COMPARISON OF THE STORAGE CHARACTERISTICS OF THREE TYPES OF FARM GRANARIES¹

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The storage characteristics of three types of farm granaries — a plywood control bin, a convection-cooled bin, and a butyl-rubber bin — were compared by storing tough and heavily infested wheat for 3 yr. By mid-winter the grain temperature at the center of the convection-cooled bin was about 4° and 10°C below that of the control bin and butyl-rubber bin, respectively. Viability decreased and *Aspergillus flavus* infection increased most rapidly in the surface layer of the butyl-rubber bin where moisture content increased from 14.8 to 20.3%. All types of fauna died faster, usually within 1 yr, in the butyl-rubber bin than in the plywood bins. A thriving population of the most important granivorous insect pest, rusty grain beetle, dwindled to negligible numbers of adults within 6 mo of storage in all three bins. Cooling of the plywood bin favored the bioindicator mites while drastically reducing the populations of the insect pests.

INTRODUCTION

Three main physical methods of preventing and controlling deterioration of stored grain are to control (i) moisture content, (ii) temperature and (iii) gaseous atmosphere. Drying the grain is the most common and probably most effective method; but as the cost of energy increases, other methods requiring less energy need to be considered. It should be possible to design granaries that can be cooled by the cold winter weather of Western Canada with the expenditure of little or no energy. It may also be possible to design inexpensive granaries, for example air-tight bins, in which gaseous atmosphere can be controlled, but the fabrication and construction of such modified granaries will probably require somewhat more energy that that required for the common types now being produced in Western Canada.

The effect of grain temperatures on the rate of deterioration of stored grain has been reviewed previously (Muir 1973; Sinha 1973; Wallace 1973). The control of the gaseous atmosphere in the granary by making the bins airtight has been reviewed by Hyde and Burrell (1973). Muir and Wallace (1971) and Muir et al. (1973b) reported on tests of airtight storages under the continental temperate climate of the Canadian Prairies.

The objective of this research project was to compare over 3 yr the storage characteristics of three types of farm granaries: a plywood control bin, a natural-convection-cooled bin and a butyl-rubber bin.

MATERIALS AND METHODS

Description of Bins

The control bin was a circular plywood type with a plywood floor, a conical plywood roof, a diameter of 2.9 m and a wall height of 2.4 m. The bin was on wooden skids so that the floor was about 12 cm above the ground. Skirts were attached to the bin to reduce air circulation under the bin.

The convection-cooled bin was the same as the control bin except that a galvanized sheet-metal tube, 7.6 cm in diameter, was inserted south to north across the center of the bin, 1.2 m above the floor. Each end of the tube protruded about 8 cm beyond the bin wall. Two right-angle elbows were placed over the tube ends with the openings facing downward to reduce the amount of snow, rain and debris blowing into the tube. The tube had a slight slope to allow condensation or melted snow to drain out.

The 4-m diameter butyl-rubber bin was described by Muir and Wallace (1971).

Test Procedure

Wheat heavily infested with the rusty grain beetle, *Cryptolestes ferrugineus* (Stephens), and mites was purchased from a farmer at Carberry, Manitoba. The infested grain, which was stored in four separate bins by the farmer, was transferred 200 km by truck to the University of Manitoba in Winnipeg during 8 — 14 October 1969. Each plywood bin was filled with 10 t and the butyl-rubber bin was filled with 14 t of wheat.

Grain temperatures were measured weekly at 48 points in each bin with copper-constantan thermocouples and a self-balancing potentiometer.

Grain samples were taken from 17 locations in each bin six times during the 3-yr storage period. The samples were taken from two vertical columns, one located 15 cm from the south wall and one located 15 cm north and 15 cm east of the center axis. The samples were taken at depths of 0, 30, 60, 90 and 120 cm below the top grain surface. An additional sample at the 150-cm depth was taken near the center axis of the bin. Samples at the deeper locations could not be taken near the end of the experiment, because the probe could not be inserted into the compacted, deteriorated grain. At 60 and 120 cm below the grain surface, samples were taken 45 cm from the east, north and west walls.

The moisture contents of the samples were determined by oven-drying two portions of 25 — 30 g for 96 h at 100°C and were reported on a wet weight basis. Viabilities were determined with two lots of 50 seeds each from each sample. Each lot of seeds was incubated on two sheets of Whatman No. 29 (black) filter paper saturated with 5 ml of sterile distilled water in a petri dish for 96 h in a germination cabinet maintained at 18°C. Fungal flora was determined on 25 seeds selected at random from each sample and incubated for 7 days at room temperature (20 — 22°C) on filter paper saturated with water. Insects and mites were extracted from 200-g portions in Berlese funnels (Sinha 1964) under 100-W incandescent electric bulbs for 24 h, and counted under a stereomicroscope. Specific identification of mites was done using a phase interference microscope.

The two terms used to present the biological data in the text are defined as follows: Frequency of occurrence of a particular species of insect or mite is the number of samples infested by that species expressed as a percentage of the total number of samples collected from the bin at the indicated sampling time. Abundance of a species of insect or mite is the mean number of that species occurring per sample in a bin at the indicated sampling time.

RESULTS

Temperature

The temperature of the center of the convection-cooled bin was normally within 5°C of the ambient air temperature while the
Figure 1. Temperatures at centers of three experimental granaries (control bin, circular plywood, 2.9 m diameter; convection-cooled bin, same as plywood bin but with a horizontal cooling pipe through the center; and butyl-rubber bin, 4 m diameter) in Winnipeg, Manitoba.

Figure 2. Temperatures (°C) on an east-west vertical plane through the center of the control granary in Winnipeg, Manitoba on 31 December 1971.

Figure 3. Temperatures (°C) on an east-west vertical plane through the center of the convection-cooled granary in Winnipeg, Manitoba on 31 December 1971.

Figure 4. Temperatures (°C) on an east-west vertical plane through the center of the butyl-rubber granary in Winnipeg, Manitoba on 31 December 1971.

tube was open in the autumn and winter (Fig. 1). In mid-winter, the center temperature of the control bin and butyl-rubber bin were about 4° and 10° C, respectively, warmer than the cooled bin. During summer, the center temperatures of all three bins rose above the ambient air temperature. The cooling tube affected grain temperatures up to about 60 cm above and to the sides of the tube and about 30 cm below the tube (Figs. 2 and 3). Even though skirts were attached to the plywood bins to reduce air circulation under the bins, the bottom temperatures in the plywood bins were 9° C below those in the butyl-rubber bin which lay directly on the ground (Figs. 2, 3 and 4).

Moisture Content

Results are presented in Tables I—III as means for each sample depth because both moisture content and microflora appeared to be related to sample depth. Results from samples taken at 6 and 19 mo are not reported in the tables because the trends in the results are adequately shown by the results from the other four sampling times. Variability in the initial results taken during the 1st mo of storage occurred because of incomplete mixing of the grain going into the test bins.

The main deviation from the mean moisture contents at< 1 mo storage was a high moisture pocket at the top center of the control bin. This pocket dried from 21.6 to 19% in 6 mo and to 12.4% in 11 mo. If this point is omitted, the mean surface moisture content would be 14.6% and the mean for the bin would be 15.6%, percentages similar to those for the other two bins (Table I).

The moisture content at the center of the control bin decreased 1.5 percentage points from 16.2 to 14.7% over the 36-mo storage period. Meanwhile, the moisture content at the center of the cooled bin decreased by only 0.4 percentage points to 15.6 from 16.0%. Because the decrease in moisture content was less in the cooled bin than in the control bin, there may have been some moisture migration from warm grain to the cooler grain around the cooling tube.

Wheat in the butyl-rubber bin increased in moisture content during the storage period (Table I). The increase occurred at the surface and at the 30- and 60-cm depths, while it dried out at the lower depths. The
TABLE II VIABILITY OF WHEAT IN THREE TYPES OF STORAGE BINS IN WINNIPEG, MANITOBA IN 1969-72

<table>
<thead>
<tr>
<th>Bin</th>
<th>Sample time (mo)</th>
<th>0</th>
<th>30</th>
<th>60</th>
<th>90</th>
<th>120</th>
<th>150</th>
<th>Mean</th>
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<tr>
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<td>86</td>
<td>80</td>
<td>59</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>94</td>
<td>74</td>
<td>45</td>
<td>54</td>
<td>57</td>
<td>13</td>
<td>59</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>71</td>
<td>5</td>
<td>2</td>
<td>7</td>
<td>6</td>
<td>0</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>36</td>
<td>20</td>
<td>6</td>
<td>ND</td>
<td>4</td>
<td>3</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Cooled</td>
<td>&lt;1</td>
<td>94</td>
<td>96</td>
<td>90</td>
<td>74</td>
<td>71</td>
<td>73</td>
<td>83</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>90</td>
<td>58</td>
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<td>32</td>
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<td>57</td>
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<td></td>
<td>36</td>
<td>26</td>
<td>4</td>
<td>0</td>
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<td>1</td>
<td>0</td>
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</tr>
<tr>
<td>Butyl-rubber</td>
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<td>96</td>
<td>97</td>
<td>95</td>
<td>76</td>
<td>56</td>
<td>52</td>
<td>79</td>
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<td>10</td>
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<tr>
<td></td>
<td>36</td>
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<td>0</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>0</td>
</tr>
</tbody>
</table>

*Number of samples at each depth was 2, 2, 5, 2, and 1 respectively.

Aspergillus flavus Link ex Fr. increased in the butyl-rubber bin during the 1st yr, while the increase was delayed to the 2nd yr in the control bin. In the convection-cooled bin, the increase was less than in the surface, while in the plywood bins the increase was the least at the surface.

Aspergillus candidus Link ex Fr. increased to 31% infection in the butyl-rubber bin after 36 mo storage, while it averaged only 4% in the plywood bins.

Insects and Mites

At the beginning of the experiment, in October 1969, all experimental bins were infested with many species of granivorous, mycophagous, parasitic, predatory and scavenger insects and mites. Generally these arthropod pests were most abundant along the bottom half and in the central columns of each grain bulk.

A thriving population of the most important granivorous insect — C. ferrugineus, dwindled to negligible numbers of adults within only 6 mo of storage in all three bins. A sparse population of a few adults, however, occurred in all bins during the length of the experiment.

Although some of the insects, such as the sigmoid fungus beetle, Cryptophagous varus Woodruff and Coombs, the square-nosed fungus beetle, Lathridius minutus (L.); the parasitic grain wasp, Cephalonomia waterstoni Gahan; and mites such as the cannibal mite, Cheyletus eruditus (Schrank); the long-legged cannibal mite, Cheyletus lepidopterorum (Shaw); the warty grain mite, Aeglyophyless robustus (Banks); Blattisocieus keegani Fox occurred sporadically in the grain during initial sampling and in later samplings from all bins, their incidence in small numbers was of little economic significance. Only four kinds of mites, the grain mite, Acarus siro (L.); the long-haired mite, Glycyphagus destructor (Schr.); the large mite species, T. granarius Lindquist, occasionally T. fusarii Cooreman; and Tydeidae (Paratriphyidae sp., Tydeus sp.) appeared consistently in the bins, reflecting changes in abiotic environmental conditions by their numbers (Figs. 5 and 6.)

Generally, most species of microfauna died within the 2nd yr in the butyl-rubber granary (Figs. 5 and 6); the few species that occurred in subsequent years were sporadic and low in number. Oxygen depletion could have been a main cause of their death. Evidently, the butyl-rubber bin provided the best protection of the stored grain from aracine invasion.

Mites were more abundant and common in the convection-cooled bin than in the control bin. G. destructor peaked only once in June 1971 (Fig. 5); these mites were equally common in both plywood bins although they were slightly more abundant in the cooled bin.
Tarsonemus was abundant in both plywood bins until the end of the experimental period (Fig. 5). The abundance and frequency of occurrence of these mites peaked after 24 mo of storage; between 6 and 19 mo of storage they appeared in larger numbers in the cooled bin than in the control bin. Afterwards populations in both bins fluctuated in a similar fashion.

Tydeid mites occurred in both the control and the cooled bins although they were most common and particularly abundant in the cooled bin in October 1971 (Fig. 6).

A. siro occurred in low numbers in both bins throughout the experiment and their numbers peaked only in the cooler bin at the end of the storage period (Fig. 6).

**DISCUSSION**

A preliminary 1-yr test (the results have not been reported here) indicated little difference among vertical and horizontal cooling tubes 7.6 and 20 cm in diameter. The vertical tube cools the full length of the center axis of the grain mass. The bottom of the tube must be open to the outside in some manner and it is difficult to make a rain-tight fit at the bin roof. A vertical tube to the floor can interfere with emptying of the bin. A horizontal tube is simpler to install in all types of bins. Although it will not cool as much grain as a vertical tube, it may reduce temperature gradients in the bin sufficiently to prevent excessive moisture migration and accumulation.

To prevent rapid warming of the bin center, the tube must be closed manually in mid-winter before the grain temperature begins to rise with the ambient air temperature. It should then be opened in the summer when the mean ambient air temperature falls below the grain temperature at the bin center.

The cooling pipe had only a small effect on the rate of deterioration of the grain in the plywood bins. The tests suggest that with small bins, no procedures such as convection-cooling, aeration, or turning are necessary to cool the grain. In larger bins (diam > 6 m), the cooling effect of the convection tube would be greater (Yaciuk 1973) and it might have a major effect on grain deterioration. A drop of 10°C (from 20 to 10°C) can cause a growing infestation of stored-product insects to begin to die out.

The high temperatures at the centers of the bins (as much as 5 — 10°C above ambient temperature, Fig. 1) indicate that biologic heating was occurring in all three bins during the summer. The high levels of fungal infection confirm the presence of microbiological respiration and grain deterioration. The increase in mean moisture content in the butyl-rubber bin must be due to microbiological respiration (Muir et al.)
Moisture migration along with microbiological respiration could increase the moisture content at specific points in the bin. The accumulation of moisture at the top-centers of the three bins confirms the theory of moisture migration due to the natural convection currents in the bins. Migrating moisture in the butyl-rubber bin is trapped by the impermeable roof cover (Table I). This trapping appears to have caused a decrease in viability (Table II) and an increase in A. flavus (Table III) near the surface of the butyl-rubber bin. The upper layer of grain in the plywood bins dried, with resultant slower decreases in viability and slower increases in A. flavus. Similar pattern of events occurred with plastic bins where grain in a non-vented bin spoiled more rapidly when more moisture accumulated at the top of the bin than in a vented bin (Muir et al. 1973a).

A. flavus is an important fungal species in grain bins, because it has a potential to produce mycotoxins which are hazardous to both men and animals (Scott 1973). The cooling pipe delayed infection of A. flavus until the 3rd yr of storage as compared with the 2nd yr in the control bin and 1st yr in the butyl-rubber bin (Table III). The reduction in viability seemed to be related to the distribution of A. flavus in the three bins.

All four kinds of mites found in three types of bins are common to grain bulks stored for prolonged periods in Manitoba. Their broad pattern of fluctuation resembles those found earlier by Sinha (1964, 1974) and Sinha and Wallace (1973). It seems that the retention of lower temperatures in the grain bulk in the cooled bin for longer periods in spring and summer has affected the mite population which prefers lower temperatures (20 to near 0°C) than that of stored-product insects (above 20°C) (Sinha 1973). Tydeidae and Tarsonomus mites are of little economic importance but they are sensitive bioindicators of deteriorative changes within stored grain bulks. Their presence in larger numbers in the cooled bin indicates that cooling of the grain by inserting a pipe does not reduce microfaunal population in a prairie climate. Nevertheless, any cooling of grain should be considered beneficial because it reduces infestation by granivorous insects (e.g. C. ferrugineus), which are of greater economic importance than mites. In addition, lowering of temperatures in the grain bulk for long periods also reduces fungal infection which, if not attenuated, is an important degrading factor in the sale of stored grain.

The limiting factor affecting all three bins was the cold winter climate because the test bins were relatively small. The differences in the bin environment would probably cause greater differences in the storage characteristics of larger bins, but the differences that were indicated show that changes in the storage environment should be thoroughly studied by an interdisciplinary team before recommendations are made.

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