Storage of pelleted wheat middlings in farm bins

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Abstract

The objective of this study was to describe the storage-related characteristics of pelleted wheat middlings (WM) and to test strategies for maintaining the desirable bulk flow characteristics of the pellets during storage in farm bins during warm, humid weather. Cattle producers located close to flour mills purchase pelleted WM in the summer when prices are low and store them into the winter when they are needed. Four Kansas flour mills were surveyed on four sampling dates to characterize samples of pelleted WM relative to storage-related factors, e.g. moisture content, bulk density, bulk flow characteristics, and mycological conditions. Physical simulations were done in environmental chambers to determine the cause of aggregation (loss of bulk flow characteristics) and develop techniques for controlling aggregation and mold growth. Findings were verified at a larger scale in farm bins.

Pelleted WM had twice the bulk density and a greatly reduced count of storage molds compared to unpelleted WM. Mold counts remained low for at least 6 weeks after pelleting, even with storage at 30°C. The moisture contents of WM pellets ranged from 128 to 149 g/kg with a mean of 140 ± 5 g/kg in March, April, and May, but the mean moisture content was reduced to about 132 g/kg by June. Pelleted WM aggregated when stored at high moisture and temperature even if the level of mold infection was low. Mold growth that caused heating and aggregation was observed at higher temperatures when pellets remained moist, but the species of molds predominating were not those associated with the production of aflatoxin. Drying and cooling the pellets by means of near-continuous summer aeration prevented mold growth to a large extent and minimized the effects of aggregation. Spout lines, areas where fine material accumulated directly beneath the fill spout, were associated with mold growth, heating, and impedance of airflow.

Keywords: Wheat middlings; Pellets; Storage; Storage molds

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1. Introduction

Wheat middlings (WM) are by-products of the flour milling process and are used for animal feed. They consist mostly of wheat pericarp, germ, and a small amount of endosperm tissue from various mill streams including the bran, shorts, germ, and flour streams. In addition, WM may contain the cleanings removed from the grain prior to milling (AAFCO, 1996). The cleanings are ground before inclusion. Several flour mills in Kansas recently have begun to market WM in pelleted form. The pellets are produced in a pellet mill after the addition of steam without additional binders. The greater bulk density and ease of handling of the pelleted WM have made them more attractive to nearby cattle feeders.

Wheat middlings from Kansas mills contain about 180 g protein/kg, 110 g crude fiber/kg, and about 250 g starch/kg on a dry-weight basis. The feeding value was roughly equivalent to that of a maize and soyabean-meal combination when WM were used with growing cattle in full-fed, sorghum silage-based rations but were only 83% of the value of that combination when WM were used in limit-fed diets (Blasi et al., 1998). WM pellets also are used in supplements for cattle on winter cereal pasture (Lusby and Gill, 1993).

Cattle feeders located close to flour mills purchase pelleted WM during the warm summer months, when their price is sometimes only half that of the peak prices in winter, and store them for use months later. However, the WM pellets tend to heat, discolor, and aggregate (lose the ability to flow from a bin) during summer storage in farm bins in Kansas (Blasi et al., 1997). Maintaining the bulk-flow characteristics of pelleted WM is desirable, because aggregated feedstuffs cause disruptions in the production and distribution of animal feed and may require potentially dangerous activity to free them for use in the feed mixing or delivery system. The objectives of this study were to describe the storage-related characteristics of pelleted WM and to test strategies for maintaining the desirable bulk flow characteristics of the pellets during storage in farm bins through the warm summer months. Because aggregation in stored commodities often occurs as a result of fungal hyphae binding individual kernels together (Christensen and Meronuck, 1986), the mycological condition of the pellets was determined in each trial.

2. Materials and methods

2.1. Survey

To determine storage-related characteristics of pelleted WM at the time of sale at the flour mill and the effect of pelleting on those characteristics, samples of 0.64 cm (1/4 in.) pellets and 1.9 cm (3/4 in.) pellets were collected on four occasions in the spring of 1997 at four Kansas flour mills. This time of year was selected because producers seeking to take advantage of low prices are likely to purchase WM in late spring or early summer. Sealable containers were supplied to the millers with instructions that samples should be taken randomly from the pellet stream on three occasions during a selected day. Ground WM (before pelleting) also were collected. The samples, weighing 13–36 kg each, were
sealed, identified, and retrieved on the following day. They were transported to the university laboratory, where portions for determination of moisture content (MC) and equilibrium moisture content (EMC) were removed immediately with a Boerner divider, sealed, and stored at 4°C for later analysis.

2.2. Simulation trials in environmental chambers

To investigate under controlled conditions the problems encountered in summer storage of WM, 158 kg of pelleted WM or 90 kg of ground WM were placed in bins 56.5 cm diameter and 89 cm tall with 45° hoppers and exit ports 35.6 cm wide at the base. Fine material was removed by cleaning the pellets over a wire screen with 6 mm x 6 mm openings. To compare clean and uncleaned pelleted WM, 30 g of the fines/kg were added back to the pellets as the bins were filled.

The initial flow rate was determined by suspending each bin, opening the slide covering the exit port, and determining the time in seconds required for the contents to flow into another container. This process was repeated after the WM were stored for a specified length of time in environmental chambers wherein the temperature and relative humidity were controlled. For comparison of cleaned and uncleaned pellets and ground WM, six bins were filled with each, and duplicate measurements were taken initially and after a specified storage time (sampling without replacement). Two such trials were done, at 24 and 30°C. For comparison of aerated and non-aerated treatments, eight bins of each treatment were prepared, and duplicate measurements were taken initially and after the required storage time.

To investigate the effects of aeration under conditions of either high or low relative humidity, 8 of the 16 bins were connected to a small centrifugal fan such that when the fan was activated a negative pressure was formed at the surface of the pellets in the bins. The fan was attached to a manifold consisting of 7.6 cm diameter polyvinylchloride pipe. This, in turn, was connected to the sealed top of each bin by a 7.6 cm diameter flexible hose. The fan withdrew air from the manifold, flexible hose, and bin, forcing air to move up through the pellets from small openings around the slide gate at the bottom of the hopper. The airflow through each bin when eight bins were attached to the system was about 4.3 l/min/t initially and increased during each consecutive aeration cycle, because fewer bins were aerated. Pellets were aerated for 24 h during the second, fifth, and eighth week, and for 48 h during the 11th week of storage.

The aeration trial was conducted at 30°C. When the fan was not activated, the relative humidity was maintained at 72% to maintain pellet initial moisture content (140 g/kg). During the aeration periods only, the relative humidity of the air was increased to 80% to simulate the high relative humidity during cool evening hours when fans would be operated to cool the pellets. The tops of bins containing non-aerated pellets were sealed during aeration periods to minimize exposure to the moist air. After the third aeration period and subsequent flow-rate determination, it became obvious that the aeration contributed to aggregation. Therefore, at week 11, the relative humidity was reduced to 50%, and all remaining bins (both “aerated” and “non-aerated”) were aerated to simulate use of the fans to dry the pellets with warm, dry air, as opposed to the moist air that would be used for cooling.
2.3. Trials in farm bins

Pelleted WM were obtained from a flour mill about 100 km from the university and placed in farm bins (cylindrical bins of corrugated metal) 4.5 m in diameter and 2.7 m to the eaves (rated capacity 34 t, 1250 bushels). Five identical bins received 25–29 t pelleted WM each between 20 May and 3 June, 1998. Four bins had 0.64 cm pellets, and one had 1.9 cm pellets. Initial moisture contents ranged from 132 to 138 g/kg. Each bin was equipped with a full aeration floor and a small fan. Samples for moisture content determination were taken from the pellet stream at loading. Subsequent samples were taken with a bullet probe from various depths and locations, as explained below.

Warm, dry, ambient air was passed through the first three bins filled, based on the results of the simulation trials in which drying with warm, dry air restored the bulk-flow characteristics of the WM pellets. Aeration fans were operated during periods when the relative humidity did not exceed 65%. Ambient temperatures during these times were usually 25–33°C. To determine whether this strategy provided benefits relative to a simpler strategy, pellets in the final two bins filled were aerated continuously unless rain threatened. Airflow through the pellets was estimated at the surface of the mass with a soap-film air velocity apparatus (Burrell, 1974). This method results in approximations which were used to demonstrate variability in airflow from one part of the mass to another.

2.4. Laboratory analyses

To determine the equilibrium moisture content (EMC) of pelleted wheat middlings as influenced by temperature and relative humidity, 10 g of pellets were weighed into tared wire-mesh baskets and placed in humidity chambers with 500 ml of saturated salt solution (Winston and Bates, 1960). Saturated solutions of KCl, (NH₄)₂SO₄, NaCl, NaCl + KCl, and NaNO₃ were used to provide relative humidities of 85, 80, 75, 70, and 65%, respectively. These salts were selected for their stable relative humidities at 20, 25, and 30°C. Duplicate chambers were used for each solution, and each chamber contained five wire mesh baskets. The sealed chambers were kept in environmental chambers at either 24 or 30°C. Pellets were weighed every 3 days until changes in weight were <0.005 g.

Moisture content was determined by the two-step method (AACC, 1995). In step one, approximately 20 g of pellets were placed in duplicate, tared moisture dishes; weighed; air-dried to a moisture content of 70–80 g/kg at 25–35°C; and then weighed again. In step two, the pellets were ground in a food blender and 2 g were weighed into duplicate, tared, moisture dishes and heated in a forced air oven for 2 h at 130°C. The initial moisture content (MC₁, g/kg) was calculated as: $MC_1 = 1000 - (W_2/W_1)(1000 - MC_2)$ where $W_1$ is the tared weight (g) of the pellets before stage one drying, $W_2$ denotes the tared weight (g) of the pellets after stage one drying, and $MC_2$ is the pellet moisture content (g/kg wet weight) determined by the air oven method at stage two. Bulk density was determined with a 0.028 m³ (1 ft³) container.

To determine the number of mold colony-forming units per gram of sample (cfu/g), 10 g of ground WM or ground WM pellets were mixed with 90 ml of 0.5% water agar
diluent and blended at high speed for 1 min. Dilutions of 1/10, 1/100, 1/1000, and 1/10,000 were made. Higher dilutions were included when samples were visibly moldy. Each dilution (1 ml) was pipetted into each of two sterile petri dishes. Malt agar containing 6% salt at ≤50°C was poured into the petri dishes. Each petri dish was shaken gently to distribute the medium. The petri dishes were placed in a plastic bag and incubated at room temperature (20–22°C). After 7 days, the colonies were counted and the species of fungi were identified with the aid of a dissecting microscope.

2.5. Statistical analysis

Data were analyzed using SAS software (SAS, 1985). Means and standard deviations were calculated by the ANOVA or MEANS procedure and were separated by ANOVA if equal numbers of replications were made, or by the General Linear Models procedure when treatments were unequal.

3. Results and discussion

3.1. Survey

A total of 41 samples of WM pellets were collected from Kansas flour mills. The mean bulk densities (BD) of the 0.64 cm pellets and the 1.9 cm pellets were not significantly different and ranged from 48.3 to 54.0 kg/hl. Whereas the overall mean bulk density of the ground WM was about 25.6 kg/hl, that of the pelleted WM was 51.0 kg/hl ± 1.15 (Table 1). This doubling of the bulk density allows twice as much WM to be transported.

<table>
<thead>
<tr>
<th>Mill number</th>
<th>Physical parameter</th>
<th>Sampling date</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MC (g/kg)</td>
<td>03/25/97 04/02/97 04/29/97 05/07/97 05/24/98 06/03/98</td>
</tr>
<tr>
<td>1</td>
<td>BD (kg/hl)</td>
<td>50.5 50.4 48.6 50.6</td>
</tr>
<tr>
<td>2</td>
<td>MC (g/kg)</td>
<td>146 141 128</td>
</tr>
<tr>
<td>3</td>
<td>BD (kg/hl)</td>
<td>51.2 51.7</td>
</tr>
<tr>
<td>4</td>
<td>MC (g/kg)</td>
<td>144 148 142</td>
</tr>
<tr>
<td></td>
<td>BD (kg/hl)</td>
<td>51.9 51.2 51.2</td>
</tr>
</tbody>
</table>

Mean MC (g/kg) 142 ± 3 141 ± 3 138 ± 3 136 ± 5 138 132
Mean BD (kg/hl) 51.5 ± 1.3 50.6 ± 0.9 48.9 ± 0.3 50.3 ± 0.9

Table 1
Moisture content (MC, g/kg) and bulk density (BD, kg/hl) of pelleted middlings collected from four Kansas flour mills in 1997 and 1998
at the same cost, which has facilitated the use of pelleted WM by farm-sized feeding operations located farther from the mills.

The overall mean moisture content of the pellets was $140 \pm 5$ g/kg, and the moisture content of individual samples ranged from 128 to 148 g/kg. The pellets, regardless of size, contained about 10 g more water/kg than the ground WM from which they were manufactured. As the ambient temperature increased during the spring, the pellets arrived drier, with the mean water content in May being 4 g less water/kg than the overall mean. This trend continued into the summer and was observed in subsequent years.

Because the heating, discoloration, and aggregation observed during summer storage of pelleted WM may be due to microorganisms, the microbiological characteristics of the pellets were examined. On average, the pelleting process reduced the level of molds in WM to about 4% of that present in the unpelleted material (Table 2). At three of the four mills, the reduction was even greater. Yeasts and *Mucor* spp. also were nearly eliminated by pelleting. Slight bacterial contamination was common. The overall impact of pelleting on microorganisms was to nearly eliminate those molds from the WM that were able to grow during storage.

### 3.2. Simulation trials in environmental chambers

Within the MC range observed in most of the freshly manufactured WM pellets, the equilibrium relative humidity would be 67–75% in the 24–30°C temperature range likely to be encountered during summer storage (Fig. 1). Because a lower ambient temperature

<table>
<thead>
<tr>
<th>Mill number</th>
<th>Sample type</th>
<th>Number of samples</th>
<th>Molds(^a)</th>
<th>Mucor spp.</th>
<th>Yeast</th>
<th>Bacteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Before</td>
<td>7</td>
<td>18120 ± 16687</td>
<td>200 ± 166</td>
<td>2525 ± 4316</td>
<td>&lt;10</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>6</td>
<td>34 ± 19</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td>610 ± 350</td>
</tr>
<tr>
<td>2</td>
<td>Before</td>
<td>4</td>
<td>12243 ± 1169</td>
<td>1775 ± 1927</td>
<td>938 ± 258</td>
<td>&lt;10</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>3</td>
<td>186 ± 174</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td>30 ± 16</td>
</tr>
<tr>
<td>3</td>
<td>Before</td>
<td>3</td>
<td>40333 ± 3952</td>
<td>2000 ± 2160</td>
<td>&lt;10</td>
<td>&lt;10</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>3</td>
<td>3163 ± 1372</td>
<td>30 ± 22</td>
<td>&lt;10</td>
<td>&lt;10</td>
</tr>
<tr>
<td>4A</td>
<td>Before</td>
<td>4</td>
<td>6993 ± 1859</td>
<td>800 ± 988</td>
<td>850 ± 659</td>
<td>&lt;10</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>3</td>
<td>52 ± 44</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td>572 ± 256</td>
</tr>
<tr>
<td>4B</td>
<td>Before</td>
<td>3</td>
<td>17433 ± 946</td>
<td>1167 ± 499</td>
<td>19500 ± 15817</td>
<td>&lt;10</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>3</td>
<td>23 ± 21</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td>1600 ± 829</td>
</tr>
<tr>
<td>Mean before</td>
<td></td>
<td>21</td>
<td>19024 ± 5573</td>
<td>1188 ± 586</td>
<td>4763 ± 7414</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Mean after</td>
<td></td>
<td>18</td>
<td>692 ± 1237</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td>562 ± 579</td>
</tr>
</tbody>
</table>

\(^a\)Include *Alternaria* spp., *Cladosporium* spp., *Fusarium graminearum*, *F. moniliforme*, *Phoma* spp., *A. glaucus*, *A. candidus*, *A. flavus*, *A. niger*, *A. ochraceus*, *A. versicolor*, and *Penicillium* spp.
is associated with a higher relative humidity during this time of the year, the likelihood exists that the pellets could gain moisture if only cool, moist, night-time air were passed through them. Preliminary tests indicated that the middlings pellets react differently to the presence of moisture than does wheat. Exposing the pellets to moisture causes them to swell and begin to lose their pellet shape. Therefore, aeration with air above the EMC could contribute to aggregation of the mass and result in the loss of desirable bulk-flow characteristics.

At 24°C and MC of 134 g/kg, ground WM aggregated before the first flow-rate test (Table 3), whereas the flow rate of the pelleted WM did not change significantly after 6

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Moisture content (g/kg)</th>
<th>Time (Weeks)</th>
<th>Condition</th>
<th>Clean a</th>
<th>Unclean b</th>
<th>Ground c</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>134</td>
<td>Initial</td>
<td>74.7 (0.5)\textsuperscript{d}</td>
<td>73.3 (2.4)</td>
<td>18.9 (1.0)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td></td>
<td>–</td>
<td>–</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td>70.0 (1.3)</td>
<td>69.1 (1.3)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td></td>
<td>73.6 (2.4)</td>
<td>71.9 (0.9)</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td></td>
<td>69.1 (0.5)</td>
<td>69.3 (3.8)</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>133</td>
<td>Initial</td>
<td>71.9 (0.5)</td>
<td>72.0 (1.6)</td>
<td>20.5 (0.1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td></td>
<td>–</td>
<td>–</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td>63.0 (5.9)</td>
<td>65.7 (0.6)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td></td>
<td>51.4 (15.3)</td>
<td>68.7 (1.9)</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td></td>
<td>18.3 (18.4)</td>
<td>38.4 (14.1)</td>
<td>–</td>
<td></td>
</tr>
</tbody>
</table>

\textsuperscript{a} Pellets with fine material removed.
\textsuperscript{b} Pellets containing 30 g fine material/kg.
\textsuperscript{c} Unpelleted WM.
\textsuperscript{d} Standard deviations in parentheses.
weeks of storage regardless of the presence of fine material. At 30°C and 133 g/kg MC, ground WM again had aggregated by the end of the first week of storage, and the flow rate of the pellets decreased significantly from ($P < 0.05$) to <40% of the initial rate within 6 weeks. In one of the cleaned replicates after 6 weeks of storage, only a small quantity of pellets exited the open port during the first 27 s after opening, then normal flow began. This observation, in combination with the significant reduction in rate of flow in the other replications, was interpreted to mean that the process of consolidation and bridging was nearly complete after 6 weeks. In no case did the presence of fines appear to significantly affect the degree of aggregation or the rate at which aggregation occurred.

To investigate the effect of aerating with moist air, pellets containing 140 g water/kg were stored at 30°C (Fig. 2). After 3 weeks, pellets in one of the bins aerated with air at 80% relative humidity had aggregated and did not flow. In the replicate bin, pellets flowed slightly less rapidly than did the non-aerated pellets, and both aerated and non-aerated pellets flowed significantly ($P < 0.05$) slower than initially. After 6 weeks and two aeration cycles with moist air, the aerated pellets did not flow, whereas no additional aggregation was observed in the non-aerated pellets. The trial did not completely simulate real-world conditions, as the aerated pellets were not simultaneously cooled. After 9 weeks, both aerated and non-aerated pellets had aggregated.

In all cases of complete aggregation, only a small quantity of pellets exited the bin when the gate was opened, exposing a dome-shaped bridge of aggregated material near the opening at the base of the bin. After 2 weeks of additional storage, the relative humidity of the air in the chamber was reduced to about 50%, and all four remaining bins were aerated. After aeration with dry air for 2 days, the mean flow rate was similar to that at the beginning of the trial, indicating that drying the pellets with dry air restored the bulk-flow characteristics even after they had aggregated. After drying, the pellets contained about 115 g moisture/kg.

Fig. 2. Flow rate (kg/s) of pelleted wheat middlings initially containing 140 g moisture/kg at 30°C as affected by aeration. Air with 80% relative humidity was passed through the “aerated” pellets at the times indicated, and air with 50% relative humidity was passed through all pellets at week 11.
Bacteria, *Mucor* spp., and field fungi (such as *Alternaria* spp. and *Fusarium moniliforme*) died out after a few weeks at 30°C and 72% relative humidity, regardless of the aeration treatment (Fig. 3). These microorganisms require very high relative humidity to grow. They were not expected to increase during storage, and normally die under the same conditions in which storage molds increase. Storage molds, including *Aspergillus glaucus*, *Aspergillus flavus*, *Aspergillus candidus*, *Aspergillus versicolor*, and *Penicillium* spp. cause heating and aggregation in grain (Christensen and Meronuck, 1986). The warm, moist conditions of this trial were ideal for growth of these molds, but only low levels were observed after 3 weeks (Fig. 4). The relatively low number (<100,000 cfu/g) of molds even after 9 weeks under these conditions probably was a result of the very low initial microbial count in the pelleted WM.
The level of storage molds increased faster in the 30°C trial than at 24°C. However, most of the increase was due to *A. glaucus*, and only low levels of *A. flavus* were observed even when total storage mold counts became large. This suggests that even if mold growth on pelleted WM is not prevented, the chance for contamination by aflatoxin, a mycotoxin produced by *A. flavus*, would be small.

The aeration trials demonstrated that mold growth was not the cause of the aggregation. The pellet flow rate was low after 6 weeks and was reduced to zero after 9 weeks. During this period, the mold density (cfu/g) was very low. In contrast, after 12 weeks of storage, large numbers of molds were observed, but the pellets, which had been dried by aeration, flowed at about the same rate as they had initially. Thus, the bulk flow characteristics of the WM pellets appeared to be related to pellet moisture content and temperature, not molds. Further, it appeared likely that drying the pellets with warm, dry air would be more successful in practice than attempting to cool them by night-time aeration. In the summer in Kansas, access to cool air is limited, and cool air is usually very moist.

### 3.3. Farm-scale trials

The farm-scale trials in bins containing about 25 t WM each were done to verify on a larger scale the results of the trials in the environmental chambers. The first three bins filled were aerated only when the air contained no more than 65% relative humidity, whereas the final two bins were aerated continuously unless it was raining. By the end of June, the temperatures of pellets aerated continuously ranged from 24 to 26°C, whereas those of pellets aerated only when the air was dry ranged from 34 to 40°C. Because the latter were higher than the mean daily temperatures, they were likely due to heating within the mass and the generally warmer air used for aeration. We interpreted this to mean that by aerating only when the relative humidity was low, insufficient air was supplied to the pellets to avoid heat build-up. Thereafter, all bins were aerated continuously unless it rained.

The low numbers of molds observed in the pellets during the first 6 weeks of storage in the simulation trials suggested that drying stored WM pellets as soon as possible with warm air would control mold growth in addition to maintaining flowability. To test this hypothesis, random portions of the samples taken at the time of bin-loading were held in a controlled chamber at 30°C and <60% relative humidity. Although 1460 ± 730 (SE) cfu/g total storage molds were observed initially, only 829 ± 730 cfu/g were detected after 3 weeks, and 1356 ± 1076, 246 ± 104, and 2306 ± 1208 cfu/g were detected after 6, 9, and 12 weeks, respectively. This indicated that no significant increase (*P* > 0.05) in mold infection occurred in the pellets exposed to warm dry air. Because storage molds require a relative humidity of >65% at these temperatures (Christensen and Meronuck, 1986), this was expected.

Pellets taken from various depths about midway between the center and the wall of the bins (outside part of the mass) contained 870 ± 399 cfu/g after 7 weeks and 2854 ± 938 cfu/g after 14 weeks. This increase was not significant (*P* > 0.05), and the pellets in the outer portion of the mass in the farm bin contained about the same low level of mold growth as the pellets stored in the dry, controlled chamber. However, pellets
taken from near the center of several bins yielded 3841 ± 919 cfu/g and 377,840 ± 377,160 cfu/g at 7 and 14 weeks, respectively. The fourfold difference in mold infection between the center of the mass and the outside after 7 weeks was not significant (P > 0.05). After 14 weeks, the level of mold infection in the center of the pelleted WM was greater (P < 0.05) than that of pellets near the outside of the mass and had increased significantly (P < 0.05) since the seventh week.

The substantially higher levels of mold near the center of the pellet mass appeared to be associated with accumulations of fine material (spout line) beneath the auger spout. Although fines did not significantly affect the bulk flow characteristics or mold growth in the environmental-chamber trials, the accumulation of fine material associated with the spout line in the larger bins appeared to reduce airflow, promote mold growth, and contribute to aggregation. Airflow through the pellets was estimated at the surface center and in the outer part of the mass. Airflow velocity in the outer part of the mass was estimated to be 0.85 m/min in one bin, and in another, 0.4 m/min at a similar location. In the center spout line, where accumulation of fine material was clearly visible, no airflow was detected in either bin. In all bins, heating to ≥38°C was observed at the center during the summer, whereas pellets located more than 0.5 m from the center were much cooler. After about 2 months of storage, pellets taken from the outer part of the mass had lost a mean of 7 g water/kg, and the overall mean moisture content was 129 ± 8 g/kg. Meanwhile, pellets collected from the center spout line had lost a mean of 4 g/kg moisture and had a mean water content of 132 ± 3 g/kg. This suggests that eliminating the spout line by removing or dispersing the fines before storage would reduce heating by suppressing mold growth and would minimize aggregation by allowing the pellets to dry faster and more uniformly.

After nearly 3 months of storage, pellets were discharged from the bins to assess their flow characteristics. In the three bins that contained pellets with about 138 g initial moisture/kg and in which aeration had been limited during the first month of storage, pellets did not flow. The center spout line had aggregated. In bins that had been filled with pellets containing about 132 g/kg and had been aerated immediately and continuously except during rain, pellets flowed with only minimal assistance. This assistance involved disaggregating small areas of the center spout-line with a rod. The strategy of aerating continuously except during rain appeared to be successful. The discharged pellets were returned to the bins, and aeration was continued until mid-October, when pellets appeared dry and cold. When removed from the bins in February and March of the following year, after more than 9 months of storage, all pellets flowed with only minimal assistance.

In summary, pelleted WM from Kansas flour mills had twice the bulk density and greatly reduced counts of storage molds compared to un pelleted WM. Mold counts remained low for at least 6 weeks, even with storage at 30°C. The MC of WM pellets ranged from 128 to 149 g/kg with a mean of 140 ± 5 g/kg in March, April, and May, but the mean was reduced to about 132 g/kg by June. Aggregation of pelleted WM appeared to be a physical phenomenon associated with storage at high moisture and temperature, and was not a result of mold growth. Mold growth, causing heating and aggregation, was observed at higher temperatures when pellets remained moist, but the species of molds predominating were not those associated with the production of aflatoxin. Drying and cooling the pellets by means of near-continuous summer aeration prevented mold growth
to a large extent and minimized the effects of aggregation. Spout lines containing large amounts of fine material were associated with mold growth, heating, and impedance of airflow.

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References


