K-STATE
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Research and Extension

Wheat Middlings

Composition, Feeding Value, and Storage Guidelines

Project Sponsors

Kansas Wheat Commission

Peterson Laboratories, Inc.

ADM Milling Company

Cargill Foods Flour Milling

Cereal Food Processors, Inc.

Stafford County Flour Mills Company

The Wall-Rogalsky Milling Company

Kansas Department of Commerce and Housing
Agriculture Products Development Division

Kansas State University Agricultural Experiment
Station and Cooperative Extension Service

Kansas grows more wheat, grinds more wheat into flour, and produces more wheat middlings than any other state in the nation. In 1997, Kansas grew a record 506 million bushels of wheat. One-fifth of that wheat production was used to manufacture flour in Kansas. According to the Sosland publication, Grain and Milling Annual 1997, the rated production capacity of Kansas flour mills is 152,440 hundredweights of flour per day. The estimated amount of millfeed produced in Kansas in 1997 was 735,729 tons or 10% of the total amount produced in the United States.

During the wheat milling process, about 70 to 75% of the grain becomes flour, and the remaining 25 to 30% is available as wheat by-products largely destined for livestock consumption. These by-products commonly are referred to as millfeed (MF), wheat mill run (WMR), or wheat middlings (WM) with little regard for the various mill streams and proportions that are combined and ultimately constitute the by-product's final composition. As a consequence of this inconsistent terminology, difficulties are encountered when ascertaining nutritional value and establishing economic worth. The term WM will be used in this publication to collectively describe WMR and MF.

USDA production estimates rank WM second to soybean meal as the dominant by-product used in the commercial feed manufacturing industry. The availability of WM is limited to a large degree by the seasonal level of production and demand for flour. Quite often, WM prices slip in relationship to their feed value in the spring and early summer before strengthening in the fall and winter months.

Astute livestock producers have purchased WM during periods of price slippage and stored them on-farm until needed during the feeding season. However, producer experience with extended on-farm storage of WM during the summer months has been variable and frequently unsatisfactory. According to a recent survey conducted by K-State Research and Extension, over 30% of the survey respondents encountered mold, spoilage and bridging when attempting to store WM long-term.

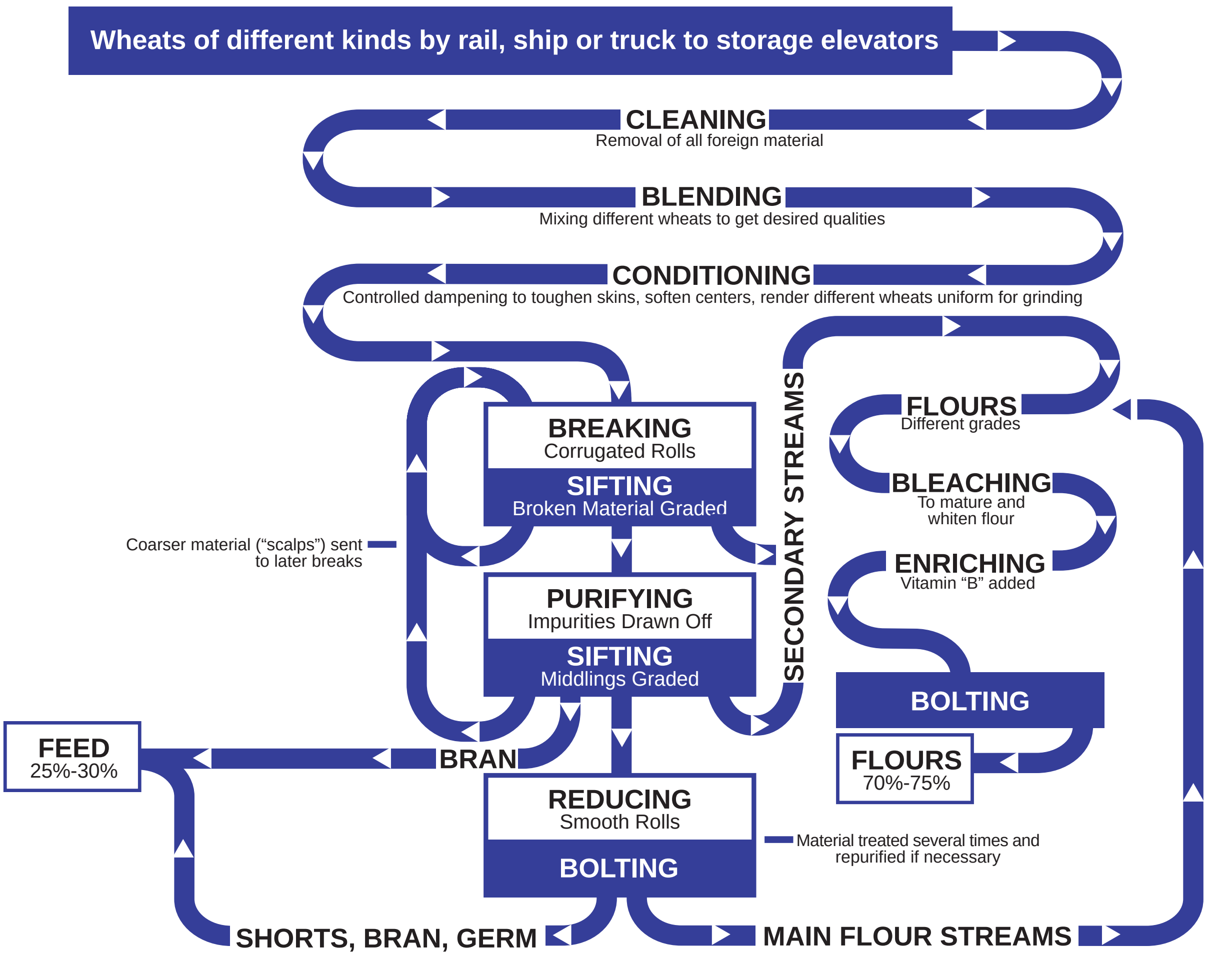
The most frequent request for information from survey respondents was the development of guidelines for WM storage systems for periods of up to 6 months. Another area of research identified by survey respondents was the determination of feeding value, specifically the substitution value of WM for corn and soybean meal in growing diets for beef cattle.

Armed with the financial support of the project sponsors and efforts of K-State Research and Extension personnel, research evaluating optimal storage conditions and feed value of WM has been conducted, and the results are presented in this publication. Peterson Laboratories, Inc., and the major flour mills in Kansas have contributed to this research along with Kansas wheat producers through the Kansas Wheat Commission.

The Flour Milling Process

Wheat grain (all analyses), milled flour, and wheat by-products, with their respective nutrient analyses, are shown in Table 1. As a result of focusing flour extraction efforts on the endosperm fraction, substantially higher levels of crude protein (CP), fat, crude fiber (CF), and macro and trace minerals result in WM from the concentration of the bran, aleurone cell layer, and germ components of the wheat kernel. From a human nutrition standpoint, it is a paradox that wheat milling methods to produce white flour eliminate those portions of the wheat kernel (bran, germ, shorts, and red dog mill streams) that are richest in proteins, vitamins, lipids and minerals. For example, highly refined (patent) flour may contain only 10 to 12% of the total thiamine and niacin, 20% of the phosphorus, and 50% of the calcium of the parent grain (Shellenberger, 1970).

Figure 1. Highly simplified flow chart of modern milling operations.[a]



Dust collectors protect the entire system from losses

[a]Storck and Teague (1952)

A brief description based on a simplified flow chart (Figure 1) of the flour milling process and the by-products that result at each step are discussed with the primary objective of shedding light on the origin(s) of each by-product stream created during the milling process (Martin et al., 1976). Table 2 describes, from an industry perspective, the various flour milling by-products composited by the milling industry. For example, unless there is a specific market for coarse bran (typically marketed as Baker's Bran), it is commonly hammer-milled and included in the WM fraction. The germ can be blended with shorts and used as a component of WM or extracted to produce wheat germ meal and oil for human food purposes. Typically, wheat screenings composed primarily of broken or shriveled wheat kernels and weed seeds are ground and blended into the WM fraction at levels of approximately 2 to 3%.

Premilling Steps

Cleaning and scouring. Damaged wheat kernels, weed seeds, foreign material, and dockage are removed and directed to the WM stream.

Conditioning. This step, also referred to as tempering, adds water to the cleaned wheat to increase its moisture content to approximately 15%. The grain is allowed to stand for 2 to 24 hours so the added moisture can penetrate the kernel to the proper depth. The objective of conditioning is to toughen the bran coat and soften the endosperm so that larger flakes can be removed during the breaking step, thus separating the coarse bran from the flour more completely.

Milling Steps

Breaking. The grain is crushed gradually through the shearing action of four to six pairs of breaker rolls. The grist (fines) from each pair of breaker rolls are sifted, and the coarsest particles are transferred to successive breaker rolls where the process is repeated. Each successive pair of breaker rolls has finer corrugations and closer distances between the rolls in order to grind the grain into progressively smaller particles. The finest particles from the breaks are sifted off as flour. The objective of milling on the breaker rolls is to physically separate the branny portion from the white endosperm fraction. The wheat germ usually is separated at the breaker rolls in a stream called sizings, in which the germ is attached to large particles of bran.

Table 1. Comparison of all analyses wheat grain to by-products resulting from the flour milling process.[a]

Nutrient	All Analyses Grain	Flour <2% CF	Grain Screenings	Bran	Red Dog <4.5% CF	Shorts <7% CF	WM <9.5% CF	Mill Run <9.5% CF
		Expressed as % of All Analyses Grain						
Crude protein, %	16.9	79	95	101	103	110	111	102
NEm (Mcal/lb)	.97	114	81	74	107	97	91	86
NEg (Mcal/lb)	.66	117	77	68	108	95	89	83
TDN, %	89	111	84	80	104	97	92	89
Ether extract, %	2	65	190	220	190	275	260	230
Crude fiber, %	2.8	43	300	414	96	264	279	332
Phosphorus, %	.43	51	93	330	128	214	216	265
Potassium, %	.41	27	—	400	144	261	273	346
Magnesium, %	.17	18	—	347	94	171	235	335
Copper, ppm	6.5	28	—	220	112	205	317	320
Zinc, ppm	50.8	14	—	230	145	238	334	—

[a]Ensminger and Olentine (1980). Nutrient values expressed on a dry matter basis.

Purifying. The middlings are rebolted (sifted) and also aspirated in a middlings purifier to remove small, light, bran particles.

Reducing. The purified middlings pass through a series of paired, smooth, reduction rolls. They are spaced such that each successive reduction produces finer particles. Flour is sifted out after each reduction. Most of the fine bran is removed from the germ at this step.

Description of Flour Milling By-Products

An understanding of the milling constituents derived from the wheat kernel is essential for determining the feeding value of flour milling by-products. **Aside from obvious differences in maximum crude fiber restrictions as outlined by the Association of American Feed Control Officials (AAFCO, 1996), the following definitions in many instances are vague, particularly for use in sorting out the discrepancies that exist between WM and WMR.** For example, when compared to all analyses wheat grain (Table 1), WM can contain 9, 5 and 6% more CP, NEm, and NEg, respectively, than WMR. Furthermore, WM can contain 49, 73, and 100% less phosphorus, potassium, and magnesium, respectively, compared to WMR. Crude fiber content can differ significantly between WM and WMR, yet both are limited to a maximum of 9.5%. **This comparison of nutrient differences between WM and WMR illustrates that although only subtle distinctions are noted in the AAFCO (1996) descriptions of these major by-products, significant differences in nutrient content can exist.** Yet, the livestock and milling industries routinely use the terms WM and WMR interchangeably.

The descriptions of flour milling by-products are outlined below (AAFCO, 1996):

93.1 Wheat Bran is the **coarse outer covering of the wheat kernel** as separated from cleaned and scoured wheat in the usual process of commercial milling. (Adopted prior to 1928.) IFN 4-05-190 Wheat bran.

93.2 Wheat Flour consists principally of wheat flour **together with fine particles of wheat bran, wheat germ, and the offal from the "tail of the mill."** This product must be obtained in the usual process of commercial milling and must not contain more than 1.5% crude fiber. (Adopted 1949.) IFN 4-05-199 Wheat flour less than 1.5% fiber.

93.3 Wheat Germ Meal consists chiefly of wheat germ **together with some bran and middlings or shorts.** It must contain not less than 25% crude protein and 7% crude fat. (Adopted 1949, Amended 1953.) IFN 5-05-218 Wheat germs ground.

93.4 Wheat Mill Run consists of **coarse and fine particles of wheat bran**, wheat shorts, wheat germ, wheat flour, and **the offal** from the "tail of the mill." This product must be obtained in the usual process of commercial milling and must contain not more than 9.5% crude fiber. (Proposed 1959, Adopted 1960.) IFN 4-05-206 Wheat mill run less than 9.5% fiber.

93.5 Wheat Middlings consist of **fine particles of wheat bran**, wheat shorts, wheat germ, wheat flour, and **some of the offal** from the "tail of the mill." This product must be obtained in the usual process of commercial milling and must contain not more than 9.5% crude fiber. (Proposed 1959, Adopted 1960.) IFN 4-05-205 Wheat flour by-product less than 9.5% fiber.

93.6 Wheat Shorts consist of **fine particles** of wheat bran, wheat germ, wheat flour and **the offal from the "tail of the mill."** This product must be obtained in the usual process of commercial milling and must not contain more than 7% crude fiber. (Proposed 1959, Adopted 1960.) IFN 4-05-201 Wheat flour by-product less than 7% fiber.

93.7 Wheat Red Dog consists of **the offal from the "tail of the mill"** together with **some fine particles of wheat bran, wheat germ, and wheat flour**. This product must be obtained in the usual process of commercial milling and must contain not more than 4% crude fiber. (Proposed 1959, Adopted 1960.) IFN 4-05-203 Wheat flour by-product less than 4% fiber.

Table 2. Flour milling by-products.[1,2]

Mill Stream Constituents	Wheat Bran	Wheat Red Dog	Wheat Shorts	Wheat Germ Meal	Wheat Middlings	Wheat Mill Run
	By-Products					
Ground screenings					P	P
Coarse bran	O, P					O, P
Fine bran	P		O, P	P	O, P	O, P
Germ			O, P	O, P	O, P	O, P
Red dog		O, P	O, P		O, P	O, P

[1]Stevens, 1995.
[2]O = Official AAFCO (1996) definition. P = Probable in many commercial milling operations.

Factors Affecting the Nutrient Content of Flour Milling By-Products

Flour milling by-products arising from a fairly homogeneous parent grain can vary greatly depending upon the objectives of the milling process. Thus, the degree of nutrient variation in WM can be a major consideration in determining whether its inclusion in a ration or formula feed is beneficial.

The most important nutritional consideration with flour milling by-products is that no practical way exists for commercial milling operations to produce flour to the buyer's specification(s) and simultaneously produce a standardized WM. The quality and consistency of these wheat by-products can be affected by several factors. First, the nutrient content of WM can be influenced by wheat type and variety, and environmental factors experienced during production and storage of the wheat crop. Second, the production of various grades of flour for individual customer specifications may alter the amount of second clear fraction (low grade flour) included in the WM-destined stream. Finally, the ultimate nutrient composition of WM can vary because millers occasionally extract a specific constituent of the wheat kernel that is valued higher by itself than by its contribution as a portion of the WM.

An average milling yield of 72% flour from wheat that contains nearly 85% endosperm indicates the difficulty of making a perfect separation of the kernel constituents during the milling process (Martin et al., 1976). Typically, 2.3 bushels of hard red winter wheat (72.5% flour extraction yield) are required to produce 100 pounds of flour, resulting in 38 pounds of wheat by-products consisting primarily of bran, shorts, and red dog. Because the miller must fractionate the kernel in a manner that will produce a flour of specific analytical limits and use properties, WM must absorb the quality and quantity fluctuations. In general, bran and shorts each form approximately 40% of the WM produced, and red dog composes the remaining 20% (Morrison, 1961). However, the specific amounts of each by-product produced will depend upon the physical properties of the wheat, the milling operation, and the end products desired (Shellenberger, 1970). Shorts consist mostly of fine particles of bran and germ with small amounts of wheat red dog. Red dog is the by-product from the "tail of the mill," consisting chiefly of the aleurone layer with small particles of bran, germ, and flour.

Wheat test weight can play a significant role in determining flour and by-product yields. Swanson (1938) reported flour yields ranging from 40 to 79.6% (low grade flour included) for test weights ranging from 40 to 64 pounds, respectively. Because flour yield is not a linear function of test weight, it was concluded that bran thickness is nearly the same in kernels of different shapes and sizes. Consequently, smaller or less plump kernels have a greater proportion of bran material than the larger or more plump kernels. Prior to harvest, the test weight of wheat in the field can be affected by 1.5 to 2.5 pounds per bushel due to wetting and drying. To avoid milling low test weight grain, millers will blend wheat from different elevators and locations to maintain average test weights, normally not less than 58 pounds, with minimum guidelines for CP content. Typically, millers will blend wheat to contain CP levels approximately 1.5 percentage points higher than flour buyer specifications.

Concentrations of ash and protein are the two primary factors affecting flour quality and value. Depending upon flour buyer specifications, the ash content of patent flour may range from .4 to .6%. As a rule, the more bran particles a flour contains, the higher the ash content. Generally, lower quality flour such as second clear contains a higher ash content than does patent flour. Hard wheats tend to have higher ash contents than soft wheats. However, high ash content is not necessarily an indication of lower flour extraction rates, poor milling practices, or dirty wheat because varieties may differ in ash content (P.J. McCluskey, Kansas State University, personal communication, 1995). In general, the elements composing ash include oxygen, phosphorus, potassium, magnesium, sulfur, and calcium. Protein content dictates baking quality in terms of moisture retention and baking yield and the end-use of the flour.

Extensive analyses of flour and millfeeds produced from hard red winter **(HRW)**, hard red spring (**HRS)**, Pacific white (**PW**), and soft red winter (**SRW**) wheats suggest that milling characteristics may vary across wheat types (Farrell et al., 1967). The percentages of bran, shorts, red dog, and germ ranged from 51.4 to 58.7%, 28.9 to 34.1%, 7.1 to 16.9% and 2.8 to 4.1%, respectively of the total WM produced across the four wheat types. Moreover, the ratio of bran:shorts was approximately 2:1 for HRW and HRS wheats and lower (1.6:1 and 1.8:1, respectively) for PW and SRW wheats. The proportion of starch extracted into straight grade flour across the four wheat types varied from 83.7 to 91.1%. Inversely, the proportion of starch in the parent grain remaining in the total WM fractions varied from 8.9 to 16.3%. Consequently, the percent starch content of WM from the four wheat types ranged from 11.4 to 17.3%. The analyses included five HRW varieties that were grown in different locations and years. Substantial differences occurred in nutritional composition, including starch content of the WM produced, indicating notable variation within a wheat type. Obviously, quality of wheat cultivars and milling technology have improved over the past 31 years since this study was conducted. However, the results of this study illustrate the importance of distinguishing flour milling by-products from different wheat types when merchandising or reporting research results with WM.

In addition to the variation in nutritional composition of WM from different wheat types, the results of a small-scale survey of WM and screenings obtained from several flour mills in south central Kansas and northern Oklahoma suggest that substantial nutrient variation also exists from mill to mill (Arensdorf et al., 1995). They reported WM coefficients of variation of 4.8, 13.4, 14.5, 14.2, and 14.8% for CP, ash, acid and neutral detergent fiber (ADF, NDF), and starch, respectively. Some interesting observations can be made from these data. First, moisture content of WM is highly dependent on the degree of tempering of the wheat prior to the milling process and can range from 10 to 18%. Secondly, the low variation in CP across samples was expected because of the standard practice of blending wheats prior to milling. Finally, a two- to threefold difference existed in WM fiber (NDF and ADF) and starch contents relative to those determined for wheat screenings. Grant County Feeders, Inc. (B.S. Dalke, personal communication, 1995) analyzed 165 daily composited samples representing 579, 25-ton truckloads of WM derived from HRW wheat over the first 7 months of

1995. On a dry matter (DM) basis, WM had average percentages of 86.9 ± 1.24, 17.7 ± .98, .27 ± .17, 1.03 ± .07, 1.5 ± .75 and .4 ± .09 for DM, CP, calcium, phosphorus, potassium, and magnesium, respectively.

More recently, the nutrient variation of WM over several months was determined from three flour mills located across central Kansas (Table 3), Blasi et al., 1998. The CP content of WM from mill to mill deviated by less than 1 to 2 percentage points over the time period sampled (Figure 2). In contrast, percent total starch deviated abruptly in two of the three flour mills during the same time period (Figure 3).

While commercial feed manufacturers are required to guarantee the minimum nutrient content of all formula feeds and supplements sold, thereby ensuring nutrient consistency, requirements are less stringent for feed by-products such as WM. By AAFCO (1996) standards, flour milling by-products such as WM and WMR must contain not more than 9.5% crude fiber. As illustrated earlier, variation in the nutrient content of WM can be considerable. The end user must accept the challenge of some nutrient variation when utilizing flour milling by-products.

Figure 2. Percent crude protein content and variation of WM from three central Kansas flour mills.

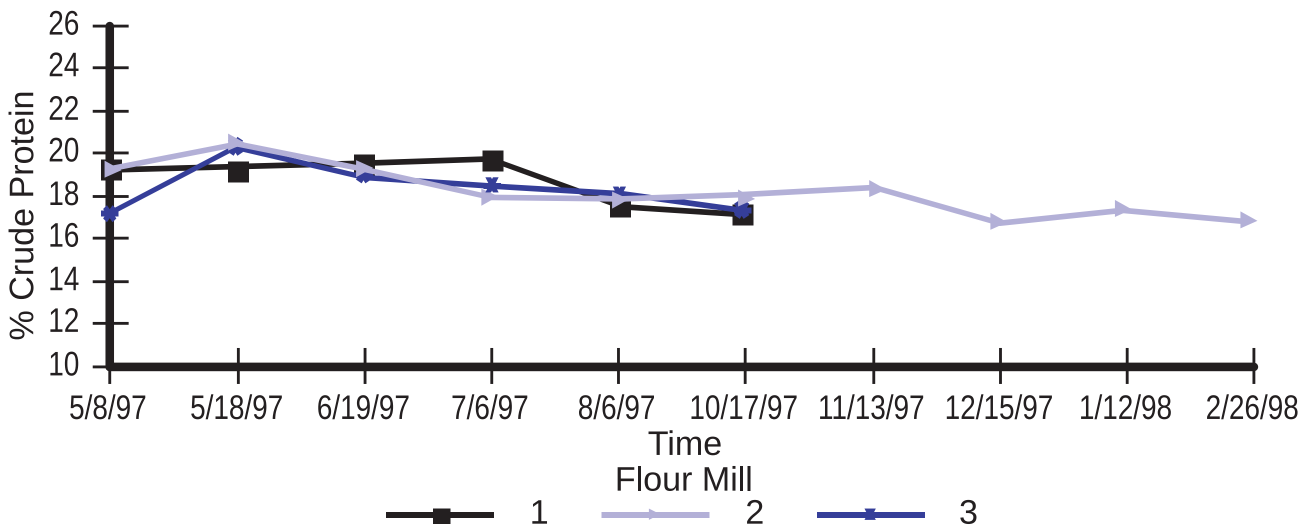


Figure 3. Percent total starch content and variation of WM from three central Kansas flour mills.

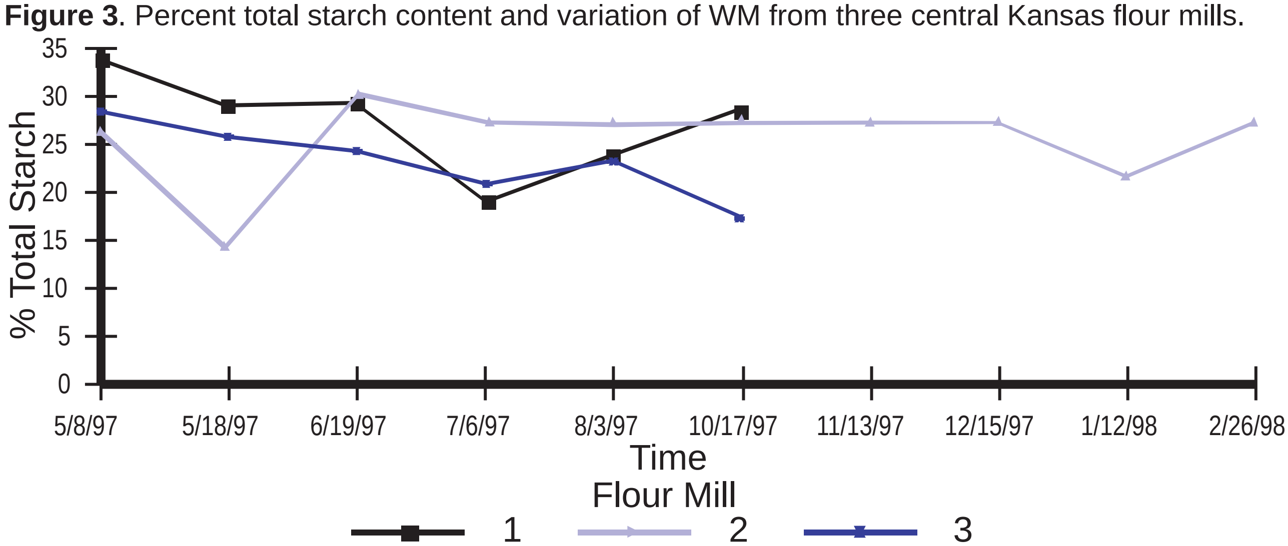


Table 3. Nutrient variation of WM samples collected from three Kansas flour mills.[a]

Nutrient	Flour Mill 1 (n=11)	2 (n=10)	3 (n=10)
Dry matter, %	87.62 ±.58	88.25 ±1.38	89.05 ±.75
Crude protein, %	18.30 ±1.49	17.89 ±1.20	18.21 ±1.08
Crude fiber, %	10.73 ±1.49	11.05 ±.66	11.18 ±1.14
Acid detergent fiber, %	13.63 ±.40	13.28 ±.66	13.72 ±1.31
Neutral detergent fiber, %	38.3 ±12.42	38.8 ±5.2	41.91 ±3.61
NEm, Mcal/lb	.829 ±.02	.832 ±.009	.828 ±.011
NEg, Mcal/lb	.504 ±.02	.504 ±.011	.501 ±.012
TDN, %	73.1 ±1.46	73.1 ±.74	72.8 ±.92
Fat (Ether extract), %	3.55 ±.24	3.72 ±.26	3.78 ±.23
Total Starch, %	24.83 ±5.8	26.92 ±5.03	25.2 ±4.32
Ash, %	5.47 ±.82	4.75 ±1.11	5.32 ±.48
Calcium, %	.135 ±.03	.137 ±.03	.122 ±.04
Phosphorus, %	1.08 ±.14	1.03 ±.17	1.09 ±.14
Potassium, %	1.21 ±.18	1.48 ±.70	1.34 ±.12
Magnesium, %	.514 ±.09	.480 ±.07	.515 ±.69
Sodium, %	.035 ±.01	.037 ±.01	.032 ±.023
Sulfur, %	.21 ±.02	.21 ±.02	.20 ±.02
Aluminum, ppm	50.5 ±25.0	32.65 ±20.4	43.94 ±23.6
Cobalt, ppm	.197 ±.02	.233 ±.10	.21 ±.02
Copper, ppm	12.92 ±1.1	12.85 ±2.93	13.07 ±1.06
Iron, ppm	146.1 ±46.1	136.8 ±19.0	135.8 ±14.82
Manganese, ppm	155.6 ±16.2	163.8 ±13.8	154.8 ±28.2
Molybdenum, ppm	1.00 ±.08	1.61 ±.99	1.45 ±.43
Selenium, ppm	.299 ±.08	.33 ±.11	.486 ±.15
Zinc, ppm	85.8 ±14.0	80.25 ±13.5	81.6 ±12.45

[a]Dry matter basis.

Wheat Middlings for Beef Cattle Grazing Low Quality Forages

Cattle producers located in regions where large amounts of grain and oilseeds are produced and processed have tremendous opportunities to significantly reduce supplemental feed input costs. In the past, beef cattle producers have used cereal grains as a source of supplemental energy to meet requirements of grazing cattle, often with less than satisfactory results in animal performance. Studies by Rush et al. (1986) and others have illustrated the negative associative effects of feeding high starch-containing feedstuffs with poor quality forages. WM contain approximately 40% NDF, which is highly digested in the rumen. Therefore, when fed to ruminants consuming low-quality forages, WM do not elicit the negative impact on fiber digestibility and subsequent decline in forage intake to the extent seen when cattle are fed high starch-containing feedstuffs. Hence, the “fiber friendly” nature of energy provided by WM permits total energy intake of the ruminant to increase at little or no expense to utilization of low quality forage. Sunvold et al. (1991) evaluated mixtures of WM, soybean meal (SBM) and grain sorghum formulated to contain 15, 20 and 25% CP and fed at the same level. They found that dormant range forage intake increased quadratically, whereas NDF digestibility increased linearly with increasing CP concentration. They concluded that WM-based protein supplements were most effective with dormant bluestem forage when formulated to contain at least 20% CP. Moreover, Lusby and Wettemann (1988) concluded the lower apparent energy content of WM compared to corn was offset by beneficial changes in forage intake and/or digestibility that resulted in similar total digestible energy intake of cattle on winter range.

Several trials at Oklahoma State University have evaluated the use of WM as a source of CP and/or energy for fall- and spring-calving cows grazing dormant, native range. In short, Lusby et al. (1991 a and b) concluded that protein and energy in WM are well utilized to increase precalving cow weight, so WM can be used to replace SBM when the cost per pound of CP is favorable. Generally, 5.1 to 6.2 pounds of WM/day can be used to replace 3.1 pounds/day of SBM (Table 4). However, if more severe weather conditions and/or less forage is available, 5.1 pounds of WM may not be adequate.

Table 4. Comparison of supplemental protein sources for spring-calving cows.[a]

	Treatments, Lb/Head/Day (As Fed)			
	SBM	Wheat Middlings		
Item	3.1	5.1	6.2	7.5
Initial BCS[b]	6.1	6.0	6.0	6.0
Cow wt. change, lb	90.2	74.8	110.0	103.4
Pregnancy rates, %	86	98	97	100

[a]Lusby et al. (1991b).
[b]Body Condition Score, 1-9 point system.

Wheat Middlings as an Energy/Protein Source for Growing Cattle

Research with WM has focused primarily on its use as a supplement with beef cows on poor quality roughages where forage utilization is an important consideration. A few studies have indicated that growing cattle respond very favorably to WM as a replacement for grain and SBM in backgrounding rations (Allison and Poore, 1993; Poore, 1993). A recent study was conducted by Blasi et al. (1998) at Kansas State University to evaluate the performance of beef heifers fed WM in traditional full-fed, sorghum silage-based rations and in limit-fed, high-concentrate rations. Diets were formulated without WM or with WM replacing 33, 67, or 100% of rolled corn plus SBM. Over the spectrum of WM evaluated in either the silage or limit-fed diets, a similar linear decline ($P<.01$) in daily gain occurred as the proportion of WM was increased (Figure 4). The heifers’ dry matter intake of the silage-based 100% WM diet was approximately 10% less ($P<.10$) than intakes of the other silage diets. With full-fed silage diets, feed efficiency changed little ($P>.30$) as WM increased. However, with the limit-fed diets, efficiency decreased ($P<.01$) as WM replaced corn and SBM (Figure 5).

Based on the feed efficiency data from this study, WM had a feed value almost equal to that of corn and SBM when used in full-fed sorghum silage-based rations but had a value of 83% when used in limit-fed diets. WM also have been used successfully in winter cereal pasture supplements (Horn et al., 1992). These results suggest that the feeding value of WM is comparable to that of protein equivalent mixtures of grain and SBM in high forage, growing programs. Table 5 illustrates the relative value per ton of WM (based on protein, energy, and phosphorus content) at various market prices for corn and SBM.

Figure 4. Effect of increasing levels of WM on daily gain of growing heifers fed either a sorghum silage or a limit-fed diet.

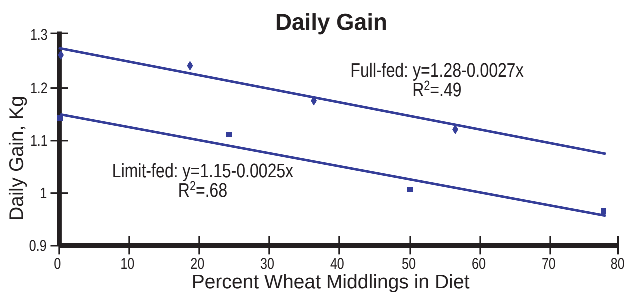


Figure 5. Effect of increasing levels of WM on feed efficiency of growing heifers fed either a sorghum silage or limit-fed diet.

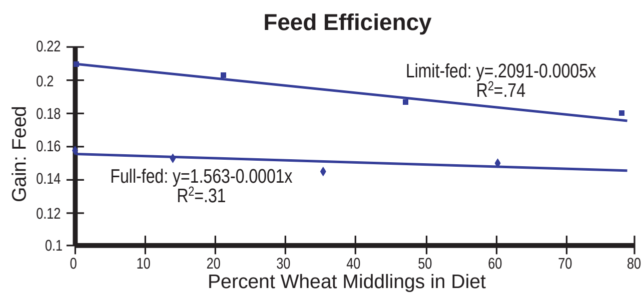


Table 5. Relative value of WM (based on protein, energy, and phosphorus content*) at various market prices for corn and soybean meal.

Soybean Meal, $/Ton	Corn, $/Bushel 1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00
	Relative Value of Wheat Middlings, $/Ton														
120	73	80	87	94	100	107	114	121	128	135	141	148	155	162	169
140	77	84	91	98	105	111	118	125	132	139	145	152	159	166	173
160	81	88	95	102	109	115	122	129	136	143	150	156	163	170	177
180	85	92	99	106	113	120	126	133	140	147	154	161	167	174	181
200	90	96	103	110	117	124	131	137	144	151	158	165	172	178	185
220	94	101	107	114	121	128	135	142	148	155	162	169	176	183	189
240	98	105	112	118	125	132	139	146	153	159	166	173	180	187	194
260	102	109	116	123	129	136	143	150	157	164	170	177	184	191	198
280	106	113	120	127	134	140	147	154	161	168	175	181	188	195	202
300	110	117	124	131	138	145	151	158	165	172	179	186	192	199	206

*One ton of WM is approximately equal to 1,530 pounds of corn, 415 pounds of high protein (48%) soybean meal and 55 pounds of monocalcium phosphate ($260/ton)

Wheat Middlings as an Energy Source for Finishing Cattle

Few studies have been conducted to evaluate the value of WM either as a roughage or grain substitute in finishing diets. Brandt et al. (1986) evaluated 10, 20, and 30% replacements of cracked corn with pelleted WM for finishing steers (Table 6). Linear reductions in daily gain and feed efficiency were observed with increasing WM level over the 120-day trial. They concluded that WM could replace up to 10% of the grain portion in high concentrate finishing rations without notably sacrificing performance. Dalke et al. (1995a) noted a similar pattern but recommended replacing only 5% of the corn because steers fed WM at 10 and 15% grain replacement levels gained 10% less than predicted using net energy equations (Table 7). However, they found that pelleted WM could replace either 50 or 100% of the roughage portion of finishing diets without compromising cattle performance or increasing the incidence of liver abscesses. In a companion digestion study, Dalke et al. (1995b) found that with increasing replacement levels of pelleted WM for grain, DM, organic matter (OM) and starch digestibilities decreased linearly, but replacing 50 or 100% of the roughage increased DM and OM digestibilities linearly. These finishing studies suggest that WM can replace up to 5% of the grain or at least 50% of the roughage portion of finishing rations.

Table 6. Pelleted WM for finishing cattle.[a]

	Level of Wheat Middlings in Ration			
Item	**0%**	**10%**	**20%**	**30%**
Daily gain, lb[b]	3.92	3.89	3.74	3.63
Dry matter intake, lb	22.00	23.40	23.30	24.20
Feed/gain[b]	5.59	6.00	6.22	6.68

[a]Brandt et al. (1986). 120-day trial.
[b]Linear reduction in performance (P<.05).

Table 7. Substitution of pelleted WM for grain or alfalfa hay in feedlot diets.[a]

		Wheat Middlings for Corn			Wheat Middlings for Hay	
Item	**Control (0%)**	**5%**	**10%**	**15%**	**5%**	**10%**
Daily gain, lb	3.10	3.17	3.08	3.12	3.10	2.95
Dry matter intake, lb[b,c]	21.6	22.0	23.4	23.6	20.9	19.6
Feed/gain[b]	6.9	7.0	7.6	7.6	6.8	6.6

[a]Taken from Dalke et al. (1995a).
[b]For concentrate substitution, linear increases in DM intake and feed/gain occurred.
[c]For hay substitution, a linear decrease in DM intake occurred.

Pelleting of Flour Milling By-Products

Because of its low bulk density (BD, 20 pounds/cubic foot), the handling and storage transport of WM in the loose meal form can be an inconvenient and expensive endeavor for the flour mill operator and end user. Compared to bulk, loose WM, pelleting offers several distinct advantages (Robinson, 1975):

- Conversion of the physical form from a relatively light, hard to handle, dusty product requiring special bins and handling equipment and relatively extensive dust collection systems into a dense, free flowing, relatively dustless material suitable for handling with conventional grain handling facilities.
- Greatly increased bulk density for more efficient utilization of bulk storage and shipping facilities.
- Dust and wind losses in loading and unloading operations virtually eliminated.
- Greatly improved storage and handling characteristics that enable the producer to speed loading and feeding operations.
- Price stabilization either by storage or export of pelleted WM.

Behnke (1995) recently conducted a study to determine the pelleting efficiency and pellet quality of WM processed through a $^3/_{16}$-inch and $^1/_4$-inch die. In addition, the study was to include a similar pelleting study of a 24% crude protein formulated cube, processed through a $^3/_4$-inch die. One formula included urea and one was formulated without (Table 8) to evaluate the effect of urea on the process and to demonstrate typical industry practices. Die size used in pelleting WM caused no significant differences (P>.05) in electrical energy consumption, production rate, pellet durability, or pellet density (Table 9). Furthermore, no significant differences (P>.05) were found in pelleting $^3/_4$-range cubes (Tables 8 and 9). On average, pelleting increased bulk density of WM by approximately 115%. Even after regrinding, the pelleted/reground WM had a density nearly 50% greater than that of unprocessed WM. The particle size of the reground pellet was similar to the original WM and nearly ideal in size for mixing with other ingredients. Observed flow characteristics were greatly improved compared to bulk WM. These factors should improve the marketability of WM and the market radius as well. Pelleting cost should be in the range or $4 to $7 per ton depending upon volume.

Table 8. Ingredient composition of complete range cubes for cattle.[a]

Item	$^3/_4$" With Urea	$^3/_4$" Without Urea
Wheat middlings, %	84.95	67.85
Soybean meal (48% CP), %	4.60	23.60
Defluorinated phosphate, %	4.60	4.80
Molasses, %	3.00	3.00
Urea, %	2.10	——
Trace mineral salt, %	.50	.50
A,D,E vitamins, %	.25	.25

[a]Cubes were formulated to contain: 24% CP, 2.4% Ca, 1.7% P, and 6.0% CP equivalent from NPN.

Table 9. Effects of pelleting WM and complete range cubes.

	Die Size			Die Size		
Item	3/16" x 1 1/2"	1/4" x 1 1/2"	P>[c]	3/4" x 3 1/2" (2.1% urea)	3/4" x 3 1/2" (no urea)	P>[c]
Pellet durability index, %						
Standard[a]	97.40	95.83	0.11	94.67	94.97	0.42
Modified[b]	96.90	95.00	0.11	93.37	94.10	0.38
Electrical consumption, kwh/t						
Net	11.07	6.83	0.15	5.07	6.83	—
Total	18.93	14.30	0.18	10.80	13.17	—
Production rate, lbs/hr	1951.57	2071.03	0.57	2766.63	2459.47	0.21
Fines, %	1.23	1.47	0.63	1.50	1.47	0.94
Hot pellet temp., C°	79.40	75.90	0.17	74.70	71.90	—
Density, lb/cubic ft						
Before	18.82	19.90	0.54			
After	41.57	42.20	0.52	28.87	24.82	0.16
Change	22.80 (120%)	22.30 (112%)	0.86	43.65	40.40	0.14
After grinding through						
3/16" screen	28.30 (50%)	28.60 (44%)		14.78 (52%)	15.58 (63%)	0.94

[a]Pellet durability index method ASAE S269.3.
[b]Tumbled with 5, 1/2" nuts.
[c]Probability of a statistically significant difference.

Summer Storage of Pelleted Wheat Middlings

Many Kansas producers who have tried to store pelleted wheat middlings through the summer have observed heating, caking, pellet discoloration, and loss of flowability (Blasi et al. 1997). Therefore, K-State researchers initiated a study in March 1997 to investigate the characteristics of pelleted WM that influence their storability, especially during summer months.

Experimental Procedures

Pelleted WM were collected from four Kansas mills from March 1997 to May 1997. Sealable containers were supplied to the millers. Instructions stating that samples should be taken randomly from the pellet stream on three occasions during each selected day were included with the containers. The pellets collected were no more than 1 day old and were representative of pellets purchased directly by livestock producers. Bulk WM also were collected for comparison. The samples, weighing 30 to 80 pounds each, were identified, collected and sealed on the following day. They were transported to the university laboratory, where sub-samples for moisture content and equilibrium moisture content were removed immediately, sealed, and stored at 40°F for later analysis. Moisture content (MC) was determined using the AACC two-step air-oven method, and bulk density (BD) was determined with a 1-cubic-foot container.

To determine the relationship between the air temperature and moisture content and the tendency of the WM to gain or lose moisture (equilibrium moisture content), small quantities of pellets were weighed and placed in sealed chambers with saturated salt solutions that produce known relative humidities. The sealed chambers then were

Table 10. Moisture content (MC, %) and bulk density (BD, lb/cu ft) of pelleted middlings collected from four Kansas flour mills in 1997 and 1998.

Mill Number	Physical Parameter Average	Sampling Date					
		3/25/97	4/2/97	4/29/97	5/7/97	5/24/98	6/3/98
1	MC	13.9	14.4	14.1	13.9	13.8	13.2
	BD	40.1	40.0	38.6	40.2		
2	MC	14.6	14.1		12.8		
	BD	40.6	41.0				
3	MC	14.4	14.8		14.2		
	BD	41.2	40.6		40.6		
4	MC	13.9	14.2	13.5	13.6		
	BD	38.5	39.1	39.0	39.0		
Overall	MC	14.2±0.31	14.4±0.27	13.8±0.30	13.6±0.52	13.8±0.1	13.2±0.1
Average	BD	40.1±1.0	40.2±0.7	38.8±0.2	39.9±0.7		

placed in controlled temperature rooms at 75°F or 85°F, where the weights of the samples were checked periodically until no change was observed over several days. The pellet moisture content at this equilibrium condition then was determined. To investigate the problems encountered during summer storage, 350 pounds of pellets and fine material were placed in experimental bulk bins. The bins were placed in controlled chambers at summertime temperatures and relative humidities. Samples were taken periodically to determine the moisture content and mold counts and to identify mold species. Mold counts were estimated by standard dilution plating procedures using malt agar with 6% salt (MS6). Counts were expressed as number of colony forming units (cfu) per gram of pellet. The flow rate upon discharge out of the bins also was tested periodically.

Characteristics of Pelleted Wheat Middlings

Forty-one samples of $^1/_4$-inch and $^3/_4$-inch pelleted WM were collected from Kansas mills. The average BD of the two pellet sizes were not noticeably different and ranged from 37.7 to 42.2 pounds/cubic foot with an average of 39.9 ± 0.9 pounds/cubic foot (Table 10). Most pelleted WM, regardless of the sampling time, weighed 38 to 41 pounds/cubic foot, which is equivalent to approximately 50 pounds/bushel. In contrast, the ground middlings from which the pellets were manufactured weighed only about 20 pounds/cubic foot.

The overall average MC of the pellets was 14.0±0.5%, and individual samples ranged from 12.8% to 14.9%. All pellets, regardless of size, were about 1% wetter than the ground middlings from which they were manufactured. As the ambient air warmed during the spring, the pellets were drier, with the average MC in May being 0.4 points lower than the overall average. This trend continued into the summer and was observed in subsequent years. WM pellets purchased from Kansas mills in April or May likely will contain 13.5 - 14.0% MC. Those purchased in June, July, or August likely will contain between 13.0 and 13.5% MC.

Because the heating, caking, and discoloration observed during summer storage may be due to microorganisms, specifically molds, the microbiological characteristics of the pelleted middlings also were examined. On average, the pelleting process

Table 11. Mean number (cfu/g) of microorganisms in wheat middlings before and after pelleting.

Mill Number	Sample Type	Number of Samples	Microorganism Counts, CFU/Gram: Molds[1]	*Mucor* spp.	Yeast	Bacteria
1	Before	7	18,120±16,687	200±166	2,525±4,316	<10
	After	6	34±19	<10	<10	610±350
2	Before	4	12,243±1,189	1,775±1,927	938±258	<10
	After	3	186±174	<10	<10	30±16
3	Before	3	40,333±3,952	2,000±2,160	<10	<10
	After	3	3,163±1,372	30±22	<10	<10
4A	Before	4	6,993±1,859	800±988	850±659	<10
	After	3	52±44	<10	<10	572±256
4B	Before	3	17,433±946	1,167±499	19,500±15,817	<10
	After	3	23±21	<10	<10	1,600±829
Mean	Before		19,024±5,573	1,188±586	4,763±7,414	<10
	After		692±1,237	<10	<10	562±579

[1] Include *Alternaria* spp., *Cladosporium* spp., *Fusarium graminearum*, *F. moniliforme*, *Phoma* spp., *Aspergillus glaucus*, *A. candidus*, *A. flavus*, *A. niger*, *A. ochraceus*, *A. versicolor*, and *Penicillium* spp.

reduced the level of molds in wheat middlings to about 4% of that present in the unpelleted material (Table 11). At three of the four mills, the reduction was much 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 drastically reduce the presence of those molds that are able to grow during storage.

Pelleted Wheat Middlings and Air Moisture

WM pellets swell and soften significantly when they gain moisture, thus losing their integrity and ability to flow. The information developed in the equilibrium moisture content trials showed that pelleted WM at 13.5% MC are in equilibrium with air containing 67% relative humidity (RH) at 75°F, and with air containing 68% RH at 85°F (Figure 6). This indicates that air in the temperature range most often encountered during summer storage (60°F to 95°F) must have an RH lower than 65% to ensure that WM pellet moisture does not increase.

To test this, half of the pellets stored at 85°F and 14% MC were aerated with high-humidity air, as would happen if nighttime air was used to cool the pellets in April, May, or June in Kansas. The pellets treated in this way began to lose flowability after 3 weeks and would not flow at all after 6 weeks (Figure 7). Pellets not aerated in this way still flowed, although slowly, at 6 weeks but had lost their flowability when tested after 9 weeks. In a separate study (not shown), pellets stored under less severe conditions (13.3% moisture, 75°F) maintained their original flow rate after 6 weeks. After 11 weeks of storing the 14% moisture pellets at 85°F, warm, dry air was passed through both the previously aerated and the nonaerated pellets. This air dried the pellets to 11.0 to 12% MC, and all pellets flowed at about the same rate as before storage. Thus, drying reversed the loss of flowability.

Summer Storage and Molds

Bacteria, *Mucor* spp., and field fungi (such as *Alternaria* spp. and *Fusarium moniliforme*) died out after a few weeks in storage (Figure 8). These microorganisms require very high relative humidity to grow and were not expected to increase during storage. Storage molds, including *Aspergillus glaucus, A. flavus, A. candidus, A. versicolor,* and *Penicillium* species that cause heating and caking, increased faster at higher temperatures than at lower temperatures. Nevertheless, the only storage mold that increased substantially in the first 12 weeks, even at 85°F and 14.0% MC, was *A. glaucus* (Figure 9). This is a common and normally nonthreatening grain mold. The unexpectedly slow increase of storage molds, considering the high moisture contents and temperatures, was probably due to the very low level of inoculum present after pelleting. *A. flavus* was nearly absent in pellets from both the 85°F/14.0% MC trial and the 75°F/ 13.4% MC trial. This is the storage mold most often associated with aflatoxins in grain, and its near-absence indicated that aflatoxins should not present a problem in stored, pelleted WM even under less-than-ideal storage conditions. *A. candidus* was observed in relatively high numbers in the nonaerated pellets stored for 12 weeks at 85°F and 14.0% MC. This species requires a moderately high relative humidity to flourish and often is associated with rapid respiration, heating, and caking. Its presence indicated that mold-induced deterioration was beginning in the pelleted WM stored for 12 weeks without aeration at this high temperature and moisture content.

Figure 6. Observed equilibrium moisture content of pelleted wheat middlings at 75°F and 85°F.

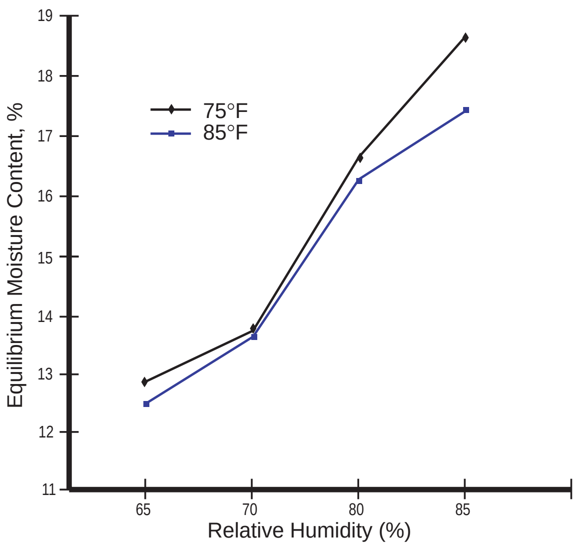
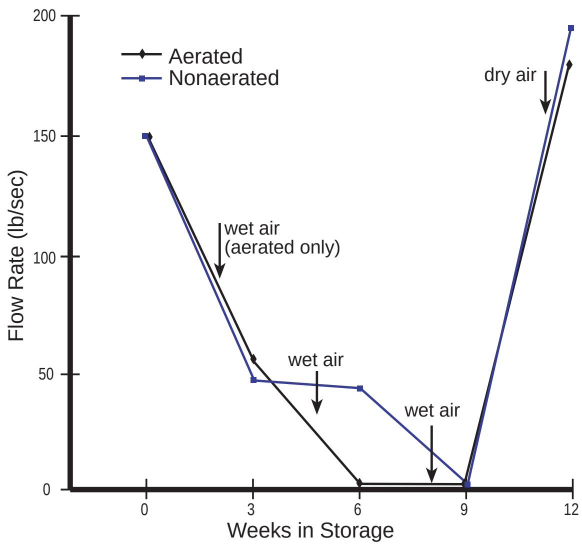


Figure 7. Flow rate (lb/sec) of pelleted wheat middlings initially containing 14.0% MC, stored at 85°F. Moist air at 85°F was passed through the “aerated” pellets at the indicated times, and dry air was passed through the “aerated” and “nonaerated” pellets to restore flowability.



The aeration trials showed two important effects of aeration on mold growth. First, because all pellets flowed well after aeration with dry air (12 weeks), despite the large increase in mold presence, loss of pellet flowability obviously was not related directly to mold abundance. Second, pellets that were aerated repeatedly did not support significant growth by mold species usually associated with heating and /or toxin

Figure 8. Levels of field fungi, *Mucor* spp., and bacteria on aerated (aer) and nonaerated (non) pelleted WM stored at 14% MC and 85°F at certain storage periods.

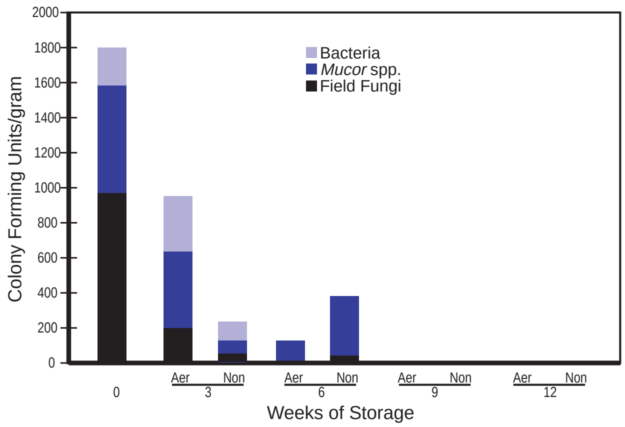
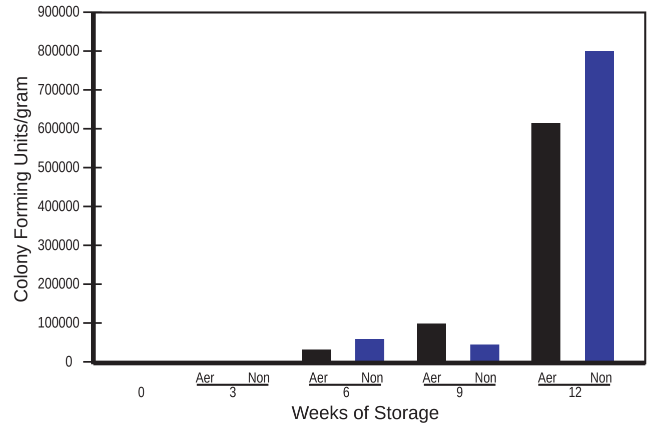


Figure 9. Level of *Aspergillus glaucus* on aerated (aer) and nonaerated (non) pelleted WM stored at 14.0% M C and 85°F at certain storage periods.



formation (i. e., *A. candidus*, *A. flavus*, *A. versicolor,* and *Penicillium* spp.). This was true even when the air used for aeration was too moist and caused loss of pellet flowability. We interpret this to mean that the use of only dry air for aeration, which would dry the pellets to below 12.5% MC within the first few weeks of storage, should eliminate the flowability problem while retarding mold growth.

In some experimental bins, caked WM remained on the sides of the container after the pellets had flowed out. This caked material had a different appearance than the pellets that had simply lost flowability. The caked material had lost the shape of pellets and had become a dark homogeneous mass. It contained 10 times as much *A. glaucus* and up to 2,300 times the counts of other storage fungi, compared to uncaked pellets at the same sampling time. Thus, molds caused small quantities of pelleted WM to lose their pellet shape and to become a caked, colored mass. However, this was obviously a different phenomenon than the simple loss of flowability of the pelleted WM.

Management Issues

Most pelleted WM contain a small amount (2 to 5%) of fine material. Cleaned and uncleaned pelleted WM were stored side by side to determine the effect of the fine material on loss of flowability. No significant differences occurred. However, fine material may affect management by forming a vertical spout line through which aeration air passes less readily.

Pelleted WM are extremely sensitive to water. When they contact water or a moist feed ingredient, they immediately begin to disaggregate to the bulk form. In contrast to whole grain, which dissipates water through the mass, pelleted WM bind large amounts of water tightly. Thus, any leak or drip causes a part of the mass of stored, pelleted WM to quickly come apart, cake and discolor.

Practical Tips

Our recommendations of temperature management during summer storage of pelleted WM are exactly opposite of our recommendations for summer storage of wheat grain. Wheat should be cooled as soon as possible after harvest and is best stored in a cool place, such as on concrete floors. Pelleted WM should be stored away from contact with concrete floors or soil. Wheat, because of its low moisture and high heat content at harvest, can tolerate air with high relative humidity and small amounts of water, whereas high relative humidity or liquid completely destroys WM pellets.

1. Fix leaks. The best storage for WM pellets is a bulk bin or a farm grain bin with a full false floor. Most farm bins leak at the roof and where the walls meet the floor. Therefore, the first task is to find and fix leaks. The wall/floor juncture should be sealed, if pelleted WM are to be placed on the floor. Check the surface of the pellets after the first rain. “Nests” form below a leak in the roof. The leaks must be sealed so that a hot spot does not develop around them. Do not assume because you have successfully stored grain in your bin for many years that it does not leak. Dry grain absorbs large amounts of water and slowly passes it to surrounding grains. Often, this process is rapid enough that deterioration never develops. In contrast, WM pellets immediately come apart when they contact liquid water. They hold water tightly and usually deteriorate before the water can evaporate.

2. Level the surface. Pelleted WM form a steep peak and typically contain 3 to 5% fine materials. The peak and concentration of fine material below it interferes with proper air movement if the surface is not leveled.

3. Dry. Don’t cool. It is important to pass air through the middlings with an aeration fan. However, the objective should be to dry the pellets, not to cool them. Air used for aeration should contain less than 65% RH. The drying should be done within the first month of storage, before molds begin to increase and before loss of flowability. If pellets are to be stored into the fall or winter, cool dry air may be used beginning about mid-September. Automatic controllers that activate the fan based on air temperature and RH are available from 7-M Inc., HC 01 Box 56, Palco, KS 67657, 800-235-0427 or Boone Aeration, P.O. Box 369, Boone, IA 50036, 800-265-2010. Specify a controller unit with an upper-limit RH control.

Bins loaded through a permanent spout from an elevator leg create a particular problem that must be managed carefully. If the aeration fan pushes air up through the pellets, condensation in the metal spout causes liquid water to fall back on the pellet surface during cool or rainy weather, especially when the initial heat of pelleting has not yet been removed from the pellets. Either the airflow must be downward, or care must be taken to operate the fans only during warm, dry conditions.

4. Start small. Pelleted WM do not behave like stored grain. It is best to store small quantities of this product until experience with summer storage has been gained.

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Contribution No. 99-35-E from Kansas Agricultural Experiment Station

Kansas State University Agricultural Experiment Station and Cooperative Extension Service

MF-2353 August 1998