and pesticide treatments. IPM techniques should be considered as tools in a toolbox; not all of them are needed every time, such as pesticides, but still need to be available.

1. Sanitation

The key to prevent insect infestation is to clean and maintain the structure at all times. Stored grain insects breed in the old grain from previous storage season. They live and feed on cracked grain, grain trash, or left over grain from previous crop. Both birds and rodents are also attracted to spilled grain. Rodents seek harborage in tall weeds and equipment piles. The following are sanitation practices used for empty storage facilities:

- Harvest and transportation machines are cleaned before harvest.
- Storage structures are emptied of old grain. New crop should never be stored on top of old grain.
- Floors and walls inside empty bins are swept of old grain and debris.
- Weeds around the bins are removed.
- Spilled grain outside the storage structure is removed.
- All grain handling equipment is repaired and kept in good condition before harvest.
- For additional protection against infestation, the inside and outside surfaces, foundations and floor of a storage facility are sprayed with residual insecticide, four to

six weeks prior to harvest, to kill any insects that were not removed during cleaning and those that migrate into the bin.

- Various traps (live traps, glue boards, and bait boxes) are used to control rodent populations.
- Birds are managed with the use of screens, porcupine wires to prevent roosting, flashing lights, and loud sounds or noisemakers.

2. Monitoring

Scouting is an important IPM post-harvest management practice of stored grain. Inspections should be done frequently, especially during the summer and fall. Initially, grain is inspected for insects weekly until the history of the grain is known. Then the grain is monitored every 2-3 weeks during September, October, and November until the grain is cooled to 50-55°F or below, and monitored monthly for the remainder of the year. Grain managers monitor grain quality, grain temperature, and insect density, looking for insects, hot spots, mold growth, and any “off odor”.

Temperatures below 60°F prevent insect activities, while higher temperatures allow for increased insect growth and breeding. Large storage structures are equipped with temperature monitoring cables that provide the temperature of the grain through the grain mass. Information is transmitted for each thermocouple to a reading device that helps grain managers record temperature over time. More than a five-degree rise recorded by one of the thermocouples over a two-week period indicates a pest or moisture problem exists in that location. Monitoring also detects changes in grain temperature during aeration or seasonal temperature fluctuations. Temperature of the stored grain in bins without temperature monitoring devices can be monitored by a thermometer mounted on a probe and inserted into the grain mass, or simply by inserting one’s arm into the top layer of the grain mass. Surveys from 2001-2002 OSU grain elevator workshops showed that 77.5% of elevator managers monitor the grain temperature during storage.

Frequent grain sampling from several locations throughout the storage structure provides grain managers with the status of insects and grain quality. Of those managers who attended 2001 and 2002 OSU grain elevator workshops, 94.5% sample for insects, predominantly when grain is turned. Initial sampling should be done at least weekly until the history of the grain has been clarified. Samples are collected from standing grain using either a deep bin cup or a long spear-like grain trier. Numbers of insects and species are recorded to assess a monthly pattern. The presence of insects in dry whole grain is an indication of future economic loss (in terms of live insects at time of sale). The presence of IDK-causing insects will result in discounts at the time of sale. A moldy appearance, dampness, off-odor, presence of IDK, and high moisture levels can also indicate insect problems. Consistent findings of internal feeders and IDK call for fumigation to protect grain value.

3. Aeration

Aeration is used to cool stored grain and to prevent moisture migration when ambient temperature drops below that of the grain temperature. Prevention of moisture migration by maintaining a uniform temperature throughout the grain mass greatly reduces the possibility of mold development, and insect feeding and reproduction. Aeration will not kill insects, but will slow their growth and development. Aerated bins contain lower insect populations

than non-aerated bins through the winter, thus aeration greatly reduces the requirement for fumigation. Additionally, a second aeration in mid-winter will have a residual control effect that extends into the warm season for grain stored through the next summer. In a survey of Oklahoma grain elevator managers who attended a 2003 fumigation workshop, 67% reported using aeration to cool the grain to bring the mean grain temperature down to 48.5°F ($\pm 9.6^\circ\text{F}$).

Aeration fans at the base of the bin blow out and draw cool air down through the mass from vents in the roof. Airflow rates of 0.1 to 0.5 cfm/bu are recommended for wheat at normal moisture levels. Aeration in Oklahoma is most effective during late summer and fall, when the air temperature is below 60°F; however, warm temperatures can persist until December. In Oklahoma the air temperatures conducive for cooling occur in the fall during evenings. The number of aeration hours depends on the amount of wheat cooled, the depth of the grain in the bin, airflow rates, and the difference between grain and ambient air temperatures.

Automatic controllers turn the aeration fans on when the ambient air temperature falls below the set point (below 60°F) to cool the grain. The controllers turn the fan off when the air temperature exceeds the set point.

4. Biological Control

There are a number of insect predators and parasitic wasps that attack insect pests of stored grain. All are effective if used inundatively. However, biologicals are not used because FDA and food processors do not accept live insects or insect parts in raw grain. Biological agents have limited commercial availability and are cost prohibitive, except perhaps for organic production. Specific species that attack the different groups of pests are listed below.

Internal Grain Feeders

Anisopteromalus calandrae

Choetospila elegans

Lariophagus distinguendus

Predaceous mites

Warehouse pirate bug

External Grain Feeders / Mold Feeders

Predaceous mites

Warehouse pirate bug

Indianmeal Moth

Habrobracon hebetor

Predaceous mites

Trichogramma pretiosum

Warehouse pirate bug

5. Pesticide Treatments

Insects and Related Arthropods

- **Empty-Bin Treatments** include residual insecticides applied in and around the fan, aeration ducts, auger, door openings, and hatch covers, or fumigants, before bins are filled at harvest. Surveys from OSU fumigation workshops in 2000-2003 revealed that 86.7% of grain elevator managers apply empty-bin treatments, predominantly using Tempo (81.3%)

and Reldan (81.3%). Commercial facilities must comply with OSHA bin entry permits. Following are pesticides available for treating empty bins in Oklahoma:

Table 2. Insecticides Labeled for Use as Empty Bin Treatments in Oklahoma, 2003

Active Ingredient	Example Brands	Comments / Usage
Cyfluthrin	Tempo Sc Ultra Premise Spray	Most effective residual as compared with malathion and chlorpyrifos-methyl. Cyfluthrin will Control Lesser Grain Borer.
Chlorpyrifos-methyl	Reldan 4E	Can only be applied from outside of bin and sprayed downward into the bin. Reldan does not control Lesser Grain Borer.
Diatomaceous earth	Insecto, Protect-it	Excellent empty bin treatment. Special grade required for grain use. Must use DE labeled for grain.
Malathion	Malathion	No longer recommended for empty grain bins because of high insect resistance and rapid degradation in warm, relatively moist grain.
Chlorpyrifos-methyl + cyfluthrin	Storcide	Can only be applied from outside of bin and sprayed downward into bin. It is not recommended for grain intended for export.
Chloropicrin	Chlor-o-pic	Empty bin fumigant, under false floor, aeration tubes, and tunnels.
Methyl bromide	Brom-o-gas, others	Empty bin fumigant; seldom used.
Phosphine	Phostoxin, others	Empty bin fumigant.

- **Grain protectants** are insecticides sprayed directly onto grain going into the storage or already in storage. Grain protectants do not kill insects inside the kernels. Following are insecticides labeled as protectants.

In Oklahoma, use of protectants are limited to high-value crops that need protection during storage for several months and for which it is cost effective to use them. For direct application to wheat that will be stored, there have been very few cases for which protectants are required.

Table 3. Liquid Insecticides Labeled for Use as Grain Protectants in Oklahoma, 2003

Active Ingredient	Example Brands	Comments
Chlorpyrifos-methyl	Reldan 4E	Reldan does not control lesser grain borer. Can only be applied from outside of the bin and sprayed downward into the bin.
Malathion	Malathion 5EC	Existing stocks are available but label has been withdrawn. Most stored grain insects are resistant.
DDVP	Vapona	Also as strips. Used in the head space against Indianmeal moth.
Methoprene	Gentrol, Diacon II	Kills developing insects only, slow kill of larvae, no kill of adults though causes sterility. High cost and must use other products before sale. Newly marketed.
Chlorpyrifos-methyl + cyfluthrin	Storcide	Can only be applied from outside of the bin and sprayed downward into the bin. It is not recommended for grain intended for export.
Pyrethrins	Pyrenone	Expensive and short residual.

Table 4. Dust Insecticides Labeled for Use as Grain Protectants in Oklahoma, 2003

Active Ingredient	Example Brands	Comments
Malathion	Big 6 Grain Protector, Agrisolutions 6% Malathion Grain Dust	Top-dress treatment. Most insects are resistant. Millers resist purchasing grain with strong malathion odor.
Diatomaceous earth	Protect-It, Cringe, Insecto	Can lower the test weight of grain and is expensive if applied to entire grain mass, so is best applied to empty bins and to the top and bottom layers of the grain mass.

- **Fumigants**

As grain samples reveal the presence of IDK and insects that cause them (lesser grain borer, rice weevil), fumigation is recommended. Fumigations will stop the infestation and grain degradation from getting worse. When fumigation is effectively conducted in August or September, followed by fall and winter aeration, pest populations can be drastically reduced.

Fumigants registered for use in Oklahoma are phosphine, either released from aluminum or magnesium phosphide or directly as a gas, methyl bromide, and chloropicrin (used for empty bin treatment only). Tablets or pellets of aluminum or magnesium phosphide are sold under Weevilcide, Fumitoxin, and Phostoxin trade names. Phosphine gas mixed with carbon dioxide is sold in gas cylinders as ECO₂Fume. Methyl bromide is expensive, difficult to use properly on raw grain, kills the germ, and is not recommended for stored grain, especially seed wheat.

The phosphide pellets or tablets release phosphine gas as they are exposed to moisture in the air. In a concrete facility, phosphide pellets/tablets are added to infested grain as grain is moved from one silo to another silo, bin, railcar, or truck (trailers must be stationary or on rail cars). For larger facilities, pellets/tablets are probed as deeply into the mass as possible and also distributed on or near the top surface. The released gas is more effectively distributed through the mass using an air-circulation system known as closed-loop fumigation. From surveys conducted at OSU grain elevator and fumigation workshops during 2000-2003, 30.3% of facilities were using closed loop fumigation. For an effective fumigation, the facility must be well sealed to prevent gas leakage to maintain a high enough dosage for sufficient time to kill all life stages of the infesting insects.

In Oklahoma, phosphine can only be sold to or used by pesticide applicators that are certified in the Fumigation category, which requires passing both a written and practical fumigation exams. In 2001, the rule was expanded to require private applicators to also take and pass both the written and practical fumigation exams.

Phosphine is used extensively because it has excellent cost-benefit factors, is safe for workers when used properly, is environmentally safe, has no residue, is highly effective, and is remedial when high insect populations are found. Phosphine can be corrosive to copper and precious metals, such as those found in electronic equipment (computers, aeration fan motors, etc.), which limits its use in buildings.

Fumigation is more effective when sanitation, grain leveling, removal of fines, and thorough bin sealing has been done in advance. It is essential that the level of phosphine remain adequate (> 200 ppm) for as long as possible, with a minimum of 100 hours recommended to kill all life stages of the pest insects.

- **Pipeline Materials**

These are new products that are in the “pipeline” to be registered and available for use within the next year or two.

Profume (Sulfuryl fluoride) - a tolerance recently granted and registration for cereal grains has been approved.

Storicide II (Chlorpyrifos-methyl + deltamethrin) - Works on both IDK insects and has a codex MRL for both ai. but does not have a tolerance for deltamethrin at this time.

Spinosad not yet labeled for stored grain but has a tolerance for wheat grain and can be used on wheat in the field.

Table 5. Efficacy of Insecticides Currently Registered on Stored Grain¹

	Fumigants			Organophosphates			Other Pesticides						
	Phosphine	Chloropicrin	Methyl Bromide	Chlorpyrifos-methyl	Malathion	DDVP	Cyfluthrin		Pyrethrins		Diatomaceous Earth	<i>Bacillus thuringiensis</i>	Methoprene
Internal Grain Feeders													
Lesser Grain Borer	G	E	E	P	R	--	G		P		E	--	E
Rice Weevil	E	E	E	E	R	--	P		P		E	--	E
External Grain Feeders	E	E	E	E	R	--	E		P		E	--	E
Mold Feeders	E	E	E	E	R	--	E		P		E	--	E
Indianmeal Moth	E	E	E	E	R	E	E		G		E	E	E

¹ Includes all insecticides labeled for use on stored wheat in Oklahoma. No carbamates are registered and so this category is not included. More information about each insecticide including brand names and usage information is found in Tables 3 and 4.

² Efficacy abbreviations E = Excellent, G = Good, P = Poor, R = Resistant, -- = not used against that pest

Rodenticides

While there are several rodenticides labeled for use in Oklahoma, stored grain managers rely on strict sanitation, traps, and use of warfarin baits as needed.

Table 6. Rodenticides Labeled for Use in Oklahoma, 2003.

Active Ingredient	Example Brands
brodifacoum	Talon, Havoc
bromadiolone	Contrac
bromethalin	No-Pest Rat & Mouse Killer Bait Blocks
chlorophacinone	Rozol
cholecalciferol	Quintox, Rampage
difethialone	Generation
diphacinone	Ditrac, Ramik
warfarin	Toxhid Bar Bait
zinc phosphide	Eraze Rodent Pellets

Birds

Stored grain producers rely on non-chemical methods to manage birds, as listed under “Sanitation” above.

Table 7. Avicides Labeled for Use in Oklahoma, 2003

Active Ingredient	Example Brands	Comments
Polybutene	Tanglefoot, Bird Repellent	Applied to the surface and very sticky. Not effective for dusty conditions, e.g. grain facilities.
4-Aminopyridine	Avitrol	avicide

D. Resistance Management Issues

- Grain storage facilities lend themselves to pesticide resistance by virtue of the enclosed, protected structures, limited immigration and emigration of insects, and the repeated use of the same chemicals without rotation between chemical classes and modes of action. Of particular concern are the organophosphates, pyrethroids, and *Bacillus thuringiensis* (B.t.) protectants.
- The same fumigant is used with no rotation with other chemical classes. Methyl Bromide is to be phased out in 2005, leaving phosphine as the only registered fumigant for application directly to stored wheat.
- Resistance to phosphine can occur, but so far there have been no real control failures in Oklahoma. However, proper use of phosphine is essential to prevent resistance development, including correct bin sealing and dosage to maintain phosphine concentration at high levels for a sufficient amount of time.

E. Consumer Education Issues

- Pesticide Residues – many of the grain protectants can be detected in the final milled product. However, phosphine fumigant does not leave any residues once the grain is ventilated.
- Insect fragment/parts, rodent / bird droppings – the amount of insect fragments and animal droppings allowed in the final milled product are regulated by FDA. Flour mills will not accept grain with live insects or animal droppings, and strictly control the presence of insect fragments. Millers also note that these fragments are not just of pest insects, but of beneficial (e.g., predators, parasites) insects as well, thus limiting their use.

F. Export Issues

- The Food and Agriculture Organization and the World Health Organization have established the Codex Alimentarius, which sets international residue limits. Insect-infested grain is not acceptable, and only those pesticides that are on the Codex can be exported unless accepted by the receiving country. Given that much of Oklahoma’s wheat is exported, this further limits insecticides that can be used on stored grain. For example, the product Storcide contains cyfluthrin as one of its active ingredients, but since there is no Codex Maximum Residue Limit (MRL) for this chemical, wheat destined for export cannot be treated with the product.

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V. Appendices

Appendix A. Workshop Participants

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Rod Marrs	Shawnee Milling Co.	Shawnee, OK
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Ted Rogers	USDA-OPMP	Washington, D.C.
Joe Royster	Dacoma Coop	Dacoma, OK
Eugene Thilsted	EPA Region 6	Dallas, TX
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Appendix C. Oklahoma Fumigation Certification

Oklahoma Pesticide Applicator Certification Procedures

All commercial applicators are required to be certified in the appropriate application category, whether they use Restricted Use Pesticides (RUP) or not.

Certification in the Fumigation Category (7c) entails successfully completing the Core and category exam plus completing the practical exam. The practical consist of attending a 1.5 day educational program at the Oklahoma State University Stored Product Research and Education Center. Course instructors are from OSU's Division of Agricultural Sciences & Natural Resources research and extension, Oklahoma Department of Agriculture, Food & Forestry and industry. The program includes classroom and hand-on activities that are conducted indoors and outdoors. A written exam is given at the end of the practical.

Oklahoma has a Non-Commercial category. This category is for applicators who, as part of their employment apply pesticides. The pesticide applications are not made for hire. Most grain fumigation employees are classified as non-commercial applicators. The exceptions are commercial fumigant company employees. Certification requirements for non-Commercial are the same as for commercial applicators.

The above exams (Core, Category, Practical) are all proctored, closed book exams.

Private Applicators take a self study, open book exam. They are required to take the Fumigation category exam and Fumigation practical if they are to purchase and use fumigants. The Private Applicator exam suffices for the Core exam. It needs to be noted that the Private Applicator and Core exam are from the same manual – *Applying Pesticides Correctly*. Therefore, Private Applicators must successfully complete the Private Applicator self study exam and take the proctored, closed book Fumigation Category and Fumigation Practical exams to purchase and use fumigants in Oklahoma.

Appendix D. Glossary

a.i. Active Ingredient. The chemical(s) in a pesticide that causes death of the pest

Bin Types.

- Concrete silo (left) – used in commercial facilities; silos are interconnected via interstitial spaces
- Round metal bin (center) – 1000 - 1,000,000 bu capacity, usually 250,000 bu for commercial facilities. On-farm storage is typically in round metal bins with 1,000-3,000 bu capacity.
- Flat storage (right) – a large rectangular building on a concrete base, with peaked roof and reinforced walls.



Bu. Bushel. A unit of measurement, equaling four pecks, 2150.42 cubic inches, or 35.239 liters

Caking. Wheat kernels and fine particles (dust) that is packed rather than free-flowing, usually caused from moisture in the grain bin. The encrusted region limits air flow, thus decreasing the effectiveness of aeration and fumigation, and does not flow out of a bin easily. The latter requires physical break-up of the packed area, and can result in the worker falling into a grain mass (if working from above) or burial by the grain mass (if working from below).

Cfm. Cubic feet per minute, a measurement of aeration fan speed

Codex MRL. Codex Maximum Residue Limits. The Food and Agriculture Organization and the World Health Organization have established the Codex Alimentarius, which sets international residue limits for pesticides on food products.

Deep-Bin Cup. *Deep-bin* or *deep-cup probes* are used to collect samples from within a grain mass. The sample cup is attached to the end of a metal probe and inserted closed into the grain mass. Extension sections added to the top of the metal probe allow insertion of the sample cup to the desired depth. Pulling up on the probe opens the sample cup, and it fills with grain.



Discount. Decreased price received for grain based on several factors, such as high moisture, lower test weights, dockage, foreign material, damaged kernels (from heat, breakage, or insects).

Dockage. Material other than the predominant grain that can be easily removed with sieves and cleaning devices.

Dressings. A material applied to the surfaces of the grain rather than distributed throughout the entire grain mass. Diatomaceous Earth (DE) is often applied to the bottom of an empty bin and then to the top layer of grain once the bin is filled.

Fines. Crushed or powdered material; in wheat, fines are made up of dust from the kernels, additional broken material from the wheat plant, or from other plants or seeds that were harvested with the wheat.

Foreign Matter. Includes objectionable matter such as sticks, stones, weed seeds, cigarette butts, etc. Also includes the valueless parts of the raw plant material, such as stems.

Fumigant. A gas applied to a structure, such as a grain bin, for the purpose of destroying insect pests. Fumigants can be applied directly as a gas from a canister, or can be released from a solid, such as pellets or tablets, through chemical reactions. For example, aluminum phosphide tablets release phosphine gas when reacted with moisture; the phosphine gas is the fumigant.

Hand Probe. See Trier, below.

IDK. Insect damaged kernels, caused by insects feeding and boring through wheat kernels. Two insect species can cause IDK: lesser grain borer and rice weevil. Federal standards and standards of grain storage facilities limit the number of IDK allowed per sample of wheat, with assignment of a lower price for the wheat being sold. Sample grade (not suitable for human consumption) is assigned if there are ≥ 32 IDK in 100g of wheat.



Severe IDK caused by lesser grain borer.

Inundative. The release of relatively large numbers of natural enemies to suppress pest populations, without the expectation that the natural enemies will colonize and spread throughout the area.

Mycotoxins. Naturally occurring toxic chemicals produced by certain fungi (mold) growing on grain, feed, or food. Mycotoxins may be detrimental to the health of humans or animals. In stored grain, mycotoxins (fumonisin, vomitoxin, zearalenone, and aflatoxin) are more commonly associated with corn.

Porcupine Wires. Stiff wires attached at angles (see figure below) to structures, such as window ledges and roof edges, to discourage birds from roosting on those structures.

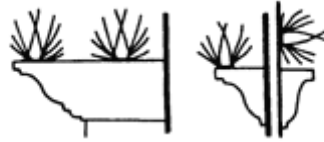


Figure from University of Kentucky, <http://www.ca.uky.edu/agc/pubs/for/for62/for62.htm>

Protectants. Insecticides registered for application on the grain itself, to protect the grain while it is in storage. Protectants kill insects that crawl and feed on treated grain or grain fragments.

Residuals. Pesticides that are applied to surfaces in empty grain storage bins or as protectants applied directly to grain, which will continue to kill insects for a period of days or weeks after application.

Residues. Traces of pesticide that remain on grain or structures after treatment and time.

Test Weight. Test weight per bushel is the weight of the volume of grain that is required to fill a Winchester bushel (2,150.42 cubic inch) to capacity. Premium grade (U.S. No. 1) is assigned to hard red winter wheat weighing at least 60 lbs. per bushel.

Thermocouple. A temperature monitoring system that consists of a cable and a monitor, either hand-held and battery-operated or permanently installed and hard-wired. The cable hangs down the center of the bin or at points between the center and side walls with temperature points at regular intervals and hangs down the outside of the bin with the connector at eye level. The top temperature point should be about 0.3 to 0.6 m below the top grain surface (after the grain settles). The monitor is plugged into the connector and the bulk temperatures are read off and recorded.

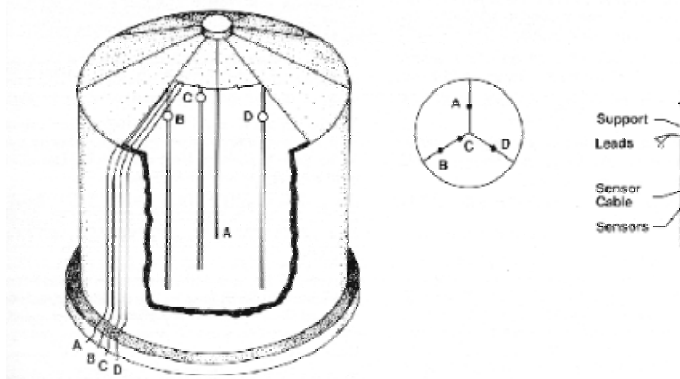
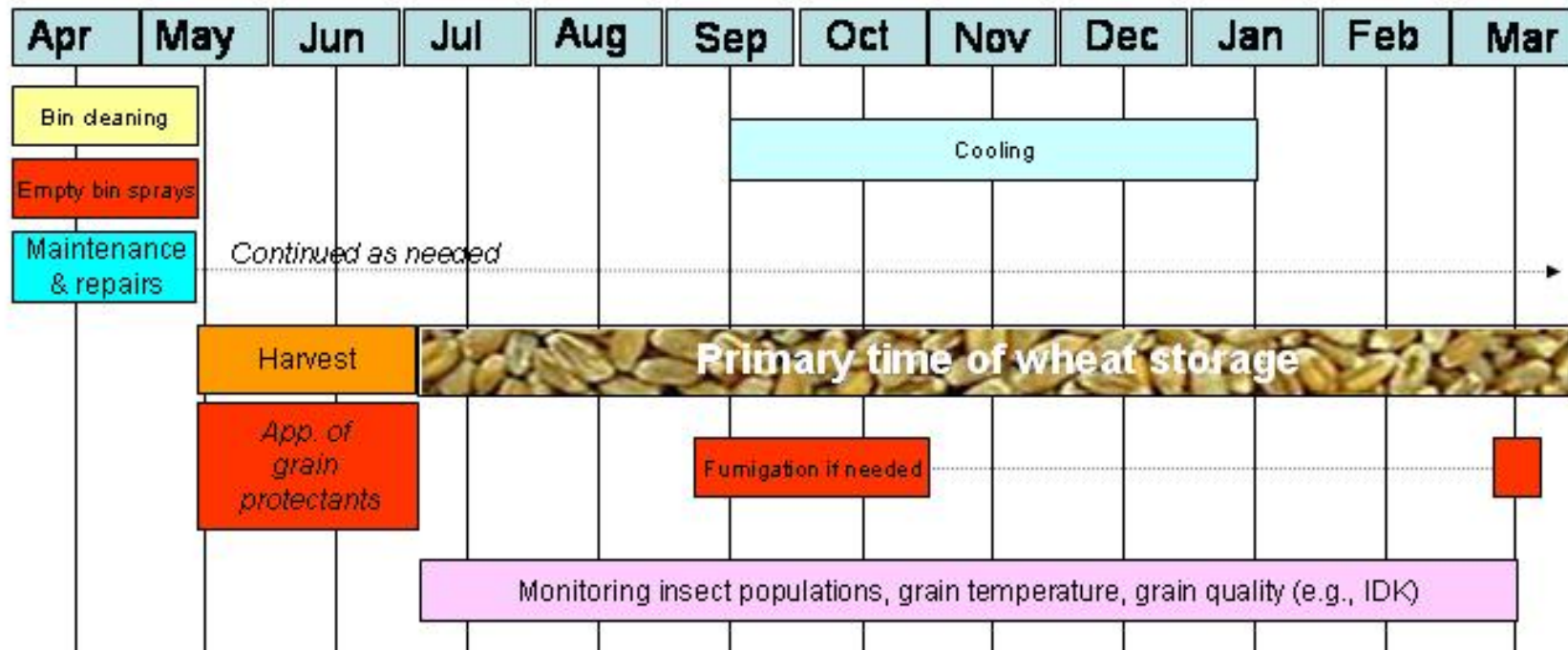


Figure from University of Nebraska, <http://pested.unl.edu/catmans/fum.skp/fumchp6.htm>

Trier. Also called Hand Probe. Probes come in various sizes with standard lengths of 5, 6, 8, 10, and 12 feet. There are two types of hand probes: compartmented probes in which slots in the outer tube match compartments in the inner tube, and open throat probes in which the inner tube is open. Open-throat probes tend to draw more of their sample from the top portion of the grain, while compartmented probes draw a representative sample from each layer. All official grain probes are compartmented probes 1-3/8 inches in diameter (outer tube).



Timeline for Pest Management of Stored Hard Red Winter Wheat in Oklahoma



In an ideal grain management system:

- Bins & equipment are repaired and are thoroughly cleaned before harvest, structures are well-sealed to make them leak-proof, and empty-bin insecticides are applied
- Grain protectants are only used in special cases, such as to protect high-value seed wheat
- During wheat storage, grain is monitored frequently and accurately for temperature, insects, and grain quality
- Grain is cooled in late fall and winter with well-maintained aeration fans
- Grain is fumigated correctly and only if needed in late fall
- The cool, insect-free grain is stored all winter and as long into spring as need be to maximize profit
- Grain may need to be fumigated to kill live insects at time of sale.