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Farm-Stored Wheat in Kansas:

Facilities, Conditions, Pest Control and Cost Comparisons

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Walter R. Woods, Director

FARM-STORED WHEAT IN KANSAS: FACILITIES, CONDITIONS, PEST CONTROL, AND COST COMPARISONS[1]

Carl Reed and John Pedersen[2]

ABSTRACT

Two surveys of on-farm facilities and practices for wheat storage in Kansas were supplemented with farm inspections and bin samplings. The mean on-farm storage capacity was 22,118 bu/farm in 1986. Storage was concentrated with a few producers in the western third of Kansas. Nonaerated, flat-floor, metal bins were most popular, followed by aerated, flat-floor and aerated, hopper-bottom bins. About 60 percent of all storage bins were equipped for aeration. Insect density was significantly reduced by low temperatures. About one-third of Kansas wheat was stored without chemical treatment. Protectant treatment was the most common, but producers with large storage capacity used both protectant and fumigation. Spraying bins with insecticide before harvest significantly decreased insect infestation in stored wheat. Malathion was not always a successful grain protectant, but was the most cost-effective treatment. It was less expensive than fumigation, reduced the need to fumigate later, as well as the probability of a price discount because of live insects, and minimized insect consumption of grain.

Acknowledgements

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[1]Contribution 87-464-B from the Kansas Agricultural Experiment Station.

[2]Research Associate and Stored-Grain Research Entomologist, respectively, Department of Grain Science and Industry, Kansas State University.

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INTRODUCTION

In recent years, Kansas wheat producers have held approximately one-fifth of the state's wheat stocks on their farms. The on-farm storage capacity that could be used for wheat has increased to well over 100 million bushels, depending on the on-farm stocks of other grains (Kansas Crop Reporting Service, 1987).

The conditions under which this wheat is held and the practices used to maintain its quality are of interest to stored-grain researchers. In order to develop extension information for farmers that will be current and cogent, the investigator must understand the cost relationships involved in pest control and grain quality maintenance. Also, in order to make reasonable recommendations relative to policies and practices that affect the quality of wheat in marketing channels, the characteristics of the farm-stored component and its contribution to the overall quality of marketed wheat must be understood.

Kansas has a long history of research in farm storage of wheat. Preliminary studies were begun in 1907, and pioneering experiment station work began in 1916 (Swanson and Fenton, 1933). Although this investigation was cut short by war-time considerations, by 1923, a joint project of the Department of Milling Industry and the Department of Agricultural Economics was underway. This study focused on the effects of farm storage on shrinkage, loss, and reduction in baking quality (Swanson and Fenton, 1933). Experiment station projects resumed again in 1929, with a study of the storage characteristics of various types of farm bins. Much was learned about the effects of moisture content, heat, and ventilation on the quality of farm-stored wheat.

Cotton and Winburn (1941) investigated field infestation of wheat by stored-grain insects, and by the mid 1940's, Walkden (1951) and others were investigating the economic consequences of insect infestation in farm-stored wheat. Beginning in 1942, on-farm movements of stored-grain insects were studied. By 1950, data from central Kansas bins had been used to describe the relationship between the reproductive rate of stored-grain insects and the moisture and fine material content of the stored wheat (Cotton et al., 1960).

Wilbur and Warren (1958) investigated on-farm wheat storage conditions on more than 300 central Kansas farms in the late 1940's and early 1950's. They included an evaluation of the effectiveness of various chemical treatments against stored grain insects. By 1960, several reports had been published to assist the public with quality maintenance and insect control in stored grain and grain products (Dean, 1908; Holman et al., 1949; Walkden, 1951; and Cotton et al., 1960). This Kansas research before 1960 provided much of the basis for currently used texts and U.S. extension literature on pest control in farm storage.

In 1971 (Bell et al., 1972) and again in 1975-76 (McGaughey et al., 1978), surveys of insect densities were published for Kansas farm-stored grain. In 1982-83, Storey et al. (1984) examined samples of marketed, farm-stored grain from 27 states including Kansas. They reported that Kansas wheat was among the most likely to have been fumigated and that the proportion of samples containing protectant residues was greater in Kansas than in most states.

Reed (1986) described on-farm wheat storage facilities and pest control practices with questionnaire data from central Kansas. The results of the 10-county survey showed that storage facilities and equipment had changed substantially from those described by Wilbur and Warren (1958) in the early 1950's. This fact and the probable effects of the recent increase in unsold wheat reserves and ban on the most commonly used grain fumigants prompted the study described herein.

Part I of this report focuses on the results of a statewide questionnaire survey carried out in 1986. It discusses storage facilities and pest control practices. Results of the 1984 survey in central Kansas were not combined with those of the larger study because sampling rates were not identical and the effect of the time difference was confounded with the effect of location. In certain instances, however, comparisons are made between results of the two surveys. Part II presents results of studies conducted in farm-stored wheat in 1984-85. The physical conditions of the storage area prior to harvest and conditions during storage were related to the cost and success of insect control practices.

PART I. FACILITIES AND PEST CONTROL PRACTICES USED FOR FARM-STORED WHEAT

MATERIALS AND METHODS

Because county lists of wheat producers who stored on-farm were not available, sample selection was randomized on the basis of location. To increase the probability of encountering wheat producers with on-farm storage capacity, the sample was biased toward areas of relatively greater wheat production. All Kansas counties (except the 10 included in the 1984 study described below) whose mean wheat production from 1979-84 was at least 50 percent greater than the statewide county average for that period were included in the original sample. To provide clusters of samples for further on-farm research, 28 counties were selected at random (Figure 1) and 55 farm locations were randomly chosen from each. Equal numbers of locations were selected from each township to facilitate representation from all parts of each county.

For the 1984 study, sample selection was similar, but the survey area was limited to within a 150-mile (241 km) radius west of Manhattan, Kansas. The 10 counties shown in Figure 1 were randomly selected from the 25 highest wheat-producing counties. With the assistance of county Agricultural Stabilization and Conservation Service (ASCS) personnel, 45 four-section areas were randomly chosen in each county, and two working farmsteads were randomly selected from each area.

Names and telephone numbers of persons owning or living at the chosen locations were obtained from county rural directories, and each selected individual was contacted by telephone to determine whether wheat was produced and stored at the chosen site. Persons who could not be contacted or who did not produce or store were not replaced. Individuals who stored more than 900 bu of wheat on-farm for 3 months or more were asked if they would complete a mailed questionnaire. If the individual agreed, a questionnaire was sent with a coded, stamped, return envelope.

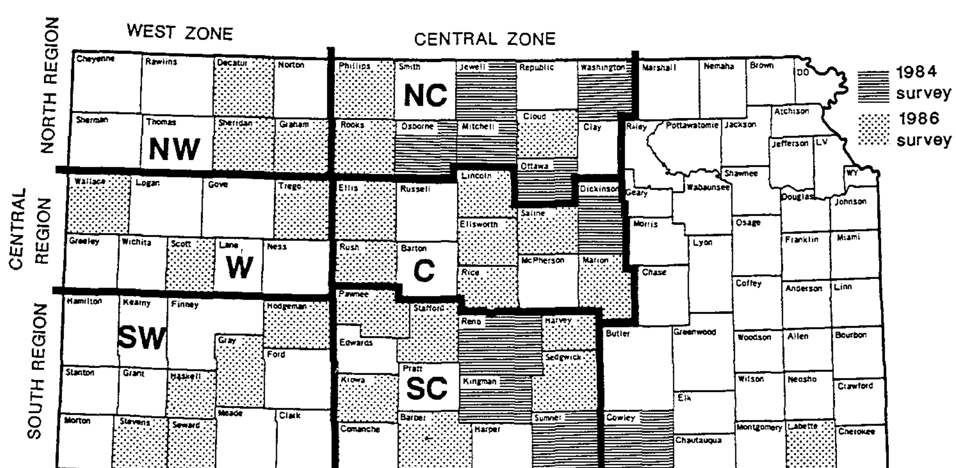
The questionnaire was developed in 1984 to provide information about the facilities and pest control practices used for farm-stored wheat. Items related to the producers' perception of losses and the costs of pest control were included. A draft of the questionnaire was completed by wheat producers attending a grain storage seminar outside the survey area. Based on the findings of that test, individual items were modified to assure that they could be completed easily without the assistance of the researcher. Respondents were instructed to answer all questions relative to wheat only and not other farm-stored grain. In 1984, 215 questionnaires were mailed and 148 were returned. In 1986, approximately 250 questionnaires were mailed and 170 were returned.

In June and July, 1986, investigators visited 79 of the originally identified farms where wheat was produced and stored. Because of time limitations, farms in Barber, Gray, Haskell, Kiowa, Seward, and Stevens counties were not observed. Data from these observations and interviews provided further descriptions of facilities for farm-stored wheat.

The system of geographical districts used by the Kansas Crop Reporting Service was adopted (Figure 1). Since the deliberate biasing of the sample effectively eliminated counties in the eastern one-third of the state*, the six districts shown in Figure 1 are the northwest (NW), west (W), southwest (SW), northcentral (NC), central (C), and southcentral (SC). To examine possible differences over larger geographical areas, certain analyses were made by east-west zones and north-south regions.

*Labette County, in southeast Kansas, met the minimum wheat production requirements and was randomly selected. For purposes of this analysis, the three questionnaires from Labette County were included with those of the southcentral district.

Figure 1. Locations of Surveyed Counties



RESULTS AND DISCUSSION

General

Table 1 shows certain important characteristics of the sample. Because not all individuals at the selected sites could be contacted and not all of those contacted were farmers, the numbers upon which the percentages were based ranged from 20 to 44 per county. Overall, wheat was produced at 88.5 percent of the farm sites and at least 900 bu of wheat were stored on-farm for 3 months or more on 40.7 percent of those farms. In the southern one-third of the survey area, however, only 32.9 percent of the contacted farmers stored wheat. Overall, 45.7 percent of the wheat producers contacted said they stored wheat on-farm, but only 37.6 percent in the southern region stored on-farm.

Storage Structures and Their Capacity

The frequency of various types of on-farm wheat storage structures and the relative numbers of each are shown in Table 2. A hopper-bottom bin is a round metal structure whose concrete floor has the shape of an inverted cone and extends below ground level. Flat-floor bins are round metal structures with metal or concrete floors at or just above ground level. False-floor bins are round metal bins typically with a ground-level floor of concrete and a metal, fully perforated floor located approximately 12" (26.4 cm) above the concrete one, designed to allow the movement of forced air through the grain. Drying bins are false-floor bins equipped with heaters to increase the temperature of the forced air. Flat stores are typically sheds with concrete floors whose prin-

Table 1. Percent and Location of Selected Farms Where Wheat Was Produced and Stored

Location	Number of Counties	Percent of All Farms That		Percent of Wheat Producers Who Store Wheat On-Farm
		Produce Wheat	Store Wheat	
District				
NW	3	88.2	43.9	50.0
W	3	84.9	41.7	49.1
SW	5	96.2	36.2	37.4
NC	3	95.2	44.9	46.9
C	7	89.3	47.6	52.9
SC	7	77.4	29.6	37.7
Zone				
West	11	89.8	40.6	45.5
Central	17	87.3	40.7	45.8
Region				
North	6	91.7	44.4	48.5
Central	10	87.1	44.7	51.0
South	12	86.8	32.9	37.6
Overall	28	88.5	40.7	45.7
Standard* Error of Mean	-	2.16	2.54	2.43

*Based on county-to-county variation

Table 2. Frequency Distribution and Numbers of Various Types of Wheat Storage Structures with and without Aeration

Type of Structure	Percent of Total Number of Farms		Percent of Total Number of Bins	
	Aerated	Nonaerated	Aerated	Nonaerated
Hopper-bottom metal bin	30.0	11.8	23.4	5.7
Flat-floor metal bin	37.6	41.8	25.8	18.9
False-floor metal bin	7.6	-	2.6	-
Drying bin	11.8	-	5.1	-
Flat store	4.7	13.5	1.5	4.2
Wooden bin	5.3	22.3	2.3	10.6

cipal function is equipment storage, whereas wooden bins are usually upright structures, originally designed for grain storage.

Nonaerated, flat-floor bins were the most common wheat storage structures (Table 2) reported by 41.8 percent of the respondents. Thirty percent reported having the more expensive, aerated, hopper-bottom bins. This was an unexpected finding, since only 12.2 percent of the farmers in the earlier central Kansas study had reported the latter type of structure. Approximately equal numbers of aerated, hopper-bottom and aerated, flat-floor bins were reported. Together they comprised nearly half of all storage structures. While wooden structures were reported on approximately one-fourth of the farm sites, only 1.8 percent had only wooden or flat storage; 98.2 percent had metal bins.

Although both the frequency and the total numbers of flat-floor bins appeared to be nearly equally divided between aerated and nonaerated structures, the overwhelming majority of hopper-bottom bins was equipped for aeration. It seems likely that an individual who is willing to invest more in the convenience and increased capacity of self-unloading, hopper-bottom bins is also more likely to install aeration equipment.

Figure 2 illustrates the distribution of aerated and nonaerated, on-farm wheat storage capacity in various types of structures. Although nonaerated, flat-floor bins were reported by more farmers than any other type of structure (Table 2), a relatively small portion of the total storage capacity consisted of this type of bin. Apparently, flat stores and wooden stores were much less likely to be equipped for aeration than round metal bins. It appeared (Table 3) that there would be more metal bins on a farm using aeration than on one with no aeration. Overall, 60.5 percent of the storage structures were equipped for aeration. One-third (35.9 percent) of the surveyed farmers reported only aerated storage. Another 37.1 percent reported having both aerated and nonaerated bins, and 27.1 percent had only nonaerated storage capacity.

Figure 3 shows the bin age distribution on 60 of the farms visited. Bin age, as estimated by their owners, ranged from 1 year to 86 years, with a mean age of approximately 27 years. Approximately one-third of the bins were 30 years or older, but nearly half were less than 20 years old. It appeared that in 1986, little wheat was being stored in the types of structure commonly observed by Wilbur and Warren (1958) in the late 1940's and early 1950's. Bins having solid metal floors without concrete slabs were reported on only 5 percent of the farms visited. No wheat storage in boxcars was observed, and eight of the 11 farmers who had wooden bins said they would not be used for wheat.

Fifteen of the farms visited had at least one bin with a fully perforated floor. This type of floor is especially difficult to clean, except with a vacuum sweeper. Approximately 15 percent of the farmers who were asked indicated that they used a vacuum sweeper to clean their bins before storing wheat.

Figure 2. Storage Capacity by Type of Structure as a Percent of Total Capacity of Surveyed Farms

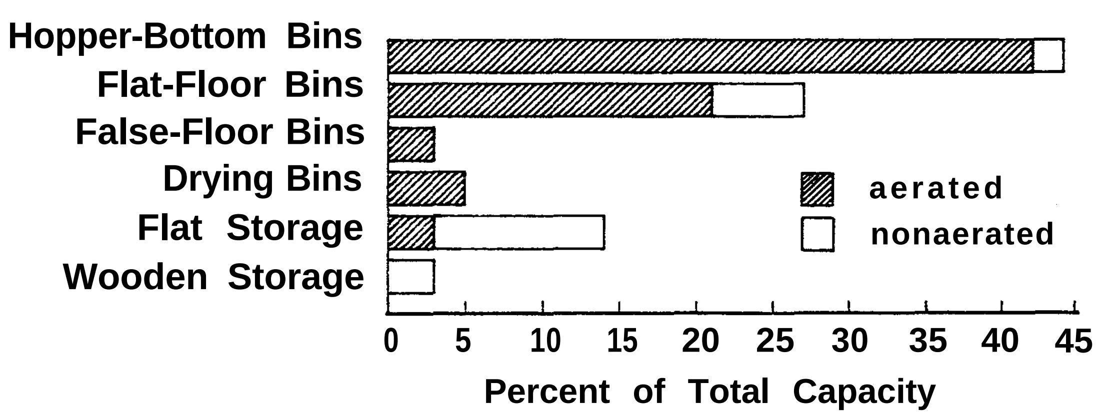


Table 3. Mean Number of Storage Structures per Farm

Type of Structure	Mean Number/Farm* Aerated	Nonaerated
Hopper-bottom metal bin	3.7	2.3
Flat-floor metal bin	3.3	2.2
False-floor metal bin	1.6	-
Drying bin	2.1	-
Flat store	1.5	1.5
Wooden bin	2.1	2.3

*Based on only those farms reporting that type of structure

The total on-farm wheat storage capacity reported by the 170 respondents was 3,760,100 bu (102,548 M.T.), and the mean capacity per farm was 22,118 bu (603.2 M.T.). Of this, 45.3 percent was located in hopper-bottom bins and 76.5 percent was equipped for aeration.

On-farm storage capacity per farm and per bin in round metal bins tended to be much greater in aerated than nonaerated structures (Table 4). The same tendency was not observed in the case of wooden or flat stores, possibly because these are often perceived as temporary or marginal storage facilities. Also, wooden structures are usually small (less than 2,000 bu capacity), and owners may feel that aeration is unnecessary.

Farmers who reported having aerated, hopper-bottom bins stored a mean of 31,430 bu in this type of structure (Table 4). Such bins apparently were favored by certain producers located in the southwest corner of Kansas, who have extremely large amounts of on-farm storage capacity. Of the 51 questionnaires listing capacity in aerated hopper-bottom bins, 11 reported a total capacity of 50,000 bushels or more, and 10 of those were received from the west or southwest districts.

Producers from those districts reported significantly (P<0.5) greater, total, on-farm wheat storage capacity than those from other districts (Table 5). In general, farmers located in the western third of the state reported

Figure 3. Age Distribution of Farm Bins, 1966

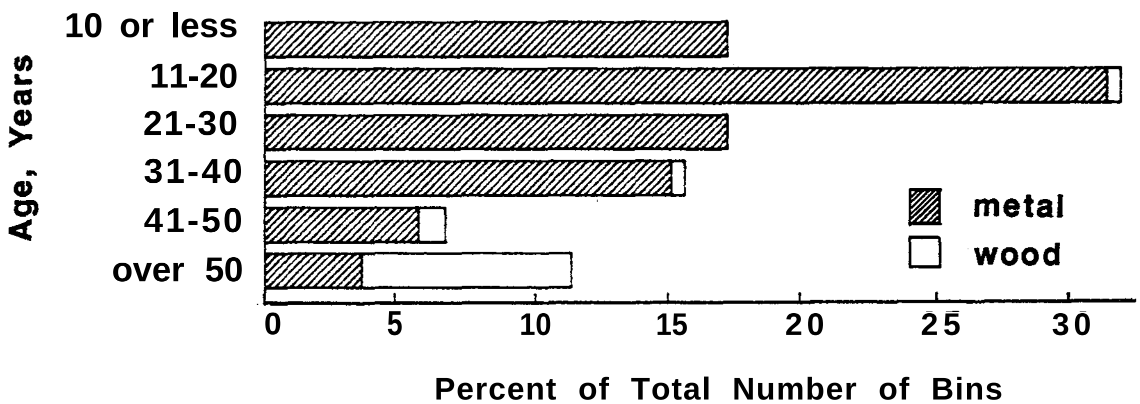


Table 4. Mean Capacity per Farm and per Bin in Various Structures

	Mean Capacity per Farm (bu)*		Mean Capacity per Bin (bu)	
Type of Structure	Aerated	Nonaerated	Aerated	Nonaerated
Hopper-bottom metal bin	31,430	5,055	8,236	2,198
Flat-floor metal bin	12,540	3,612	3,780	1,676
False-floor metal bin	9,300	-	5,757	-
Drying bin	9,850	-	4,566	-
Flat store	18,190	18,740	12,125	12,124
Wooden bin	3,320	2,920	1,574	1,326

*Based only on those farms reporting this type of structure

Table 5. Mean Wheat Storage Capacity by Geographical District

District	Mean Capacity/Farm (bu)
West	45,580
Southwest	41,350
Northwest	24,020
Northcentral	15,140
Central	10,930
Southcentral	10,840

significantly greater numbers of storage structures and greater on-farm storage capacity than those in the central zone (Table 6). No significant differences were observed, however, when the mean number of bins and mean storage capacity per farm were compared by north-south regions. The mean, total, on-farm storage capacity for wheat reported by producers from the western zone was more than three times greater than that reported for the central zone.

The on-farm wheat storage capacity reported by the surveyed farmers ranged from 500 bu to 257,000 bu. Half of the respondents listed wheat storage capacity of 10,000 bu or less, and nearly one-third listed 5,000 bu or less (Figure 4). While only 12.6 percent of the respondents reported having more than 50,000 bushels of on-farm wheat storage capacity, they collectively held nearly half (48.9 percent) of the total storage capacity (Figure 5). In contrast, those who reported 5,000 bu or less collectively owned only 10 percent of the total reported storage capacity. In summary, the majority of Kansas farmers who store wheat on their farms appeared to have a rather modest amount of storage capacity, whereas the relatively few farmers who owned large quantities of storage capacity apparently managed the bulk of Kansas farm-stored wheat.

During the 1950's, Wilbur and Warren (1958) investigated farm storage facilities and conditions in many of the same central and southcentral counties that we surveyed in 1986. Analysis of portions of their data allows a comparison with observations made approximately 25 years later. In 1950, of 24 farm stores used in a grain protectant study, 54 percent were of 1,000 bu capacity, and the mean capacity per bin was 998 bu. In 1986, only 34 percent of the bins in central and southcentral Kansas were 1,200 bu or less, and many of these bins were no longer used for storing market wheat. The mean capacity of the flat-floor bins in 1986 were 1,450 bu (nonaerated) and 2,195 bu (aerated).

In a separate study in 1952, Wilber and Warren (1958) examined 44 bins. Twenty-three percent were boxcars and only 35 percent were round steel bins, compared with 75 percent round steel bins and 18.9 percent wooden structures in 1986. In 1952, the wheat storage capacity per central Kansas farm ranged from 33 to 9,100 bu with a mean of 3,100 bu; in 1986, the mean reported wheat storage capacity was 10,930 bu in central Kansas. However, the mean storage capacity per farm in wooden bins was almost identical to that reported in 1952. This probably indicates that, although few wooden granaries have been destroyed since the early 1950's, additional storage capacity has taken the form of metal structures.

Kansas farms apparently have about the same proportion of aerated to nonaerated storage structures as Oklahoma farms, but a greater proportion of aerated bins than South Dakota farms. Prickett et al. (1983) reported that a third to a half of surveyed farm bins in Oklahoma were equipped for aeration, but only 2.3 percent of the bins examined by Ingemansen et al. (1985) in South Dakota were aerated.

In Kansas, a mean of 67.8 percent of the on-farm wheat storage capacity reported by farmers in the northern region was aerated, whereas in the central and southern regions, aerated storage was 80.3 percent and 77.2 percent, respectively. While this appears to indicate some trend toward less use of aeration in the northern part of the 1986 survey area, the differences were not statistically significant at the 5 percent level. It seems plausible that farmers in the colder northern states may rely more on natural, unassisted cooling to preserve grain quality than those in warmer states such as Kansas and Oklahoma.

Table 6. Mean Wheat Storage Capability as Influenced by Geographical Location

Mean per Farm	Western Zone	Central Zone
Mean number of storage structures	5.7	4.2**
Mean capacity in round metal bins (bu)[a]	32,230	9,960**
Mean capacity in flat storage (bu)[a]	28,810	11,450*
Mean total storage capacity (bu)[a]	37,740	11,800**

*Means different at P<0.05
**Means different at P<0.0l
[a]Based only on those farms reporting this type of structure

Figure 4. Percent of Surveyed Farms Described by Storage Capacity Ranges

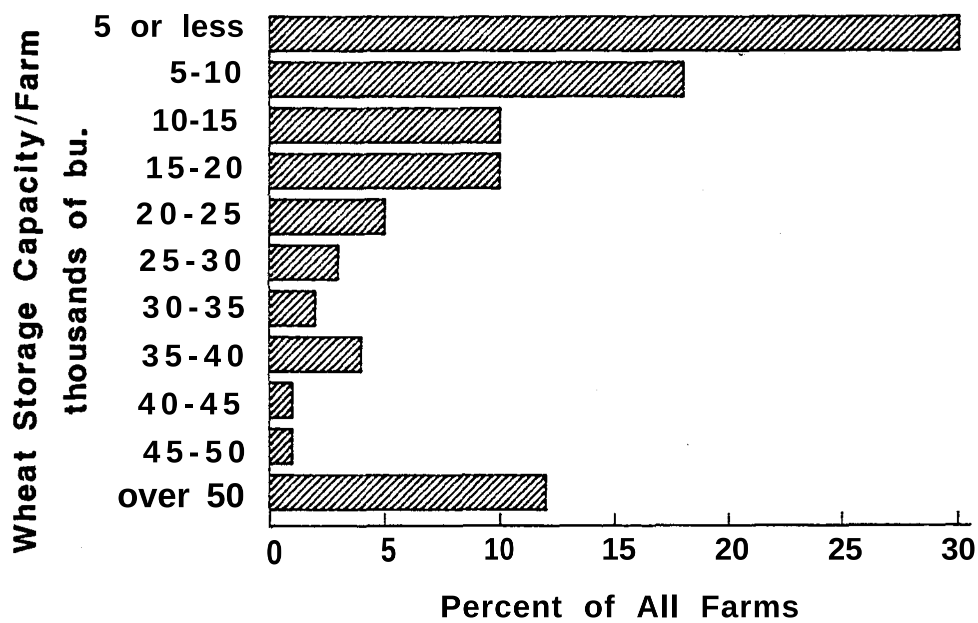
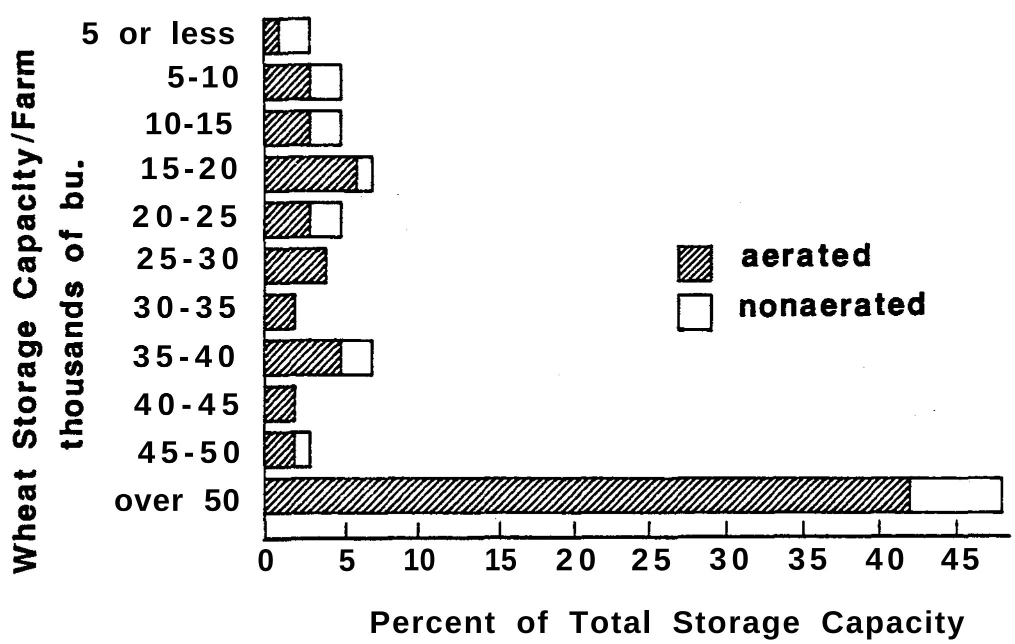


Figure 5. Percent of Total Storage Capacity Held on Farms of Various Storage Ranges



Storage Practices and Pest Control

Responses to questions about sanitation and pest control practices are summarized in Table 7. The majority of respondents indicated that they accomplished the less expensive, general sanitation practices, such as cleaning storage structures and spraying with insecticide, before adding new wheat and removing spilled grain.

Storey et al. (1984) reported that the application of a grain protectant was the most common pest control practice in stored wheat in a 27-state area. Nineteen percent of the Kansas wheat samples analyzed in that study contained residues of malathion grain protectant.

The length of storage may affect the choice of pest control measures. Approximately three-quarters of the respondents stored for at least 6 months, and nearly half usually intended to store for up to 9 months. A significant ($P < 0.05$) association was observed between intended length of storage and the choice of a pest control measure. As would be expected, those who intended to store for a short period of time usually opted for the least expensive measures.

Another factor that may increase the risk of deterioration and loss in farm-stored wheat is the proximity to old grain, which may be a source of infestation. While only 8.2 percent of the respondents reported having stored wheat from two crop years in the same bin, 37.3 percent said they had stored old- and new-crop wheat close together.

The moisture content of grain also affects its storability. Figure 6 shows the distribution of reported moisture contents of 1985 wheat at the time of storage. The histogram is very similar to that developed from 1984 data and that reported from 1950 data by Cotton et al. (1960). The majority of farmers reported storing their wheat at moisture content levels within the range tolerated by most common, stored-grain insects.

Comparison of Pest Control Strategies

From the information in Table 7, the following pest control strategies were identified:

1) *Minimum Treatment,* which may consist of bin cleaning and surface spraying, but does not include a chemical treatment to the grain;

2) *Protectant Treatment,* which consists of the minimum treatment plus the application of a grain protectant during bin filling;

3) *Fumigation Treatment,* which consists of the minimum treatment and a preventive fumigation even if no significant insect infestation is observed;

4) *Protectant and Fumigation Treatment,* which is a combination of all treatments.

The cost of chemical treatment itself is lowest for the minimum treatment and is greater for the other treatments.

Producers who reported using the protectant treatment were more common and collectively reported more on-farm wheat storage capacity than producers who used other treatments (Figure 7). The use of both protectant and preventive fumigation was selected by the fewest producers, but these collectively held 18.6 percent of the total quantity stored. Producers who indicated that they used the protectant and fumigation treatment tended to report large storage capacities. The mean, on-farm wheat storage capacity was 23,860 bu, 20,810 bu, 15,300 bu, and 33,220 bu for the minimum treatment, protectant treatment, fumigation treatment, and protectant and fumigation treatment, respectively. Apparently, about one-third of Kansas farm-stored wheat is often held without chemical treatment.

It has been suggested that aeration may be used in lieu of chemicals to control insects in farm-stored grain (Halderson and Sandvol, 1980; Cuperus et al., 1986). Information from this survey appeared to indicate that a few Kansas farmers may use this strategy. Seventy-one percent of the capacity listed by producers who used the protectant treatment and 73 percent of the capacity reported by those who used fumigation was equipped for aeration. However, 85 percent of the capacity reported by producers who claimed to use no chemicals in farm-stored wheat had aeration capability. The ratio of aerated to non-aerated capacity among individual farms, however, was extremely variable, and no significant association could be demonstrated between the proportion of aerated storage and the choice of pest control strategy.

Table 7. Percent Of Respondents Using a Storage or Pest Control Practice

Practice	Percent
Empty and sweep bins before filling	96.5
Treat bins with insecticide before filling	78.8
Use a grain spreader when filling bins	10.0
Clean wheat before storing	2.4
Apply protectant to wheat when filling bins	53.5
Apply protectant to wheat surface after filling bins	27.6
Level wheat after filling bins	53.5
Remove spills around bins and debris from auger	75.9
Hang insecticide strip above grain or in bin door	28.8
Fumigate wheat as a precautionary measure	27.1

Figure 6. Frequency Distribution of Moisture Content of Farm-Stored Wheat, 1985 Harvest

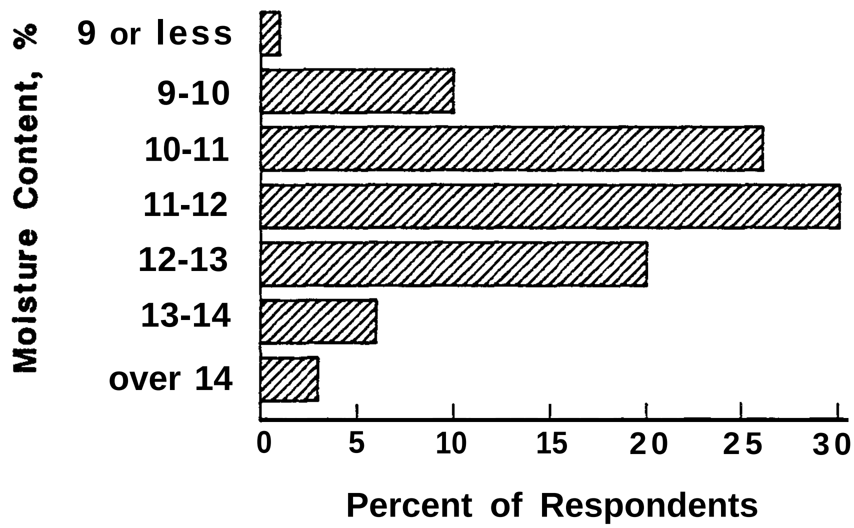


Figure 7. Frequency of Various Pest Control Strategies and Percent of Total Storage Capacity in Which Each Was Used

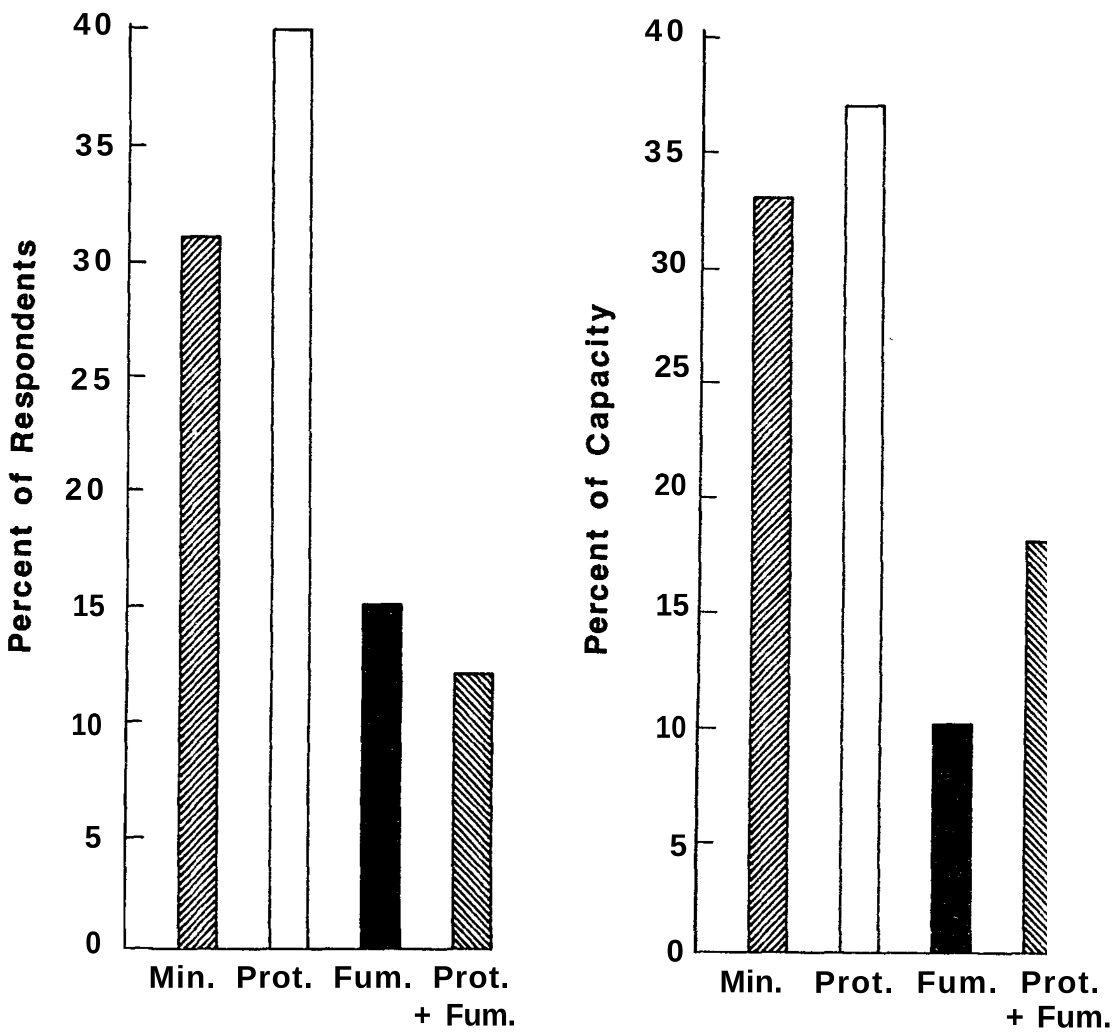


Figure 8 shows the distribution of the total reported storage capacity by pest control strategy and type of structure. The majority (55.4 percent) of the capacity in which wheat received either no treatment or only a protectant insecticide consisted of either hopper-bottom or flat-floor bins.

These results indicate that farms with extremely large storage capacity tended to have hopper-bottom bins, in which wheat received either the least expensive, minimum treatment or the most expensive, protectant and fumigation treatment (Table 8). This apparent discrepancy may be partially explained by the fact that some producers (presumably many of those who use the minimum treatment) store wheat for relatively short periods of time in bins whose main function is the storage of fall crops. It is likely that this wheat is stored without investment in chemical treatments.

This could explain the extremely large mean storage in drying bins reported by producers who use the minimum treatment (Table 8). Since most Kansas wheat is harvested at less than 12 percent moisture content (Figure 7), it is likely that those who report storing large quantities of wheat in drying bins hold it without drying until the fall crops (for which the drying bins were constructed) are harvested. This practice minimizes the amount of time devoted to transporting wheat during the busy harvest season and allows the producer to profit from typical wheat price increases during the fall months.

Another apparent enigma in Table 8 is the extremely low mean capacity of producers who used both protectant and fumigation in nonaerated, hopper-bottom bins. Three of the 170 returned questionnaires listed storage capacity of less than 500 bushels in this type of structure. Apparently, these producers sometimes store wheat in bulk-material tanks, which are round metal bins with metal hopper bottoms above ground level.

Wheat Inspection during Storage

Eighty-one percent of the respondents reported that they inspected their farm-stored wheat on a regular basis. Of those, 10.9 percent said they inspected it every 2 weeks, and 64.3 percent said their inspections were no more than 1 month apart. Another 22.4 percent reported checking their wheat every 5 to 6 weeks.

The inspection procedures they used varied considerably. Thirty-four different combinations of the six techniques listed in Table 9 were reported. The percentages are nearly identical to those calculated for central Kansas in the 1984 survey and did not appear to be affected by geographical location.

In addition to the techniques listed in the table, 7.9 percent of the respondents reported having temperature monitoring systems in their farm bins. As would be expected, producers with more on-farm storage capacity were more likely ($P<0.05$) to have this equipment. Whereas only 3.1 percent of the producer reporting 15,000 bu of capacity or less indicated that they used temperature monitoring equipment, 19.2 percent of those reporting 40,000 bu or more monitored temperature. The majority of respondents reporting this equipment said they determined the wheat temperatures every 6 to 7 weeks.

Corrective Fumigation

Some respondents who did not list fumigation as part of their intended pest-control strategy did report fumigating, if a bin was found to be insect-infested. Overall, 51.2 percent of the respondents indicated that they had fumigated farm-stored wheat during the 1985-86 storage season. Of these, 62.1 percent reported using a liquid fumigant, whereas 24.1 percent said a solid fumigant had been used. A substantial reduction from 1984 was expected in the use of liquid fumigants, since the sale of these fumigants was to have ceased by December 31, 1985. In fact, a rather small decrease (9.1 percent) in the use of liquid fumigants was observed in the central Kansas area covered by the earlier study.

Most (69.2 percent) of those who reported fumigating said they applied the fumigant themselves, and only 12.5 percent reported employing a commercial applicator for this purpose. Contrary to expectations, the use of commercial fumigators did not appear to increase from the previous study. Only 1 percent said that their farm-stored wheat had been fumigated upon delivery to an elevator.

Perception of the Cost of Deterioration in Farm Storage

Less than half of the respondents (45.3 percent) answered a question relating to the discount policy for insect-infested wheat at the elevator where they usually trade. Of those who answered, 50.6 percent said the policy seemed to vary, 18.2 percent indicated that producers were charged for only the cost of fumigating the grain at the elevator, 14.3 percent felt that there was no charge for insect-infested wheat, 9.1 percent thought that infested grain was refused until fumigated, and only 7.8 percent said that there was a price discount levied per bushel of infested wheat.

Since only 13 of the 170 respondents felt they would be subject to a price discount for delivering insect-infested, farm-stored wheat to the elevator, it is not surprising that only 15 estimated the likely cost of the discount. These estimates ranged from $0.02/bu to $0.25/bu, with four persons estimating the discount at $0.03/bu or less and seven estimating $0.05/bu or less. The median estimate was $0.05/bu.

Slightly more (52.4 percent) responded to a question about price discounts for insect-produced odor or grain damage in wheat at the elevator to which they usually delivered. Of these, 56.2 percent indicated that price discounts were applied for these factors, but only 15 questionnaires listed estimates of the cost. These estimates ranged from $0.01/bu to $0.20/bu. The most frequent estimate was $0.05/bu (five respondents), whereas two thought the discount would be less and eight estimated a greater cost.

Since the respondents were instructed to omit items for which they were unsure of the answers, the low response to these questions is taken to mean that many wheat producers who store on the farm are not aware of

Figure 8. Percent of Total Storage Capacity by Type of Structure and Pest Control Strategy

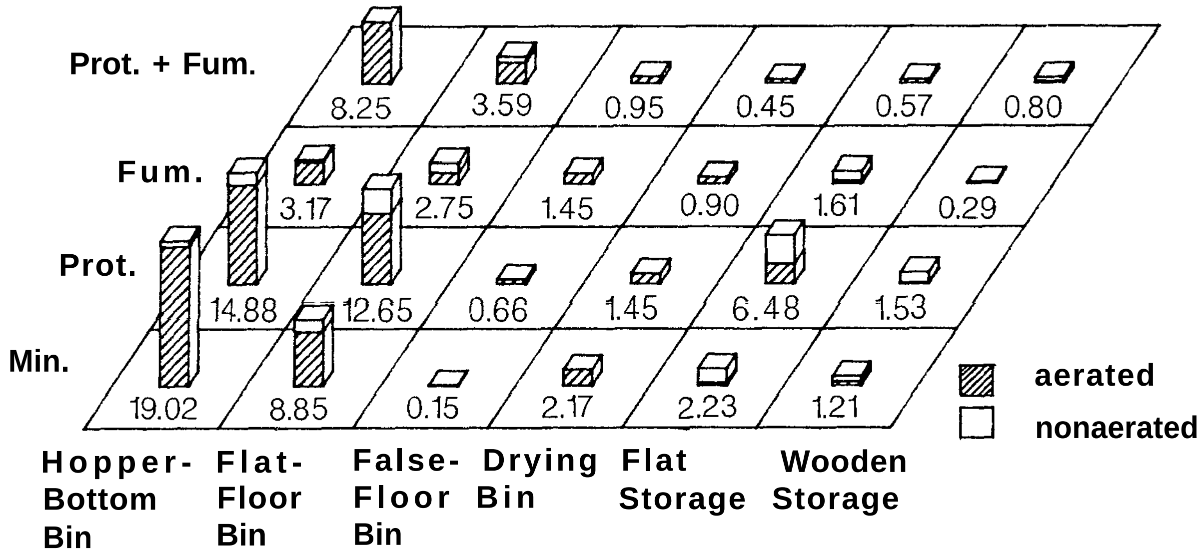


Table 8. Mean Storage Capacity (bu) per Farm by Type of Structure and Pest Control Strategy

Type of Structure	Pest Control Strategy: Minimum Treatment	Protectant Treatment	Fumigation Treatment	Fumigation & Protectant Treatment
Aerated:				
Hopper-bottom bin	42,900	21,610	15,620	61,900
Flat-floor bin	17,030	12,630	7,250	9,630
False-floor bin	1,930	6,250	13,630	17,800
Drying bin	16,340	7,790	8,500	5,670
Flat store	12,000	19,700	15,000	20,000
Wooden bin	2,550	3,210	2,160	3,430
Nonaerated:				
Hopper-bottom bin	4,100	6,880	3,300	600
Flat-floor bin	2,610	4,360	3,500	4,130
Flat store	14,340	16,110	9,100	5,000
Wooden bin	2,900	3,000	-	4,750

Table 9. Percent of Respondents Using the Indicated Wheat Inspection Procedure

Method Inspection	Percent
Observing samples taken with a probe	59.1
Observing samples scooped from the surface	59.9
Observing the grain surface	64.9
Determining the moisture content of samples	7.8
Determining the temperature of samples	20.1
Determining grain temperature with a probe	24.7

their buyer's discounting policies regarding low quality wheat. In many cases, it is likely that the respondents had never received any type of penalty or discount for storage-related deterioration and, therefore, were unable to answer. Nevertheless, 51.2 percent answered a question comparing the cost of pest control to the cost of deterioration and loss when pests are not controlled. Nearly three-quarters (74.5 percent) of those responding felt that the cost of the loss and penalties for infested and/or damaged wheat was greater than the cost of controlling pests in stored wheat. Producers who reported relatively large storage capacity appeared to be more likely to respond to this item than those with smaller quantities of on-farm wheat storage.

Aeration and Turning Practices

One hundred twenty-one of the returned questionnaires listed some aerated storage capacity and were used in the following analysis. In general, response to questions dealing with aeration practices was poor, although producers reporting relatively larger capacities appeared more likely to answer many of the technical items than those with less storage capacity. This may indicate a lack of confidence as to proper aeration techniques, especially on the part of producers with relatively small amounts of farm storage. Field observations that aeration is frequently mismanaged or not used at all for wheat lends credence to this interpretation.

When asked if they aerated all farm-stored wheat, 62.3 percent answered affirmatively. The rest apparently aerated only some of the stored wheat. Most indicated that the decision as to which wheat to aerate depended simply on which bins were equipped for aeration. Others reported that they aerated wheat that had above-normal moisture content, did not appear to be cooling normally, or had developed hot spots.

Of those who responded, 73.5 percent reported beginning aeration immediately after storage. This included 13.3 percent who operated aeration fans only during cooler times of the day and 60.2 percent who reported operating their fans continuously. Of the 26.5 percent who said they waited until temperatures cooled in the fall before aerating, about three-quarters operated fans 24 hrs/day.

Figure 9 shows the number of aeration periods reported by the surveyed producers. Slightly more than half of the producers with aerated bins responded to this item, and most of those (60.8 percent) indicated that they had used either two or three aeration periods during the previous storage season. Those farmers reporting a large amount of storage capacity were more likely ($P < 0.05$) to report three or more aeration periods than farmers with less capacity.

About 20 percent of producers with aerated capacity indicated the temperature to which they cooled farm-stored wheat. Of these, 48.1 percent said they cooled it to 35-40°F. Forty-four percent had no particular target temperature.

When asked the total number of hours of fan operation, 45.5 percent responded. Over half of those (57.1 percent) operated their fans for a total of 60 hrs or less to cool the entire bin of wheat to the desired temperature. Approximately 20 percent reported operating fans for 30 hrs or less, whereas only 16.3 percent reported more than 120 hrs of fan operation time. If recommended aeration schemes are followed, most farm bins require at least 120 hrs of fan operation.

Table 10 shows the sources of information used by respondents when determining when and how long to aerate, based on the 70.2 percent of the sample that answered the question. Percentages do not total 100, since many farmers listed multiple sources of information. Most respondents (64.3 percent), however, indicated that the sole source of this information was their own experience.

Sixty-eight percent answered a question about the practice of turning wheat from one bin to another as a measure to assist in quality maintenance. Only 10.3 percent of those said that they usually turned farm-stored wheat. Although the most-often reported month for turning wheat was January, there was no agreement among those who responded.

Figure 9. Percent of Respondents Using Various Numbers of Cooling Periods

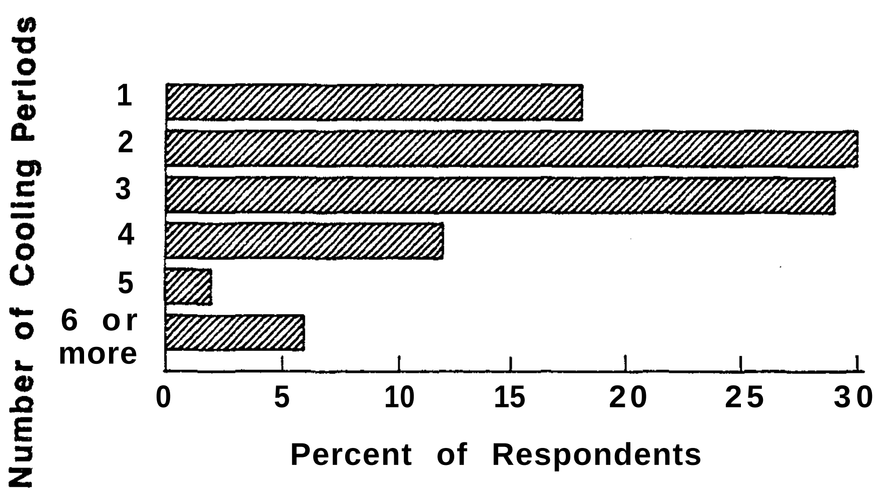


Table 10. Respondent's Use of Information Sources for Aeration Fan Operation

Source of Information	Percent
Kansas State University Extension Bulletins	8.0
The aeration equipment manufacturer's manual	13.1
The individual's own experience	92.9
Others*	13.1

*Advice from extension programs, radio shows, elevator operators, commercial pest control service personnel, etc.

PART II. CONDITIONS IN FARM-STORED WHEAT AND COSTS OF VARIOUS PEST CONTROL STRATEGIES

INTRODUCTION

Sanitation Conditions and Pest Control

Many factors influence conditions within a mass of stored grain. Temperature, moisture content, percent of fine material, amount of broken grain, type of pest control, and other physical and sanitation conditions affect the probability of successfully maintaining stored grain quality.

When Wilbur and Warren (1958) surveyed 335 central Kansas farms in the early 1950's, they found that more than half of the farms that stored market wheat held it in close proximity to feed grains and/or ground feeds, and many farms had grain bins located inside buildings that housed animals. On every farm surveyed, insect-infested grain and feed in bins, adjacent buildings, and equipment were found to be probable sources of contamination for the market wheat.

Cotton et al. (1960), investigating storage conditions on central Kansas farms, reported that from 1946-1950 the majority of farm-stored wheat contained between 11 and 13 percent moisture content. They found a positive correlation between moisture content and insect infestation.

Storey et al. (1984) examined 4,171 samples of wheat from 27 states. According to records submitted with the samples, less than 10 percent had been fumigated, and malathion was found in less than 15 percent of the wheat samples. Kansas wheat was among the most likely to have been fumigated. It was also among the most likely to contain residues of malathion.

In a 1953 study of farm conditions in Nebraska (Anonymous 1954) 97.8 percent of the farm bins had been cleaned but only 65.5 percent had been sprayed with a contact insecticide prior to filling; 43.2 percent had been fumigated. In another Nebraska study, Spitze (1980) reported that not all round bins on the farms he visited had aeration equipment. When he asked farmers whose aeration-equipped grain bins exhibited moisture condensation why they had not aerated, most said that they had been too busy or did not realize the importance of the problem.

In a study of farm-stored corn and wheat in Minnesota, Barak and Harein (1981) noted that less than 10 percent of the wheat had received a "postharvest treatment." All surveyed bins had been cleaned before newly harvested wheat was added, but fewer than 10 percent were treated with insecticide, and none of the wheat had received a malathion treatment during bin filling. Not all bins were leveled after filling, and the authors concluded that pest control recommendations were frequently ignored.

Ingemansen et al. (1985) reported that of 309 bins of farm-stored oats in South Dakota, only 2.3 percent were equipped for aeration and some had wooden floors. They reported that bins cleaned with a vacuum cleaner before filling had lower insect densities in the stored grain.

Cuperus et al. (1986) reported that from 91 to 100 percent of the northern Oklahoma farm-stored wheat bins they sampled in 1982–83, 1983–84, and 1984–85 were equipped for aeration. However, only 21 to 81.4 percent of the producers used the equipment during the storage season. Overall, 72.8 percent of the bins had been sprayed with insecticide prior to filling, 52.7 percent of the bins contained protectant-treated wheat, and 52.1 percent of the bins were fumigated during the three storage periods studied. They found substantially lower insect densities in aerated than in nonaerated wheat.

Fine Material

When grain is dropped into a container for storage, fine material tends to concentrate below the point of fall, forming a "spout line." Christensen and Kaufman (1974) reported that corn containing 2 to 3 percent of this material had more than 50 percent of it in the spout line.

Hall (1984) reported that the width of the spout line in corn was related to the particle size of the fine material. However, his data indicated that in wheat, there was little, if any, accumulation of fine material in the spout line. He concluded that fine particles tended to be carried with the wheat as it moved by gravity away from the point of impact.

Temperature Changes

The temperature near the center of a mass of nonaerated, farm-stored wheat in Kansas was found to approximate the mean ambient temperature with a lag time of approximately 2 months (Cotton et al., 1960) and was affected by the size of the grain mass. Walkden (1951) showed that uninfested wheat in Kansas farm bins began to cool with a fairly uniform temperature gradient from the outside to the center of the grain mass. By February, however, the warmest area of the grain mass was not at the center, but rather at a point near the grain surface and the southern wall. Temperature means in farm-stored grain have been reported by Bloome and Cuperus (1984) and Barak and Harein (1981), but the relationship to mean ambient temperatures was not mentioned.

Grain is aerated to shorten cooling time, to cause grain to become colder than would be possible by natural cooling, and to eliminate temperature gradients within the grain mass. Halderson and Sandvol (1980) and Cuperus et al. (1986) showed that aeration greatly reduced the cooling time in farm-stored grain. Data from the northern Oklahoma farms surveyed by Cuperus et al. (1986) showed that mean grain temperatures in aerated wheat were reduced to approximately 14°C below the lowest mean temperature observed in nonaerated wheat.

Moisture Changes

That moisture may migrate from one point in a grain mass to another, driven by differences in temperature, has long been recognized (Burrell, 1974). The subject has been investigated by Oxley (1948), Joffe (1958) and Anderson et al. (1943). Disney (1969) concluded that damage to grain near bin walls was probably due to a combination of grain moisture diffusion and convecting air rising from the center of the bin. Hall (1970) illustrated air currents in bins of stored grain when the grain was warmer than the outside air and when the outside air was warmer than the grain. Whether these were theoretical models was unclear, but no data relative to changes in moisture were offered.

Cotton et al. (1960) presented data showing that the moisture content of the upper third of a test bin increased 0.7, 0.1, and 0.5 percentage points at the northern, central, and southern positions, respectively, from November to February in uninfested wheat. The center layer, meanwhile, lost moisture from all positions (the mean moisture loss was 0.33 percentage points), while the lower third of the bin gained 0.2, 0.6, and 0.3 percentage points of moisture at the northern, central, and southern positions, respectively. Bloome and Cuperus (1984) found no evidence of warm-season moisture migration in their study of farm-stored grain in Oklahoma and stated the need for investigation to determine if aeration to warm grain in the spring was necessary in that state.

Insects and Insect Densities

Winburn (1940) surveyed farm wheat stores in late October in one central Kansas county and reported that 25 of 27 bins showed "more or less heavy" infestations. He reported finding *Cryptolestes* spp., *Oryzaephilus* spp., *Tribolium* spp., and *Sitophilus oryzae* but not *Rhyzopertha dominica*.

Walkden (1951) reported that insect densities increased from July to October in farm-stored wheat in central Kansas. The populations then tended to decline in November in wheat that contained from 11 percent to 14 percent moisture content. In October, 1971, Bell et al. (1972) sampled 154 bins of Kansas farm-stored wheat. Eighty-eight percent of those bins were found to be infested. *Rhyzopertha dominica* was found in more bins than other insects, followed by *Oryzaephilus surinamensis*, *Tribolium castaneum*, and *Cryptolestes ferrugineus.* The fungus-feeders, *Typhaea stercorea* and *Ahasverus advena*, were also commonly found. *Plodia interpunctella* was found in 79 percent of wheat bins on Kansas farms in 1975-76 (McGaughey et al., 1978), with "heavy infestations" in 24 percent of the bins.

In South Dakota, Ingemansen et al. (1985) reported that *O. surinamensis*, *Cryptolestes* spp., and *T. castaneum* were most commonly found in farm-stored oats. In 1982, the insect density was greatest in November, when 74 percent of the bins were infested. In 1983, the population densities peaked in September, when 84 percent of the bins were infested. Barak and Harein (1981), sampling farm-stored wheat in Minnesota during 1977 and 1978, found that *Cryptolestes* spp., *A. advena, O. surinamensis*, and *P. interpunctella* were the most common insects.

Samples from more than 8,000 farm stores were examined by Storey et al. (1984). They found live insects in 25.1 percent of the wheat, 56.4 percent of the oats, and 79.7 percent of the corn. Mean insect densities of samples from states from which more than 20 samples were examined ranged from 1 to 135/1,000 g, and the mean of the samples from Kansas was 15 insects/1,000 g. In wheat samples, *Cryptolestes* spp. and *Oryzaephilus* spp. were the most common insects.

In Oklahoma, Prickett et al. (1983) found live insects in all farm-stored wheat they sampled. With the exception of *Oryzaephilus* spp., which was present in fewer than 20 percent of the bins, the distribution of insects was similar to that observed in Kansas wheat by Bell et al. (1972). *Tribolium* spp. and *Oryzaephilus* spp. were found in 49 percent and 47 percent, respectively, of farm-stored grain in Idaho (Halderson and Sandvol, 1980) but *Cryptolestes* spp. and *Rhyzopertha dominica* were present in very few bins.

Losses and Their Consequences

There have been few attempts to estimate losses to farm-stored grain in the United States. Walkden (1951) investigated losses in four wheat bins in central Kansas. He reported that the percent damage ranged from 3 to 14, but it is not clear whether this indicated percent of insect-damaged kernels or dry weight lost. He also found that the decrease in test weight ranged from 2 to 8 lb/bu, resulting in discounts of 1¢ to 30¢ at the time of sale. Eden (1967) estimated losses totaling $10 million per year to corn stored in three southern states. This estimate was made by determining the percent weevil-damaged kernels and multiplying by a regression factor relating percent damaged kernels to percent loss of nutrients. A General Accounting Office study (GAO 1981) found that 23.1 percent of farm-stored wheat under government loan in 1978 was infested. Wheat in approximately 10 percent of the bins (2.4 percent of the wheat, by weight) was sample grade or lower.

In many other countries, attempts have been made to estimate losses to grain stored on the farm (Adams, 1977; Barreveld, 1982). These studies have been reviewed by several authors, including Mphuru (1976) and Morris (1978).

The study reported here was undertaken to evaluate conditions in the mid-1980's in farm-stored wheat in Kansas and to determine the costs associated with commonly used pest control practices. The goal of the study was to identify the most cost-effective means of maintaining quality in farm-stored wheat.

MATERIALS AND METHODS

Bin Selection

The questionnaires completed by randomly chosen farmers during the 1984 central Kansas study were stratified by the pest control strategy used for farm-stored wheat according to the following categories: 1) Minimum Treatment—no pest control chemicals applied to the wheat; 2) Malathion (Protectant) Treatmen—-malathion* insecticide applied to the wheat during bin filling; 3) Fumigation Treatment—wheat without malathion fumigated; and 4) Fumigation and Malathion (Protectant) Treatment—wheat treated with malathion insecticide and also fumigated. Bin spraying (e.g., treating the bin with a residual insecticide before filling) was also accomplished in some of the bins in each treatment group. Since each of the practices was used with or without aeration, eight treatment groups in all were identified.

Sixteen farms were selected randomly from the minimum treatment group, eight from those who reported aerating and eight from those who did not. Four farms were selected randomly from each of the remaining combinations of chemical pest control methods and aeration to provide 40 farms for the bin sampling study. Alternates also were chosen randomly for each treatment group, and the selected producers were contacted by telephone and asked to cooperate in the bin sampling study from July, 1984 until May, 1985.

A large proportion of producers who used the minimum treatment were unable or unwilling to cooperate, and many other producers changed their pest control practices from one year to the next. Thirty-four cooperators were ultimately identified, with most of the attrition occurring in the minimum treatment group. One bin per farm was then selected for sampling, based on whether the bin was equipped for aeration, whether the producer intended to store some wheat lots longer than others, etc. When all other factors were equal, the choice of which bin to sample was made by the toss of a die.

Wheat Sampling

The selected bins were sampled at 3-month intervals beginning in July, 1984. Wheat samples of about 1,000 g were taken with a Cargill vacuum probe fitted with 2 ft (0.6 m) sections. When possible, samples were taken at the four cardinal points, at two-thirds the distance from the center to the wall, and at the center. A surface sample was taken from the top 1 in (2.5 cm) of grain. Where lack of space prohibited entry into the bin, samples were taken at the center port and at the roof hatch near the bin wall.

When the depth of the wheat was 8 ft (2.4 m) or less, two samples were taken at the positions described above at one-third and at two-thirds the distance from the grain surface to the bin floor. When the grain depth exceeded 8 ft (2.4 m), samples were taken at one-quarter, one-half, and three-quarters the distance from the grain surface to the bin floor at each point described above. During return visits, samples were drawn from points as close as possible to those where the first samples were obtained. Wheat samples were sealed in plastic bags and kept from freezing (above 40°F, 4.4°C) until analyzed.

Temperature Measurement

Temperatures within the wheat mass were measured with a 20 ft (6.1 m) probe (Yellow Springs Instruments (YSI) Co, Yellow Springs, OH) threaded into a plastic rope, which was inserted into the grain with steel rods. Temperatures were measured with a YSI battery-powered telethermometer. Surface temperatures were measured with a dial thermometer inserted 4 to 7 in (10.2 cm to 16.8 cm) into the wheat. When possible, temperatures were measured at the northern, central, and southern of the bins, with the probes being inserted at approximately two-thirds of the distance from the center to the bin wall for the northern and southern positions. At each position, wheat temperatures were measured at the surface and 6 ft (1.8 m) and 9 ft (2.7 m) below the surface. Where lack of space prohibited entry into the bin, probes were inserted through the center port and at the roof hatch.

Sample Analysis

Samples were weighed and passed over a 0.065 in × 3/8 in (0.16 cm × 0.95 cm) oblong-hole sieve to remove fine material and insects. The fine material was weighed, and live and dead, adult insects were counted. Then a 4 g portion was separated with a Boerner divider and used for moisture measurement. The moisture content was determined using 10-g samples of whole grains held at 130°C for 19 hr according to the method of Hart et al. (1959).

The fine material was sealed in a plastic bag and held at 4°C to await insect identification. The remainder of each sample also was sealed in a plastic bag and stored at 4°C for further analysis.

Loss Estimations Using Insect Density Information

Measurements of bulk density were taken in an attempt to use changes in this parameter as an indicator of the loss of dry weight in the selected wheat bins. However, this technique failed to reliably estimate loss, and information relative to the numbers and types of insects present in each sample had to be used in lieu of the bulk density technique. A straight-line relationship in the population density changes of each species of insect was assumed be-

*Although several insecticide preparations were commercially available in 1984, only malathion was commonly used on Kansas farm-stored wheat. Chlorpyrifos methyl had not been approved for application to wheat.

tween sampling times. The mean number of insects of each type for each month was calculated and multiplied by a factor to estimate the amount of dry weight of wheat consumed for each adult present.

Consumption factors were calculated from data presented in the following papers: Lefkovitch (1964) for *Cryptolestes* spp., Hurlock (1966) and Lefkovitch (1964) for *Oryzaephilus* spp., Daniels (1952) for *Tribolium* spp., and Golebiowska (1969) and Rao and Wilbur (1972) for *R. dominica.* The factors used were: 4.6 mg/month/adult for *Cryptolestes* spp., 6.0 mg/month/adult for *Oryzaephilus* spp., 6.5 mg/month/adult for *Tribolium* spp., and 12 mg during the larval stage plus 9.75 mg/month/adult for *R. dominica.*

It is recognized that, because of the assumptions made in the calculation of these consumption factors and because the amount of material consumed by these insects is greatly affected by the environment (Campell and Sinha, 1976), there may be considerable error in the loss estimates. In addition, the sampling method used was designed to sample grain, not insect populations, and may not have given a precise measure of insect presence. However, since all bins were sampled in a similar manner and the same factors were applied to all samples, the loss estimates presented here are considered adequate for comparisons within this study.

Prestorage Sanitation

Twenty-four producers who had cooperated in the 1984 bin-sampling study were selected to participate in a study to describe the sanitation conditions on central Kansas farms prior to wheat storage and to relate certain preharvest conditions to rapid infestation of newly stored wheat. Cooperators who had empty bins in which 1985-crop wheat was to be stored were visited approximately 2 weeks before the expected harvest time. The investigator thoroughly examined the selected storage bins (including auger ports, augers, aeration ducts and plenum chambers), neighboring grain storage bins, farm buildings, feed bins, grinders and grinding areas, livestock feeders and feeding areas, seed storage areas, truck beds, combines, and other possible harborages for stored-product insects. The presence and density of the types of stored-product insects known to develop in farm-stored wheat, the distance from the source of infestation to the selected bins, and other pertinent information were recorded.

Unbaited, plastic insect traps, described by Burkholder (1983), were inserted vertically to about 1 in (2.5 cm) beneath the surface of the wheat stored in the selected bins within 1 week after filling. Traps were placed at the cardinal points, at about two-thirds the distance from the wall to the center, and at the center, except in very small bins (less than 1,000 bu). In those, three traps were inserted at equidistant points about two-thirds the distance from the wall to the center. After 72 hr, the traps were removed, and the number of each type of captured, stored-product insect was recorded.

RESULTS AND DISCUSSION

Prestorage Sanitation

More than 40 percent (41.7) of the selected empty bins were located within 12 m of farm buildings and 75 percent were located close to other storage bins (Table 11). The location of the bin relative to other farm structures may be important. It has been shown that wheat in Kansas arrives at the bin relatively free of stored-product insects, and, thus, infestation must originate from farm sources (Cotton and Winbur, 1941; Walkden, 1951). More than one-third of the selected bins (37.5 percent) were located on farms where feed and/or feed ingredients, which often contain stored-product insects, were being received and/or processed.

Five of the 24 selected farms appeared to be free of stored-product insects shortly prior to wheat harvest. Seven of the farms were found to have one lightly infested source of insects within 12 m of the selected bin, and on one farm, more than one such source was discovered. On nine of the farms inspected, one heavily infested, potential source of infestation was found within 12 m of the selected bin, and two farms had more than one such source. More than a third of the farms also had significant sources of infestation outside the 12 m radius.

Live, stored-product insects were observed in half of the empty bins inspected, with light infestation in 20.8 percent, moderate infestation in 16.7 percent, and heavy infestation in only 12.5 percent. More than half (58.3 percent) of the bins had been sprayed with insecticide prior to inspection.

Samples of the fine material under perforated floors and in aeration ducts were taken from five bins. In most cases, large quantities of fine material containing dust, pieces of broken grain, whole grains, weed seeds, dead insects, and rodent pellets were present. However, live insects were found in only one sample.

Live insects were discovered in two of 21 combines and six of 18 truck beds. In every case, only two or three insects were found, but in one truck bed, *Rhyzopertha*

Table 11. Percent of Selected Empty Bins Characterized by Physical Conditions that May Affect Sanitation in Farm-Stored Wheat

Physical Condition	Percent
Other farm buildings within 12 m	41.7
Other grain bins within 12 m	75.0
Feed grains stored within 12 m*	8.3
Wheat stored within 12 m*	8.3
Livestock feeding operation on farm	37.5

*at the time of inspection

dominica was discovered. Bulk feed, especially in open wooden bins, was often infested, and every sack of "calf starter" examined contained large numbers of *Oryzaephilus* spp. Three of the sampled grinders and grinding areas were infested, one with *R. dominica.*

To test for associations between sanitation conditions, pest control practices, etc., and the likelihood of infestation in the selected empty bin, chi-square tests of association were performed. The presence of a livestock feeding operation was not associated with an increased likelihood of infestation in the selected empty bin nor was the level of infestation in the selected empty bin associated with the presence of a feeding operation.

Contrary to expectations, insecticide treatment was not significantly associated with a reduced incidence of infested empty bins. Live, stored-product insects were discovered in seven of the 14 bins that had been sprayed with a residual insecticide prior to the inspection, whereas five of the 10 bins that had not been sprayed were apparently not infested. In many of the infested bins that had been sprayed, insects were found in accumulations of grain and fine material in auger ports and augers. This indicated that the spraying techniques used did not completely eliminate the residual insect populations. In other cases, it appeared that the insect populations in the surrounding area were so large that insects had entered the bin shortly after it had been treated.

On the other hand, there was consistent evidence that spraying bins substantially reduced the numbers of stored-product insects present. In one bin, samples of fine material were taken from under the perforated floor the day before and the day after the bin was sprayed. This bin was adjacent to a bin of heavily infested grain sorghum, and the fine material contained 46 live insects/1,000 g before spraying. After spraying, the number was reduced to 17 insects/1,000 g. In nearly all bins that were sprayed prior to inspection, dead, stored-product insects were observed, especially at the wall/floor juncture, where they may have moved out of cracks or fallen from the walls.

The likelihood that the selected empty bin would be infested was not significantly associated with the presence of other buildings within 12 m or with the presence of feed grains or other wheat within a 12 m radius. The number of infested sites close to the selected bin and the degree of infestation at these sites were not significantly associated with the probability that the empty bin would be infested. The presence of sources of infestation outside the 12 m area also did not significantly affect the likelihood that the selected bin would be infested. Thus, none of the conditions examined were significantly associated with the likelihood of insect infestation in the selected bin.

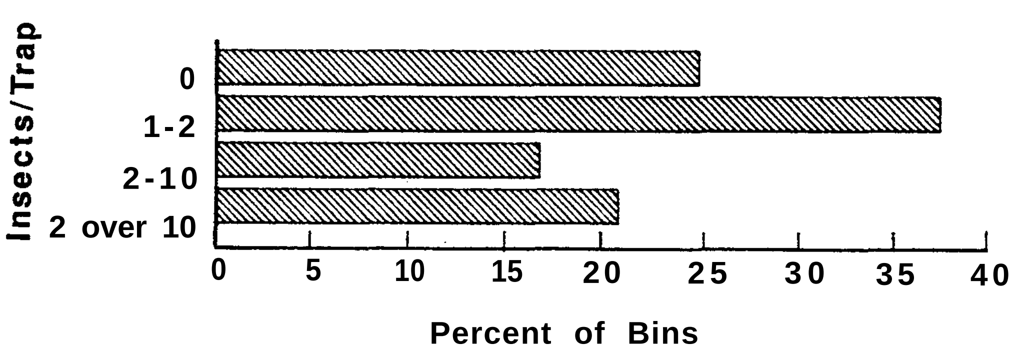
Within 1 week after harvest, live insects were trapped from wheat in 75 percent of the selected bins. Most of these bins were not heavily infested, but a mean density of 32.8 insects/trap was encountered in one bin (Figure 10). In most infested bins, insects appeared to be dispersed, and traps adjacent to the door were not more likely to contain insects than traps in other positions.

To determine which prestorage practices and conditions were associated with rapid infestation of new or harvested wheat, tests of association were made. Surprisingly, no significant association was found between the presence of live insects in the bin prior to filling and the likelihood that infestation would be detected in the wheat stored within a week after harvest. Exactly half of the bins in which stored-product insects were trapped 1 week after harvest had apparently contained no live stored-product insects prior to filling. Conversely, half of the lots of apparently insect-free stored wheat were located in bins that had contained obvious insect populations just prior to harvest. Neither was there a significant association between the level of infestation found in the empty bin and the probability that wheat infestation would be detected early in the storage period.

Whether the bin had been sprayed did not appear to affect the probability that wheat stored in it would be rapidly infested, nor was the density of the infestation detected within 1 week of harvest significantly affected by a prestorage insecticide treatment.

Other factors, such as the proximity of other infested or noninfested storage bins, the location of sources of infestation outside the 12 m area about the selected bin, or the presence of a feeding operation, were not significantly associated with the presence or density of stored product insects in the wheat shortly after harvest. However, an unlikely factor was closely associated ($P<0.01$) with both the presence and the density of infestation by stored-product insects in new or harvested wheat, although the

Figure 10. Percent of Bins with Various Insect Densities One Week after Harvest



reason for the association is unknown. Of the 18 infested bins, 14 were located more than 12 m from other farm buildings; only four were close to farm buildings (mostly equipment or animal shelters). All of the bins wherein no insects were trapped from the new or harvested wheat were located close to other farm buildings. The number of bins with high insect density (> 2 insects/trap) was significantly ($P < 0.01$) lower among those bins located within 12 m of farm buildings.

Although substantial insect populations were found on many of the farms visited, the overall sanitation conditions on central Kansas farms appear to have improved since the 1950's. Wilbur and Warren (1958) reported more than 50 percent of the farm bins they examined were located inside buildings that housed animals. In 1985, no such grain storage was observed. Five of 24 farms in 1985 were apparently free of stored-product insects; in the late 1940's and early 1950's, investigators readily found stored-product insects on all farms visited.

Pest Control Practices and Strategies

In the 1984 survey, the initial 34 bins contained 100,681 bu of new-crop wheat. During the crop year, producers sold their grain, and the number of bins available for sampling decreased. At the November sampling, 23 bins contained 69,044,bu; in February, 1985, 17 bins still contained wheat (56,589 bu); in May, only six bins, containing 23,474 bu, remained.

The percentage of bins in which various pest control procedures were used in shown in Table 12. The proportion of producers using aeration and fumigation (the more expensive pest control measures) generally increased as the length of storage increased. Some wheat in the minimum or malathion treatment groups in July and/or November was later fumigated, increasing the proportion in the fumigation group and combination treatment group and decreasing the numbers in the minimum treatment and malathion treatment groups. Of the lots that were held through February, six of eight minimum-treatment bins were fumigated, but only three of nine malathion-treated bins were fumigated.

Although chi-square tests of association indicated no significant relationship between the incidence or density of infestation within 1 week after harvest and whether the bin had been sprayed before filling, there was a significant reduction in insect density in sprayed bins in November, when the mean moisture content and temperature were used as covariates (Table 13). Density is defined as live, external- or internal-infesting insects/1,000 grams of wheat. Since the proportion of sprayed to unsprayed bins was similar among pest control strategy groups, this reduction in insect density indicated that bin spraying reduced insect numbers early in the storage season. Since no significant differences were found later, it appeared that bin spraying became a less effective insect control measure as the length of storage increased.

Although not significantly different, the mean insect density in nonaerated bins was consistently greater than that in aerated bins (Table 13). Some investigators (Halderson and Sandvol, 1980; Cuperus et al., 1986; and Amitage and Stables, 1984) concluded that although aeration does not eliminate insect populations from masses of wheat, it does appear to substantially reduce their rate of increase.

Although analysis of covariance indicated no significant differences in insects because of pest control strategy in November (Table 14), a significant ($P < 0.05$) association between pest control strategy and insect density was indicated by chi-square tests. Six of eight (75 percent) bins in which the minimum treatment was used had more than 5 insects/1,000 g of wheat. Only three of 12 bins (25 percent) treated with malathion (without fumigation) had more than 5 insects/1,000 g. Of the four bins that had been fumigated by November, one had received malathion and all had insects at low densities (<2 insects/1,000 g).

In February, significant ($P < 0.05$) effects of pest control strategy on the insect density were found by regression (Table 14) and chi-square tests of association. The pattern of insect densities was the same as that of the previous sampling time, with the lowest mean density in the fumigation group, followed by the malathion, then the malathion and fumigation group, and finally, the minimum treatment group.

Table 12. Percent of Bins in Which Various Pest Control Practices Were Used

Pest Control	Sampling Time: July	November	February	May
Practice:				
Bin spray	77.3	78.3	88.2	83.8
Fumigation	0.0	17.4	52.9	66.7
Malathion	54.5	52.5	52.9	16.7
Aeration	0.0	17.4	29.4	33.3
Strategy:				
Minimum treatment	47.8	34.8	11.8	16.6
Malathion treatment	52.2	47.8	35.3	16.6
Fumigation treatment	0.0	13.0	35.3	66.7
Malathion and Fumigation treatment	0.0	4.4	17.6	0.0

Table 13. Mean Total Insect Density per 1,000 g Wheat as Affected by Aeration and Bin Spraying

Procedure	November	February	May
Bin sprayed	5.2[a]	7.4b	0.1
Bin not sprayed	49.4[a]	0.3b	1.0
Aerated	-	0.0[c]	0.3[b]
Nonaerated	-	9.9[b]	1.6[b]

[a]mean temperature and mean moisture content used as covariates, significant differences at P < 0.01
[b]means not significantly different
[c]least squares mean was negative and was truncated to 0

Table 14. Mean Total Insect Density per 1,000 g Wheat as Affected by Type of Pest Control Strategy

	Pest Control Strategy			
Sampling Time	Minimum Treatment	Malathion Treatment	Fumigation Treatment	Malathion and Fumigation Treatment
Nov.[a]	35.3	4.3	2.9	1.7
Feb.[b]	22.3	6.2	1.8	6.6
May[c]	0.0[d]	0.7	0.4	-

[a]no significant differences in means found, with or without covariates
[b]means significantly different at P < 0.05
[c]means significantly different at P < 0.05 when mean temperature used as covariate
[d]least squares mean with mean temperature as covariate was negative and was truncated to 0

In February, the mean insect density in bins in which both protectant and fumigation were applied was greater than that in bins in which either was applied alone (Table 14). At this time, three bins had received both malathion and fumigation treatments. One bin had contained large numbers of insects at the surface, but very few within the grain mass. This bin was fumigated by a commercial applicator, and no insects were found in subsequent visits. The other two bins had insect densities of 31.3 and 34.8 live insects/1,000 g at the previous sampling. These bins were fumigated by their owners, and the insect populations were reduced to about 70 and 30 percent, respectively, of their previous levels. The implication is that fumigation, as practiced on central Kansas farms, is only marginally successful under conditions where protectant has failed to control insect populations. Halderson and Sandvol (l980) reported similar situations in the farm-stored grain they sampled.

One factor that appeared to be important to the success of a farm-bin fumigation was the time of year. By February, nine bins had been fumigated (including three that had received a malathion treatment), four before the November sampling and five after November. Three of the four bins fumigated before November had insect densities of less than 1/1,000 g by February, and the highest density observed in this group was 1.1 insects/1,000 g. In contrast, only one bin fumigated after November contained less than 1 insect/1,000 g, and in one bin of this group, 23.5 insects/1,000 g were found.

The application of malathion (regardless of fumigation) was also significantly (P < 0.05) associated with lower insect densities in February. Of seven bins in which no insects were found, six had received malathion treatment, whereas only three of the 10 bins in which live insects were found had been treated with malathion.

When used as a covariate to examine the effect of pest control strategy on insect density, the mean moisture content was not found to significantly affect the density. However, the mean temperature of the wheat was closely related to the number of insects present in February. At that time, with the effect of the pest control strategy held constant, the mean insect density was reduced by 1.44/1,000 g for every 1°F reduction in mean temperature.

Distribution of Fine Material

The mean amount of fine material (material passing through a 0.065 in × 3/8 in, 0.16 cm × 0.95 cm, oblong-hole sieve) was significantly (P < 0.01) greater in the center of the sampled bins than at other positions. Analysis of variance of the mean percent fine material over all bins and levels for each position (north, center, west, etc.) was used to test for significant differences, and the variability in means at a given sampling point over the four sampling times was used as the measure of error. The results indicated that the mean content of fine material at the center (3.1 percent) was significantly greater (P < 0.05) than the means at the cardinal points, which varied from 2.5 percent to 2.7 percent. The overall mean percent of fine material was 2.7.

These results indicate that a center spout line was present in many farm wheat bins, although the fine material was not as concentrated as that found in corn by Hall (1984). However, in many bins, within a given level the percent of fines at the center was lower than that at one or more of the other positions. No significant differences were found between levels over all bins, although some bins showed definite stratification of fine material.

Temperature Changes

Mean temperatures of all aerated and nonaerated bins at various sampling points and sampling times are shown in Table 15. A definite north-center temperature gradient was apparent in nonaerated bins, but not in aerated bins. The northern part of the nonaerated wheat mass tended to lose heat faster than other parts of the mass and gain it back more slowly than wheat near the southern bin wall. Wheat in the center of the nonaerated mass tended to experience less rapid changes in temperature than wheat located nearer the northern wall.

In contrast, wheat at the southern sampling points appeared to cool as slowly as that in the center during the fall, but by mid-winter had lost more heat than wheat in the center of the mass. Cotton et al. (1960) observed a distinctly different trend: the outside of the mass cooled fairly uniformly early in the cool season, and by February, the warmest place in the grain mass was near the southern wall. It appears likely that annual variations in weather conditions cause substantial variations in the cooling patterns within masses of stored grain.

The effectiveness of aeration in reducing horizontal temperature gradients within the masses of wheat was observed at both the November and February sampling times. Analysis of variance indicated that the mean temperature difference between the northern and central sampling points was significantly ($P<0.05$) smaller within aerated bins than within nonaerated bins in both November and February. Aeration also reduced the overall mean temperature by 8.9°C (16.0°F) in November, 3.8°C (6.9°F) in February, and 4.7°C (8.5°F) in May, from that of nonaerated bins (Table 15).

The effect of bin diameter on the rate of cooling in nonaerated bins is shown in Figure 11. By the first week of November, the mean temperature at the center of the smaller bins (18 ft or less) was about 70°F and lagged behind the mean ambient temperature by approximately 6 weeks. The mean temperatures of the bins whose diameters were between 18 and 22 ft were not reduced to 70°F until about the first week of December, lagging behind the mean ambient temperatures by about 10 weeks. The wheat in the center of bins whose diameter was greater than 22 ft remained above 70°F until approximately the first week of January, lagging behind the mean ambient temperature by about 14 weeks.

Changes in Moisture Content

The 10 bins from which a full complement of samples was obtained were used to follow changes in wheat moisture content during the storage season. Figure 12 demonstrates the change in moisture content in the aerated and nonaerated bins. The large mean losses at the second level of the aerated bins in November were due largely to one bin. This particular bin contained a stratum of wetter grain at the middle level at harvest-time and by November, a mean of 1.46 moisture points had been removed from this stratum, while the moisture content of the top layer had increased by a mean 0.3 points. The mean moisture loss in the aerated bins is consistent with the range of loss during cooling predicted by Foster (1967).

The apparent increase in moisture content in aerated bins at the May sampling may be partially explained by the fact that some bins that had not been aerated in February were included in the May means. A more likely explanation, consistent with the large increase in the moisture content of aerated wheat at the upper central position, is that the moisture from large accumulations of snow ob-

Table 15. Mean Temperatures (°C) at Various Positions within Aerated and Nonaerated Bins at Various Sampling Times

	July			November			February			May		
Position	North	Center	South	North	Center	South	North	Center	South	North	Center	South
						-Aerated-						
Upper Level	-	-	-	10.2	9.0	10.3	-1.9	- 0.2	-0.1	15.2	15.0	15.7
Middle Level	-	-	-	13.0	12.9	13.8	2.9	6.1	5.6	9.4	8.2	10.9
Lower Level	-	-	-	14.0	14.6	15.9	2.2	7.1	4.4	8.7	7.9	10.2
						-Nonaerated-						
Upper Level	32.5	31.9	31.9	15.6	17.5	17.4	-1.1	6.5	1.4	18.9	17.8	19.6
Middle Level	34.3	34.2	33.8	22.6	24.2	24.6	7.4	14.3	7.1	12.8	13.9	17.4
Lower Level	32.1	33.9	32.7	22.0	25.4	23.8	5.6	13.1	6.2	13.1	13.5	16.8

Figure 11. Effect of Bin Diameter on Rate of Cooling in Center of Nonaerated, Farm-Stored Wheat

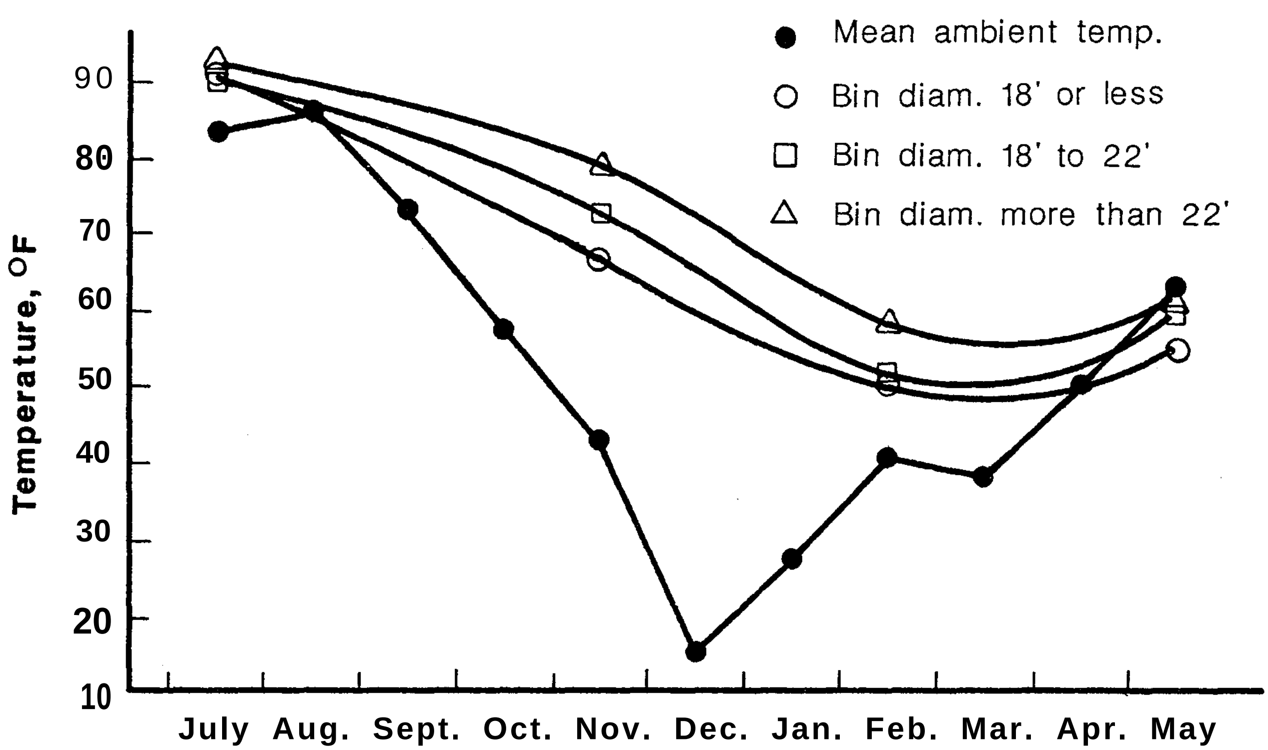
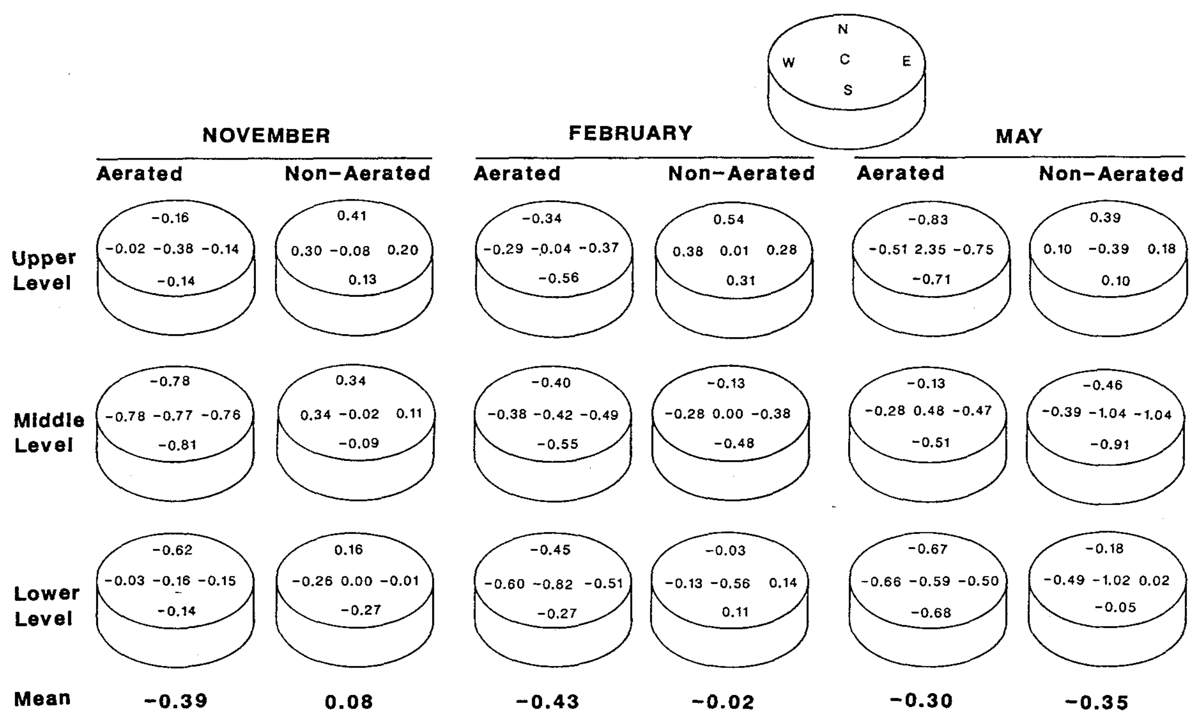


Figure 12. Mean Percent Changes in Moisture Content at Various Positions in Aerated and Nonaerated, Farm-Stored Wheat



served in two aerated bins had been absorbed by the wheat. Halderson and Sandvol (1980) also reported finding accumulations of wind-driven snow in farm bins.

The pattern of moisture change observed in the non-aerated bins is similar to that reported by Walkden (195 1) and is consistent with the generally accepted concept of moisture migration through the mechanism of convection currents in metal grain bins (Hunt and Pixton, 1974). The increase in moisture content at the northern and western positions of the upper level and the loss of moisture from the southern and central positions, especially at the middle levels, may have resulted from cold air moving downward at the cold northern side of the bin, while warm air moved upward from the warmer sections (central and southern). This warmer air may have dried the wheat as it flowed around the kernels, while relatively warm displacement air from the grain overspace, upon entering the grain mass at the northern and western sides, would have cooled when it encountered the cold wheat. Thus, the relative humidity of the air in this current may have increased enough for the wheat to slowly adsorb water from it. Neither these data, nor those presented by Walkden (1951) are entirely consistent with the illustration of moisture translocation given by Hall (1970), which depicts uniform currents moving downward at the bin walls, across the bin floor, and upwards through the center of the grain mass, and depositing moisture at the center surface.

Insects and Insect Populations

The frequency of infested farm-stored wheat was highest in late fall (Figure 13). (A bin was considered infested if an insect was found anywhere within it.) This agrees with the findings of Walkden (1951), Ingemansen et al. (1985), and Cuperus et al. (1986). The insect densities within the grain mass (excluding the surface sample) were also highest in November and were reduced during winter months (Figure 14).

Cryptolestes spp. were the most commonly found stored-product insects, present in from 75% to 100% of the infested bins (Table 16). *Tribolium* spp. and *Oryzaephilus* spp. were also very common, but less so when grain temperatures were at their lowest. The more destructive *Rhyzopertha dominica* was not as abundant as the other species. In February, *R. dominica* constituted 15.5 percent of the insects present in samples, mostly because of one bin in which very large numbers of this insect were found.

Oryzaephilus spp. beetles were present in more bins located in the northern counties (Osborne, Jewell, Mitchell, and Ottawa) than in the southern area. In November, for example, *Oryzaephilus* spp. were found in only one of 11 bins located in southern counties, but were present in five of 12 northern bins and were the most abundant species in three of those bins. That *Oryzaephifus* spp. were the most abundant species in more bins at the May sampling may have been an artifact, since all bins sampled at that time were in northern counties.

Oryzaephilus spp. were reported to be very common in South Dakota (Ingemansen et al., 1985) and Minnesota (Barak and Harein, 1981), occurring in 78.9 percent of the wheat bins in the latter, but were relatively rare in Oklahoma (Cuperus et al., 1986) occurring in 18.3 percent of the bins surveyed over 3 years. The implication may be that the incidence of this insect is highest in the northern U.S. and becomes increasingly rare in the southern states, with the effect of this population density gradient being obvious within the borders of Kansas.

While the four genera of insects named in Table 16 were by far the most abundant, others were found. These included fungus-feeders, such as *Ahasverus advena* and *Typhaea stercorea,* and granivores, such as *Trogoderma* spp., *Plodia interpunctella,* and *Tenebroides mauritanicus.* One *Lutheticus oryzae* was found. One or more of this less abundant group was present in 31.3 percent of the bins in July and 52.3 percent in November, but in only 8.3 percent by February (6 months after harvest), and none was found after 9 months of storage.

It appeared that the composition of insect populations in Kansas farm-stored wheat has varied considerably over time. *Rhyzopertha dominica,* for example, was not found by Winburn (1940), was found in more bins than other insect species 15 years ago (Bell et al., 1972), and was less commonly found than other species in the present study. Bell et al. (1972) found *Cryptolestes* spp. in only 26 percent of Kansas wheat bins in the fall of 1970, whereas in the fall of 1984, this insect was found in 90.5 percent of the sampled bins.

Various measures of insect density (e.g., number of live external-infesting insects/1,000 g, total number of live and dead insects per 1,000/g, and total number of live insects/1,000 g) were correlated with percent fine material to determine if more insects were found where there was a greater amount of fine material. The highest correlation coefficient was 0.29, and related percent fine material to the number of live external-infesting insects at the May sampling time. We inferred that, within a mass of wheat, the likelihood of finding greater insect densities in areas of fine material accumulation is very small.

Losses and the Consequences of Deterioration

Wet weight losses, calculated using the insect density information presented above, were 0.019 percent from July to November (6.2×10^{-3} percent/month), 0.023 percent from November to February (7.6×10^{-3} percent/month), and 0.002 percent from February until May (5.4×10^{-4} percent/month). In 19 of the 23 bins sampled, losses of less than 0.1 percent were calculated, whereas in four bins, weight losses of 0.15, 0.18, 0.27, and 0.35 percent were estimated. If the weight losses reported are representative, their economic consequences would be minor, ranging from approximately $0.01 to $10.72/1,000 bu, based on a hypothetical price of $3.00/bu.

The dry weight lost is but one component of the cost of deterioration in farm storage. Price discount or other forms of penalty applied when deteriorated wheat is sold must be considered. Of the 34 cooperating producers whose stored wheat was sampled in July, 10 had sold the wheat before the November sampling visit. None of those reported having received a price discount because of the presence or action of insects or molds. It is unlikely that any significant weight loss would have occurred before

Figure 13. Percent of Wheat Bins Infested at Various Times

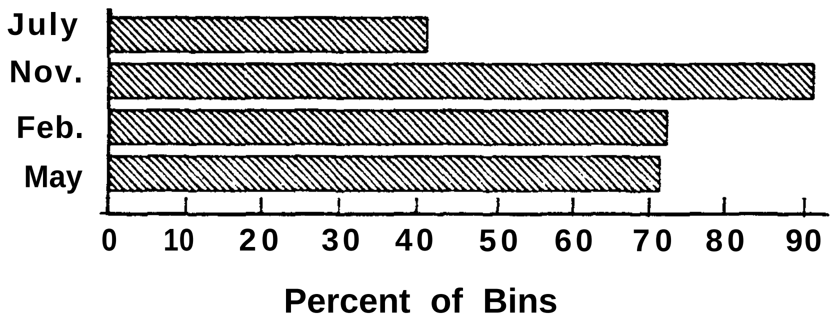


Figure 14. Percent of Wheat Bins with Various Ranges of Insect Densities at Various Times

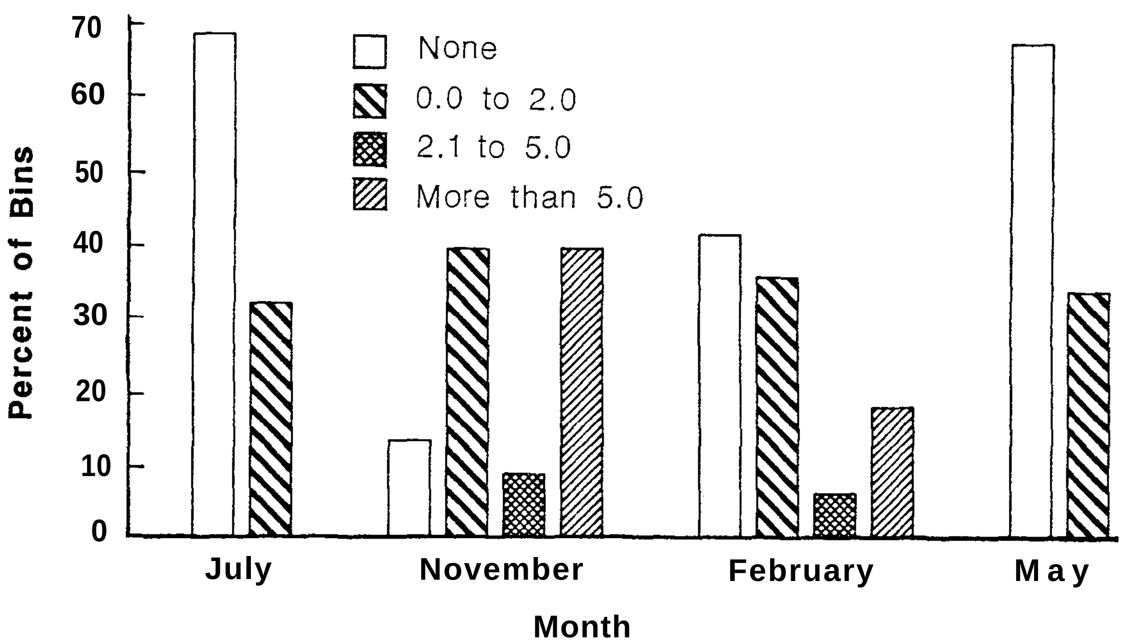


Table 16. Percent of Infested Bins with Stored-Product Insects and Percent in Which Each Was Most Abundant

Sampling Time	Cryptolestes Present	Cryptolestes Most Abund.	Tribolium Present	Tribolium Most Abund.	Oryzaephilus Present	Oryzaephilus Most Abund.	Rhyzopertha Present	Rhyzopertha Most Abund.
July	75.0	68.8	12.5	0.0	43.8	31.2	6.3	0.0
November	90.5	61.9	95.2	23.8	42.9	14.3	38.1	0.0
February	100.0	91.7	16.7	0.0	8.3	8.3	16.7	0.0
May	100.0	60.0	40.0	0.0	60.0	40.0	14.3	0.0

the wheat was sold. Thus after 3 months of storage, no demonstrable economic loss from deterioration in storage had occurred.

By February, one producer had fed the wheat being sampled to livestock and five others had sold their wheat. Three lots of wheat, in which mean densities of live, external-infesting insects and live, internal-infesting insects, respectively, at the previous sampling were 0.0 and 0.0, 0.9 and 0.0,and 1.5 and 0.3/1,000 g, were sold without discount, according to the producers. In the fourth lot that had been sold, means of 124.8 live external-infesting insects and 2.7 internal-infesting insects/1,000 g were found at the previous sampling time. According to the producer, this wheat was fumigated 2 weeks before selling and received no discount.

Wheat in another bin, in which mean densities of external- and internal-infesting insects were 72 and 1.3/1,000 g, respectively, was reportedly sold without discount and without fumigation. Assuming the cooperator gave accurate information, the reason that a penalty was not assessed despite the presence of large numbers of insects may have been that there were only 665 bu of wheat in the lot. Previous work (Reed, 1986) showed that small lots of deteriorated wheat were significantly less likely to receive price discounts than larger lots. Thus by February, after 6 months of storage, no economic losses from price discounts were documented, despite substantial insect activity.

By May, 11 more cooperators had sold the wheat being sampled. The mean insect density in five of the lots had been less than 1/1,000 g at the previous sampling time, with no internal-infesting insects present. None of these producers reported receiving a price discount. Two other lots had mean densities of 2 insects or less/l,000, and neither received a discount.

A mean density of 17.3 external-infesting insects/1,000 g had been measured in the eighth bin. This bin previously had been fumigated, and the infestation was confined to the center bottom area. The producer reported that the wheat was accepted without discount. The ninth lot was small (950 bu), had contained a mean of 23.5 external-infesting insects/1,000 g at the previous sampling time, but was not discounted, according to the producer.

The mean insect density of the tenth lot had been 5.3/1,000 g in February, and although no internal-infesting insects were found, the insects were dispersed throughout the grain mass. The producer reported receiving a discount of 4¢ bu on most of the wheat, amounting to approximately $65.00.

The remaining lot had developed a hot spot, with temperatures in excess of l00°F (37.8°C) in mid-February. The moisture content of the affected area had risen to 20.1%, and the wheat was caked with mold. Although a fairly small portion of the grain mass was directly affected, a mean density of external-infesting insects of 48.5/1,000 g and a mean, internal-infesting insect density of 26.5/1,000 g had been measured. The producer refused cooperation after samples were taken in February, so the extent of further damage is unknown.

After the May sampling time, two lots that had very low insect densities were sold, reportedly without discount, and the other lots were kept into the next storage season. Thus, for the entire storage year, only one producer reported a price discount because of storage damage. In a study of wheat received at country and terminal elevators during the 1984-85 storage year (Reed, 1986), 30.9 percent of the lots received a price discount because of grain quality factors. Therefore, it is unlikely that only one of the 34 cooperating producers, in the same geographical area during the same time period, would have experienced a price discount. Rather, it appeared that either producers were unaware of price reductions at the time of sale or were reluctant to report them.

Least-Cost Method of Pest Control

One reason that wheat is stored on the farm in Kansas is to profit from the typically higher winter and spring market prices. To increase potential profits, the least-cost method of quality maintenance in storage is sought. Information obtained in this study was used to examine the costs of various pest control practices.

The malathion cost used for this analysis was calculated on the basis of $2.39/pint of 57 percent malathion (mean quotation from four country elevators in the survey area) and an application rate of 2 pint/ 1,000 bu. Using the mean recommended dilution rate (3.5 gal/1,000 bu), the value of the added water and formulation was $1.50/1,000 bu, based on wheat at $3.00/bu. Assuming that all added water was adsorbed and remained in the grain, the cost of the treatment less the value of the added water was $0.0009/bu. No labor cost was included.

The cost of farmer-applied fumigation was based on the medium dosage recommendation for two liquid fumigants commonly used in the survey area. A mean price of $7.83/gal had been determined in a previous study (Reed, 1986). No labor cost was included. A cost of $0.0281/bu was used for custom fumigation, based on the mean of five price quotations from commercial applicators involved in farm bin fumigation in the survey area.

The cost of the risk factor involved in marketing infested wheat was based on information from a previous study (Reed, 1986) in which it was determined that 69.2 percent of wheat lots that met the requirements of the "weevily" designation were discounted, whereas only 25.5 percent of wheat lots having fewer insects were discounted. Further, the probability of receiving a given level of discount was determined.

Based on these costs and probabilities, the weighted mean discount was found to be $0.031/bu.. "Weevily" wheat, therefore, was subject to a projected cost of $0.022/bu (0.692 × $0.031/bu), whereas the projected cost of discounts in "nonweevily" wheat was only $0.007/bu (0.255 × $0.031/bu). The difference between these projected costs ($0.022/bu - $0.007/bu = $0.015/bu) was the risk factor for "weevily" wheat. This risk factor was multiplied by the number of bushels that would have been graded "weevily" in each pest control group.

Table 17 shows the relative cost of pest control and loss among the identified pest control strategies in November. The use of malathion without fumigation was competitive with the minimum treatment, even without considering the risk factor, and obviously advantageous when the risk of discount was included.

The observed and risk costs per 1,000 bushels of having to fumigate after 3 months of farm storage were $11.63 (self-applied) vs. $13.66 (custom-applied) and $6.08 (self-applied) vs. $7.40 (custom-applied) for minimum treatment and malathion treatment, respectively. The costs associated with the application of malathion, relative to the costs of not applying malathion, were 1:1.92 and 1:1.85 in November, depending on whether the fumigant would have been applied by the producer or a custom fumigator. By November, therefore, the cost of applying malathion was about half as great as the cost of not applying it, principally because of the lower risk of price discounts and the lower probability of having to fumigate when malathion was applied.

The costs associated with four pest control strategies after approximately 6 months in storage (Table 18) again indicated the economic advantage of controlling pests with malathion when possible. Of the wheat that had not received malathion and was held until February, 74.2 percent had been fumigated. In contrast, of the wheat held until February that had received malathion, 30.1 percent was fumigated. The costs per 1,000 bushels of fumigating were $15.77 (self-applied) vs. $22.97 (custom-applied) and $9.67 (self-applied) vs. $12.88 (custom-applied) for minimum treatment and malathion treatment, respectively. As in November, the costs associated with the application of malathion (including the risk of having to fumigate) were substantially lower than those associated with not applying malathion.

Table 17. Costs Associated with Four Pest Control Strategies in Wheat[a] after Three Months' Farm Storage (November, 1984)

Parameter	Minimum Treatment	Malathion Treatment	Fumigation Treatment		Malathion & Fumigation Treatment	
Number of Bushels	24,909	32,440	6,595		5,100	
Total Observed[a]			Self	Custom	Self	Custom
Cost ($/1000 bu.)	0.95	1.30	18.52	28.22	19.30	29.00
Risk Factor[b] ($/1000 bu.)	8.85	2.70	0.0	0.0	0.0	0.0
Observed + Risk Cost ($/1000 bu.)	9.80	4.00	18.52	28.22	19.30	29.00

[a]includes cost of estimated weight lost at $3.00/bu. and estimated cost of treatment (for 23 observations)
[b]based on the number of bushels that met the "weevily" designation requirements

Table 18. Costs Associated with Four Pest Control Strategies in Wheat after Six Months' Farm Storage (February, 1985)

Parameter	Minimum Treatment	Malathion Treatment	Fumigation Treatment		Malathion & Fumigation Treatment	
Number of Bushels	7,200	20,065	20,674		8,650	
Total Observed[a]			Self	Custom	Self	Custom
Cost ($/1,000 bu.)	2.79	1.16	19.10	28.20	22.11	32.74
Risk Factor[b] ($/1000 bu.)	3.45	0.00	0.00	0.00	7.31	7.31
Observed + Risk Cost ($/1000 bu.)	6.24	1.16	19.10	28.80	29.42	40.05

[a]includes cost of estimated weight lost at $3.00/bu. and estimated cost of treatment (for 17 observations)
[b]based on the number of bushels that met the "weevily" designation requirements

In May, it appeared that the small number of observations allowed random external factors to substantially affect the calculated costs (Table 19). The minimum treatment and the malathion treatment groups, for example, were represented by only one bin each. The minimum treatment wheat had been dried, turned, and aerated, but this investment was not reflected in the analysis. The cost of the malathoin treatment was relatively large, because the wheat with malathion had received a price discount.

The costs per 1,000 bushels of fumigating were $14.53 (self-applied) vs. $21.67 (custom-applied) and $8.42 (self-applied and custom-applied) for minimum treatment and malathion treatment, respectively. The lot of malathion-treated wheat still in storage after 9 months had not been fumigated, whereas four of the five lots of wheat without malathion had been fumigated by May. Thus, the calculated costs associated with applying malathion were again lower than those associated with not applying it.

To evaluate the costs and benefits of aerating farm-stored wheat, the total cost of aerating (e.g., weight loss, risk factor, and electricity for aeration) was compared with the cost of weight loss and the risk factor in nonaerated bins within the malathion group. (Sufficient aerated bins in the other pest control groups were not available to allow a meaningful analysis.) The calculated cost of aeration was $0.0113/bushel. This was based on the use of a 0.75 HP motor in a 3,000 bu bin, where the wheat depth was 18 ft (5.5 m) and the cost of electricity was $0.075/KWH. The aeration scheme recommended by the Kansas State University Extension Service was used. Initial equipment costs were not included.

In November, three bins of wheat that had received malathion had been aerated and eight had not. The total cost of aerating was $11.39/1,000 bu, whereas the cost of weight loss and the risk factor was $6.42/1,000 bu in non-aerated wheat. In February, the costs were $11.49/l,000 bu in three bins of aerated wheat and $0.82/1,000 bu in three bins of non-aerated wheat. Therefore, it appeared that aeration, as used by central Kansas farmers, was not cost-effective in wheat that had received a malathion treatment. However, it should be noted that these figures are based on a small number of observations. Further, the extent to which the cooperators used the recommended fan operation time, upon which the cost figures were based, was not known.

The information contained in Tables 17-19 allows a comparison of the cost of various pest control strategies in farm-stored wheat under current Kansas conditions. If a producer intends to sell before December 1, for example, and chooses the minimum treatment, he risks a weight reduction from insect feeding valued at approximately 0.l¢ / bu. If the price of the commodity increased, of course, the cost of this loss would increase proportionately. If he applies protectant and successfully controls the insects, the total observed cost increases to 0.13¢/bu, whereas if he fumigates before selling (without investing in malathion), the cost is increased to between 1.85 and 2.82¢/bu. If he applies both malathion and fumigant, the cost is increased to between 1.93 and 2.9¢/bu.

When the farmer chooses the minimum over the malathion treatment, the predicted advantage in reduced cost of treatment and loss is 0.035¢/bu. However, if there is a chance that he will market the wheat at an outlet where discounts are likely to be levied (e.g., elevators and some feed lots), the advantage of malathion (if successful) is 0.58¢/bu on the average. Because the cost of malathion application was only 0.09¢/bu, the return to investment in malathion (ratio of dollars returned per dollar invested) is 6.44.

Consider another hypothetical case of a producer who has applied malathion and plans to market his wheat in November. If his wheat contains from 5 to 10 insects/1,000 g, fumigation will not be profitable, unless he is certain of a discount equal to or exceeding the fumigation cost of 1.8¢/bu or more if he applies the fumigant himself, or a minimum cost of 2.8¢/bu if he hires a commercial applicator.

Table 19. Costs Associated with Four Pest Control Strategies in Wheat after Nine Months' Farm Storage (May, 1985)

Parameter	Pest Control Strategy: Minimum Treatment	Malathion Treatment	Fumigation Treatment: Self	Fumigation Treatment: Custom	Malathion & Fumigation Treatment: Self	Malathion & Fumigation Treatment: Custom
Number of Bushels	5,300	9,120	14,774		-	
Total Observed[a] Cost ($/1000 bu.)	0.04	8.42[c]	19.38	29.08	-	-
Risk Factor[b] ($/1000 bu.)	0.00	0.00	0.00	0.00	-	-
Observed + Risk Cost ($/1000 bu.)	0.04	8.42	19.38	29.08		

[a]includes cost of estimated weight lost at $3.00/bu. and estimated cost of treatment (for six observations)
[b]based on the number of bushels that met the "weevily" designation requirements
[c]includes reported price discount

In general, the alternatives available to a producer who owns farm-stored wheat in which malathion has failed to control the insect population and who is deciding when to market, are as follows:

A) Sell the wheat without fumigating, thus foregoing possible profit from future price increases as well as the possibility of a price discount, but reducing the risk of extreme loss from further storage damage and avoiding the cost of fumigation.

B) Hold the wheat and risk further deterioration.

C) Fumigate and hope to recoup the cost of fumigation by selling at a higher price later and reducing the chance of a price discount because of infestation.

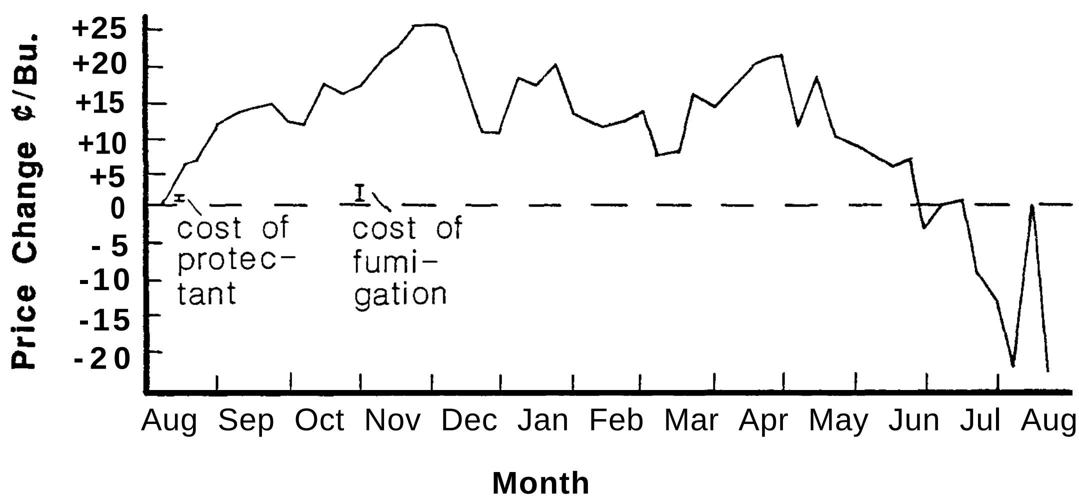
Few producers chose the latter strategy, as evidenced by the relatively small amount of wheat in the malathion and fumigation group during the winter and spring. That there were no "weevily" lots in the malathion group in February may indicate that few producers chose to hold insect-infested wheat.

Information from Table 18 indicates that if a producer choses to hold the wheat until February and to apply the fumigant himself, an average price increase of 2.8¢/bu would be required to recoup the cost of the fumigation and the risk of discounts. A 3.9¢/bu average increase would be required to make the alternative profitable using a commercial applicator.

Since the need for fumigation should be apparent by November, and the market price typically increases substantially in October (Figure 15) fumigation to permit longer storage for price speculation is likely to be profitable, if done before November. After November, however, fumigation to permit longer storage for price speculation is less likely to be profitable because 1) it is less likely to control insects and 2) further price increases are less likely to occur.

Many variables affect the cost of controlling deterioration in farm-stored grain. Weather conditions, the cost of pest control relative to the value of the commodity, general sanitation conditions, and many other random factors introduce variability in the analysis of information obtained in this type of investigation. It is hoped that, despite these difficulties, the data presented here may form the basis for better recommendations relative to cost-effective pest control in Kansas farm-stored wheat.

Figure 15. Mean Changes (1979-1985) from the August Cash Wheat Price in Central Kansas (Beloit)



CONCLUSIONS

*Nonaerated, flat-floor bins were the most commonly used structures for on-farm wheat storage, followed by hopper-bottom and flat-floor bins.

*The mean on-farm storage capacity for wheat was 22,118 bu/farm. Producers in the west and southwest districts reported a greater mean capacity.

*One-half of respondents reported storage capacity of 10,000 bu or less, and about 13 percent reported capacity of more than 50,000 bu; the latter represented nearly half of the on-farm storage.

*About 60 percent of storage structures was equipped for aeration, representing 76.5 percent of the total storage capacity.

*About one-third of Kansas wheat was stored without chemical treatment; protectant treatment was the most commonly used; producers with large storage capacities were likely to use both protectant and fumigation treatment.

*Sources of insects were found near storage bins on most farms, and live insects were observed in half of the empty bins before harvest.

*A greater proportion of insect-infested bins, involving more species of insects and greater population density, was observed in November than at other sampling times.

*The proportion of producers using aeration and fumigation increased as the length of storage increased.

*Aeration reduced temperature gradients within grain masses and produced lower mean temperatures than in nonaerated wheat. Evidence of some moisture translocation was observed in nonaerated wheat.

*The application of insecticide spray to bins before harvest reduced insect infestation in stored wheat. Fumigation was most effective if done before November.

*Although not alway successful, malathion treatment at loading was the most cost-effective pest control strategy. It reduced the need for later fumigation and the likelihood of price discount at the time of sale.

*Fumigation to permit longer storage of wheat for price speculation can be profitable, if done before November; after that time, it is less likely to be profitable.

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Agricultural Experiment Station, Kansas State University, Manhattan 66506

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