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Effects of Dry and Liquid Pellet Binder Inclusion and Conditioning Temperature on Pellet Mill Efficiency and Pellet Quality of a High-Fiber Ruminant Ration

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Effects of Dry and Liquid Pellet Binder Inclusion and Conditioning Temperature on Pellet Mill Efficiency and Pellet Quality of a High-Fiber Ruminant Ration

Abstract

The objectives of this experiment were: 1) to determine the effects of sucrose and lactose-based liquid ingredient inclusion on the pelleting efficiency and quality of a high-fiber diet; and 2) to evaluate the role of mash conditioning temperature on the binding effectiveness of the tested liquid ingredients. Binders included DLS (dry calcium lignosulfonate), LCM (liquid cane molasses), LMB (commercial liquid molasses blend), and LLB (commercial liquid lactose blend). Treatments were arranged in a 5 × 3 factorial of pellet binder (control, DLS, LCM, LMB, and LLB) and conditioning temperature (165, 175, and 185°F). Data were analyzed using the GLIMMIX procedure of SAS with linear and quadratic contrasts for increasing conditioning temperature. Treatments were arranged in a completely randomized design and replicated 3 times. Diets were conditioned for approximately 40 s and pelleted with a 0.19 × 1.75 in. die at a rate of 3.0 ton/h. Pellet durability index (PDI) was determined using the standard and modified tumble box methods. There was no evidence of an interaction ($P > 0.209$) between binder type and conditioning temperature when determining PDI according to either the standard or modified tumble box methods. Conditioning temperature alone did not affect PDI ($P > 0.119$); however, differences were observed based on binder inclusion according to either method ($P < 0.046$). Using the standard method of analysis, PDI was improved ($P < 0.046$) by LCM and LLS addition compared to both the control and LCM diets, while LLB was intermediate. According to the modified method with greater agitative stress, PDI was improved ($P < 0.005$) when using LCM and LLB compared to the control diet, with DLS and LCM being intermediate. Additionally, LCM inclusion reduced ($P < 0.001$) pellet mill throughput and increased ($P < 0.001$) energy consumption of the pellet mill motor compared to the control and other binders, with no observed differences ($P < 0.269$) resulting from increased conditioning temperature. Under the constraints of this trial, cane molasses and commercial molasses and lactose blends were shown to be effective pellet binders, regardless of conditioning temperature when included in a high-fiber ration. However, challenges with molasses handling characteristics and increased friction at the die interface may reduce its practical application and encourage the use of the alternative commercial blends.

Keywords

pellet binder, conditioning temperature, lignosulfonate, molasses, lactose, feedlot, feed, beef, pellet quality, ruminant rations

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Appreciation is expressed to Westway Feed Products (Tomball, TX) for partial financial support of this project.

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Effects of Dry and Liquid Pellet Binder Inclusion and Conditioning Temperature on Pellet Mill Efficiency and Pellet Quality of a High-Fiber Ruminant Ration[1]

Caitlin E. Evans, Marut Saensukjaroenphon, Charles R. Stark, and Chad B. Paulk

Summary

The objectives of this experiment were: 1) to determine the effects of sucrose and lactose-based liquid ingredient inclusion on the pelleting efficiency and quality of a high-fiber diet; and 2) to evaluate the role of mash conditioning temperature on the binding effectiveness of the tested liquid ingredients. Binders included DLS (dry calcium lignosulfonate), LCM (liquid cane molasses), LMB (commercial liquid molasses blend), and LLB (commercial liquid lactose blend). Treatments were arranged in a 5 × 3 factorial of pellet binder (control, DLS, LCM, LMB, and LLB) and conditioning temperature (165, 175, and 185°F). Data were analyzed using the GLIMMIX procedure of SAS with linear and quadratic contrasts for increasing conditioning temperature. Treatments were arranged in a completely randomized design and replicated 3 times. Diets were conditioned for approximately 40 s and pelleted with a 0.19 × 1.75 in. die at a rate of 3.0 ton/h. Pellet durability index (PDI) was determined using the standard and modified tumble box methods. There was no evidence of an interaction ($P > 0.209$) between binder type and conditioning temperature when determining PDI according to either the standard or modified tumble box methods. Conditioning temperature alone did not affect PDI ($P > 0.119$); however, differences were observed based on binder inclusion according to either method ($P < 0.046$). Using the standard method of analysis, PDI was improved ($P < 0.046$) by LCM and LLS addition compared to both the control and LCM diets, while LLB was intermediate. According to the modified method with greater agitative stress, PDI was improved ($P < 0.005$) when using LCM and LLB compared to the control diet, with DLS and LCM being intermediate. Additionally, LCM inclusion reduced ($P < 0.001$) pellet mill throughput and increased ($P < 0.001$) energy consumption of the pellet mill motor compared to the control and other binders, with no observed differences ($P < 0.269$) resulting from increased conditioning temperature. Under the constraints of this trial, cane molasses and commercial molasses and lactose blends were shown to be effective pellet binders, regardless of conditioning temperature when included in a high-fiber ration. However, challenges with molasses handling characteristics and increased friction at the die interface may reduce its practical application and encourage the use of the alternative commercial blends.

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[1] Appreciation is expressed to Westway Feed Products (Tomball, TX) for partial financial support of this project.

Introduction

The advantages of pelleted feed compared to mash have long been recognized. Not only is pelleted feed associated with improved handling characteristics, it has also been shown to improve animal performance through various avenues including increased palatability, prevention of selective feeding, enhanced hygienic quality, and greater nutrient availability. The multitude of benefits associated with feeding pellets, however, may not be truly realized or the cost of production justified when pellets are of poor quality. Thus, it is important to ensure that pellets maintain a certain level of physical quality to withstand the rigors of handling prior to reaching the animal. One solution for maintaining quality in marginal conditions is the inclusion of a liquid or granular pellet binder, which can help to enhance inter-particle bridges or bonds.[2] The use of a binders may be of particular interest when pelleting ruminant rations. These formulations traditionally contain increased levels of fiber, which can be problematic during the conditioning process and detrimental to pellet quality.[3] Thus, a pellet binder may be necessary to ensure pellet durability. Sugar-based liquid binders are an attractive option as they also provide a readily fermentable source of carbohydrates for energy with improved palatability. Application of sugar-based liquid ingredients, however, can be cumbersome due to high viscosity and tacky nature. Commercial liquid blends, however, may ameliorate some of the negative attributes, while maintaining the desirable traits of the original product.

While the inclusion of sugar-based liquid ingredients, such as molasses, in animal feed is an industry-recognized strategy for improving palatability and consequently feed consumption, a detailed study investigating the benefits of inclusion on pellet quality of high-fiber rations is lacking. Thus, the present study has 2 objectives: 1) to investigate the effects of sucrose and lactose-based liquid ingredients on the pelleting efficiency and quality of a high-fiber diet; and 2) to evaluate the role of mash conditioning temperature on the binding effectiveness of the tested liquid ingredients.

Materials and Methods

Feed manufacturing

A starter beef feedlot diet (Table 1) provided the basis for all 5 experimental treatments. The control diet contained no added pellet binder, while the remaining 4 treatments contained dry granulated or liquid pellet binders at the manufacturer's recommended inclusion levels. Corn level was adjusted to compensate for differing inclusion levels of the pellet binders when necessary. There were 3 liquid binders each with a 5.0% dietary inclusion: cane molasses (LCM), a commercial molasses blend (LMB; Westway Products, Tomball, TX), and a commercial lactose blend (LLB; SweetLac63, Westway Products, Tomball, TX). Calcium lignosulfonate (DLS; Ameribond $_2$X, LignoTech USA Inc., Rothschild, WI) was included in the diet as a dry granule at 0.5% of the formulation. In an effort to evaluate whether or not conditioning temperature affects binder effectiveness, mash feed was conditioned at 165, 175, and 185°F prior to pelleting.

Feed was mixed in 2000-lb batches in a 57.6 ft^3 twin shaft counterpoise mixer (Hayes and Stolz, model TRDB63-0152, Fort Worth, TX). Dry ingredients were mixed for

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[2] Kaliyan, N. and R. V. Morey. 2009. Factors affecting strength and durability of densified biomass products. Biomass and Bioenergy 33:337-359.

[3] Thomas, M., and A. F. B. van der Poel. 2020. Fundamental factors in feed manufacturing: Towards a unifying conditioning/pelleting framework. Anim. Feed Sci. Technol. 268:114612.

180 s. Liquid binders were added directly into the pellet mill conditioner via a spray pump, which was calibrated for each binder to achieve the desired inclusion rate. During testing, viscosity issues with the LCM prevented its uniform application in the pellet mill conditioner. Thus, the addition location was changed to the mixer, where dry ingredients were mixed for 60 s prior to the inclusion of LCM and followed by 120 s of additional mix time. There were three 2000-lb batches of feed per binder treatment replicate, yielding 3 tons of feed per pelleting run.

Experimental mash feed was conditioned for approximately 40 s at 165, 175, and 185°F in a single pass conditioner with a steam pressure of 30 psi. Diets were pelleted on a 100 HP pellet mill (CPM, model 3016-4 Master, Crawfordsville, IN) equipped with a 0.19 × 1.75 in. die with a target production rate of 3 ton/h. The pellet mill was warmed with 2000 lb of feed prior to proceeding with experimental batches. Conditioned mash temperature and pellet die exit temperature (hot pellet) were measured twice during each replicate pellet run. The samples were placed into a pre-warmed double-wall thermos fitted with a digital thermometer. Pellet mill throughput was also measured twice by collecting and weighing the total produced pellets within a 60-s time period.

Data collection

Pellet mill voltage and amperage was recorded every 5 s during each pelleting run with a data logger (Supco model DVCV, Allenwood, NJ). Motor amperage was averaged across the individual pelleting run once conditioning temperature and production rate stabilized. Specific energy consumption (SEC) was calculated according to Stark.[4]

Mash and pellet samples were collected and analyzed to determine changes in moisture. Mash samples were taken from a posterior port in the conditioner directly after the liquid spray nozzle (mash) and as mash feed exited the conditioner (conditioned mash). Pellet samples were taken as feed exited the die (hot pellet) and post cooler (cool pellet). Upon collection, sample bags were immediately sealed and placed in a freezer set at -0.4°F to prevent any potential moisture loss. Samples were dried at 275°F for 2 h according to AOAC 930.15[5] and analyzed in triplicate.

To assess fines level, two samples (approximately 10 lb each) from each treatment replicate were collected at regular intervals at the pellet die and allowed to cool in commercial tri-layer paper feed sacks. The entire sample was weighed and then sifted with a U.S. No. 5 (0.16 in.) sieve to separate fines from pellets. The percentage of pellet fines (PF) was then calculated as the weight of sifted fines divided by the initial sample weight pre-sifting.

To assess pellet durability (PDI), two samples (approximately 5 lb each) were collected directly at the pellet die and placed in a counterflow laboratory cooler for 10 min. Pellets were packaged and stored in commercial tri-layer paper feed sacks and rested for 24 h. Prior to analysis, pellets were sifted with a U.S. No. 5 sieve for fines removal. A 1.1-lb sample of sifted pellets was then placed in the tumble box and rotated at 50 rpm for 10 min. After tumbling, the sample was collected and sifted again to remove

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[4] Stark, C. R. Pellet quality. I. Pellet quality and its effect on swine performance. II. Functional characteristics of ingredients in the formation of quality pellets. 1994. Kansas State University, Department of Grain Science, PhD dissertation.

[5] AOAC 930.15. 1990. Official methods of analysis. 15th ed. Assoc. Off. Anal. Chem., Arlington VA.

fines. The PDI was calculated according to ASAE S269.5.[6] This standard tumble box PDI procedure was then modified by adding three 0.75 in. hex nuts to the tumbling chamber to increase the agitation stress.

Statistical analysis

Data were analyzed using the GLIMMIX procedure of SAS (v. 9.4, SAS Inst., Cary, NC) with means separated by least squares means procedure. Treatments were arranged in a 5 × 3 factorial of pellet binder (control, DLS, LCM, LMB, and LLB) and conditioning temperature (165, 175, and 185°F). Linear and quadratic contrasts were used to test the effect of increasing conditioning temperature. Date of manufacture served as a random effect to account for possible environmental differences that may influence the pelleting process. Treatments were replicated 3 times each. Results were considered significant at $P \leq 0.05$.

Results and Discussion

Feed processing

Conditioning temperatures remained comparable to their respective targets of 165, 175, and 185°F as confirmed by measured conditioned mash temperatures (Table 2). There was no interaction ($P > 0.520$) between binder and conditioning temperature on hot pellet temperature, pellet mill throughput, or pellet mill SEC. In general, feed manufacturing was similar for diets containing the DLS, LMB, and LLB binders compared to the control. When including LCM, however, difficulties with uniform application via spray nozzle arose and it became necessary to alter the application site to the mixer. The LCM diet continued to cause issues during the pelleting process where multiple instances of die choking and eventual plugging were observed, with no noticeable changes in frequency due to conditioning temperature. Hot pellet temperature at the die was increased by LCM inclusion ($P < 0.001$) compared to the control and other binder treatments and by increasing conditioning temperature (linear, $P < 0.001$). Additionally, LCM inclusion reduced ($P < 0.001$) pellet mill throughput and increased ($P < 0.001$) SEC of the pellet mill motor compared to the control and other binders, with no observed differences ($P > 0.269$) resulting from increased conditioning temperature. The noted difficulties while pelleting, LCM are likely a result of increased resistance at the feed-die interface caused by high sugar content. The increased hot pellet temperature and reduced throughput with LCM inclusion provide further indication of increased die friction. The struggle of the pellet mill to overcome these issues and stabilize production is further evidenced by the increased electrical demand (SEC) when pelleting LCM. The difficulties of manufacturing with LCM inclusion in this trial are a clear testament to the industry preference for blended molasses products.

Moisture content

There was no evidence of an interaction ($P > 0.120$) between binder and conditioning temperature on the moisture content of mash, conditioned mash, hot pellet, or cool pellet samples (Table 3). There were main effects of binder ($P < 0.006$) observed for each sample collected, but no main effect of conditioning temperature ($P > 0.187$). Inclusion of LCM, LMB, and LLB liquid binders increased mash ($P < 0.001$) and conditioned mash ($P < 0.001$) moisture compared to the control and DLS binder.

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[6] ASABE Standards. 2008. S319.2: Method of determining and expressing fineness of feed materials by sieving. St. Joseph, Mich.: ASABE.

Upon exiting the pellet die (hot pellet), moisture was greater ($P < 0.001$) in LMC, LMB, and LLB diets compared to DLS, with the control being intermediate to LCM and DLS. Once cooled, pellet moisture was greater ($P < 0.001$) in LLB compared to DLS, with control, LCM, and LMB intermediate.

Pellet quality

There was evidence of an interaction ($P < 0.001$) between binder and conditioning temperature on the percentage of PF generated at the pellet die (Table 4). Generation of PF in the control diet was decreased when conditioning at 175 and 185°F compared to 165°F. The PF level was similar for all tested binders (DLS, LCM, LMB, or LLB) with increasing conditioning temperature. When conditioning the diets at 185°F, control diets and diets containing DLS had decreased PF compared to diets containing LMB, with diets containing LCM and LLB being intermediate. Main effects of binder and conditioning temperature were also observed on PF generation. The control diet had increased ($P < 0.001$) PF, with the greatest reduction observed with the addition of DLS and LCM binders, followed by LMB and LLB binders. Pellet fines were reduced (quadratic, $P < 0.032$) with increasing conditioning temperature.

There was no evidence of an interaction ($P > 0.209$) between binder type and conditioning temperature when determining PDI according to either the standard or modified tumble box methods. Conditioning temperature alone did not affect PDI ($P > 0.209$); however, differences were observed based on binder inclusion according to either method ($P < 0.046$). Using the standard method of analysis, PDI was improved ($P < 0.046$) by LCM and DLS addition compared to both the control and LMB diets, while LLB was intermediate. According to the modified method with greater agitative stress, PDI was improved ($P < 0.005$) when using LCM and LLB compared to the control diet, with DLS and LMB being intermediate. Tumble box PDI results demonstrated that molasses and commercial blends can be an effective binding agent in a high-fiber diet. Conditioning temperature, however, had no effect on pellet durability when analyzed using the tumble box, contradicting a well-established principle of increased pellet durability with greater conditioning temperatures. The authors can only hypothesize that diet composition may have played a role, as fibrous materials are less susceptible to conditioning and thus moisture uptake. This is supported by a lack of observed difference in moisture content in the conditioned mash samples.

In conclusion, under the constraints of this experiment, cane molasses, commercial molasses, and lactose blends were shown to be effective pellet binders regardless of conditioning temperature when included in a high-fiber ration. However, challenges with molasses handling characteristics and increased friction at the die interface may limit its application and encourage instead the utilization of the more manageable blends.

Table 1. Basal calf starter diet composition

Ingredient	Inclusion, %
Corn[1]	40.0
Soybean meal	20.0
Alfalfa meal	15.0
Wheat middlings	15.0
DDGS	10.0
Total	100.00
Calculated analysis	
Crude protein, %	22.2

[1] Experimental pellet binders were included in the diet at the expense of ground corn. Dry calcium lignosulfonate (DLS) was included at 0.5%, while liquid cane molasses (LCM), commercial liquid molasses blend (LMB), and commercial liquid lactose blend (LLB) were included at 5% of the formulation. The control diet remained the same as the basal formulation with no binder addition.

Table 2. Effects of binder and conditioning temperature on pellet mill parameters and efficiency[1]

		Temperature, °F			
Binder[2]	**Cond. temp, °F**	**Cond. mash[3]**	**Hot pellet**	**Throughput, ton/h**	**SEC,[4] kWh/ton**
Interaction					
Control	165	166.0	172.6	2.95	12.14
	175	174.9	177.9	2.92	11.63
	185	185.7	188.3	2.94	11.28
DLS	165	166.4	171.9	2.84	12.02
	175	176.2	178.6	2.88	11.51
	185	186.1	186.6	2.87	11.19
LCM	165	167.3	174.8	2.23	15.76
	175	176.2	184.1	2.44	13.49
	185	185.1	191.4	1.94	20.13
LMB	165	167.1	172.1	2.92	10.99
	175	177.2	179.4	3.09	10.59
	185	184.9	187.4	2.98	11.14
LLB	165	165.1	167.4	3.00	10.48
	175	175.4	178.6	3.00	10.67
	185	185.5	183.0	3.04	10.74
SEM		0.96	1.50	0.177	1.641
Main effects					
Control		175.5	179.6^{B}	2.94^{A}	11.68^{B}
DLS		176.2	179.1^{B}	2.86^{A}	11.57^{B}
LCM		176.2	183.4^{A}	2.20^{B}	16.46^{A}
LMB		176.4	179.6^{B}	2.99^{A}	10.91^{B}
LLB		175.3	176.3^{B}	3.01^{A}	10.63^{B}
SEM		0.61	0.89	0.122	0.960
	165	166.4	171.8	2.79	12.28
	175	176.0	179.7	2.87	11.58
	185	185.5	187.3	2.75	12.90
	SEM	0.51	0.71	0.108	0.754

continued

Table 2. Effects of binder and conditioning temperature on pellet mill parameters and efficiency[1]

Binder[2]	Cond. temp, °F	Temperature, °F		Throughput, ton/h	SEC,[4] kWh/ton
		Cond. mash[3]	Hot pellet		
Source of variation		---------------------------- Probability, $P <$	----------------------------		
Binder × cond. temp		----	0.624	0.804	0.520
Binder		----	<0.001	<0.001	<0.001
Cond. temp[5]					
Linear		----	<0.001	0.745	0.554
Quadratic		----	0.833	0.276	0.269

[AB] Means within the main effect of binder followed by a different letter are significantly different ($P \leq 0.05$).

[1] Diets were conditioned for approximately 40 s prior to pelleting (Model 3016-4 CPM Co., Crawfordsville, IN) with a 0.19 × 1.75 in. die. Treatments were replicated 3 times.

[2] Experimental binders included dry calcium lignosulfonate (DLS), liquid cane molasses (LCM), a commercial liquid molasses blend (LMB), and a commercial liquid lactose blend (LLB).

[3] Temperature of conditioned mash reported as observational data with no statistical analysis.

[4] Specific energy consumption (SEC) calculated according to Stark (Stark, C. R. Pellet quality. I. Pellet quality and its effect on swine performance. II. Functional characteristics of ingredients in the formation of quality pellets. 1994. Kansas State University, Department of Grain Science, PhD dissertation.).

[5] Linear and quadratic contrasts testing the response of increasing conditioning temperature with results considered significant at $P \leq 0.05$.

Table 3. Effects of binder and conditioning temperature on moisture content[1]

		Moisture,[3] %			
Binder[2]	**Cond. temp, °F**	**Mash**	**Cond. mash**	**Hot pellet**	**Cool pellet**
Interaction					
Control	165	13.51	16.61	15.82	15.50
	175	12.77	16.25	16.02	14.07
	185	12.98	16.62	15.52	13.55
DLS	165	12.86	16.28	15.35	12.66
	175	12.87	16.24	15.23	13.21
	185	12.66	16.49	15.90	13.17
LCM	165	13.77	17.89	16.54	12.88
	175	14.19	17.54	16.90	13.10
	185	13.81	17.49	16.64	14.16
LMB	165	13.70	18.39	17.18	13.47
	175	14.40	17.93	17.24	13.93
	185	13.17	18.02	17.16	14.55
LLB	165	13.67	18.18	18.05	15.20
	175	13.66	18.32	17.55	14.67
	185	13.78	17.30	16.93	14.29
SEM		0.259	0.638	0.453	0.575
Main effects					
Control		13.09^{B}	16.49^{B}	15.79^{BC}	14.37^{AB}
DLS		12.80^{B}	16.34^{B}	15.50^{C}	13.01^{B}
LCM		13.92^{A}	17.64^{A}	16.70^{AB}	13.38^{AB}
LMB		13.76^{A}	18.11^{A}	17.19^{A}	13.99^{AB}
LLB		13.70^{A}	17.93^{A}	17.51^{A}	14.72^{A}
SEM		0.150	0.347	0.297	0.332
	165	13.50	17.47	16.59	13.94
	175	13.58	17.26	15.59	13.80
	185	13.28	17.19	16.43	13.94
	SEM	0.116	0.310	0.254	0.257

continued

Table 3. Effects of binder and conditioning temperature on moisture content[1]

Binder[2]	Cond. temp, °F	Moisture,[3] %			
		Mash	Cond. mash	Hot pellet	Cool pellet
Source of variation		------------------------- Probability, *P* <			--------------------------
Binder × cond. temp		0.120	0.851	0.680	0.182
Binder		<0.001	<0.001	<0.001	0.006
Cond. temp[4]					
Linear		0.187	0.301	0.548	0.996
Quadratic		0.202	0.758	0.730	0.644

[ABC] Means within the main effect of binder followed by a different letter are significantly different ($P \leq 0.05$).

[1] Diets were conditioned for approximately 40 s prior to pelleting (Model 3016-4 CPM Co., Crawfordsville, IN) with a 4.8 × 44.5 mm die. Treatments were replicated 3 times.

[2] Experimental binders included dry calcium lignosulfonate (DLS), liquid cane molasses (LCM), a commercial liquid molasses blend (LMB), and a commercial liquid lactose blend (LLB).

[3] Moisture content was calculated using duplicate samples from each replication analyzed in triplicate.

[4] Linear and quadratic contrasts testing the response of increasing conditioning temperature with results considered significant at $P \leq 0.05$.

Table 4. Effects of binder and conditioning temperature on pellet quality[1]

			Tumble box[4]	
Binder[2]	**Cond. temp, °F**	**Fines,[3] %**	**Standard**	**Modified**
Interaction				
Control	165	13.1^{a}	90.3	82.6
	175	5.5^{bc}	92.9	87.1
	185	3.6^{c}	93.6	89.3
DLS	165	3.9^{bc}	94.1	88.5
	175	3.0^{c}	93.4	89.6
	185	3.3^{c}	94.3	89.6
LCM	165	4.8^{bc}	94.1	90.1
	175	4.6^{bc}	93.6	91.6
	185	4.0^{bc}	93.9	90.0
LMB	165	5.0^{bc}	92.3	87.7
	175	4.6^{bc}	92.3	88.8
	185	6.6^{b}	92.3	88.8
LLB	165	5.7^{bc}	94.1	91.6
	175	5.7^{bc}	93.9	90.0
	185	4.3^{bc}	93.3	89.8
SEM		0.54	1.02	1.75
Main effects				
Control		7.5^{A}	92.3^{B}	86.4^{B}
LS		3.4^{C}	94.0^{A}	89.3^{AB}
MOL		4.5^{BC}	93.9^{A}	90.6^{A}
MB		5.4^{B}	92.3^{B}	88.4^{AB}
LB		5.3^{B}	93.7^{AB}	90.5^{A}
SEM		0.32	0.71	1.34
	165	6.5	93.0	88.1
	175	4.8	93.2	89.4
	185	4.4	93.5	89.5
	SEM	0.34	0.63	1.24

continued

Table 4. Effects of binder and conditioning temperature on pellet quality[1]

			Tumble box[4]	
Binder[2]	**Cond. temp, °F**	**Fines,**[3] **%**	**Standard**	**Modified**
Source of variation		---------------------- Probability, $P <$	----------------------	
Binder × cond. temp		0.001	0.449	0.209
Binder		0.001	0.046	0.005
Cond. temp[5]				
Linear		0.001	0.364	0.119
Quadratic		0.032	0.981	0.408

[a-c, A-C] Means within column followed by a different letter are significantly different ($P \leq 0.05$).

[1] Diets were conditioned for approximately 40 s prior to pelleting (Model 3016-4 CPM Co., Crawfordsville, IN) with a 0.19 × 1.75 in. die. Treatments were replicated 3 times.

[2] Experimental binders included dry calcium lignosulfonate (DLS), liquid cane molasses (LCM), a commercial liquid molasses blend (LMB), and a commercial liquid lactose blend (LLB).

[3] Fines were calculated as the proportion of fines recovered from a sample at the die using a U.S. No. 5 sieve.

[4] Standard and modified tumble box methods with three 0.75 in. hex nuts used for modification.

[5] Linear and quadratic contrasts testing the response of increasing conditioning temperature with results considered significant at $P \leq 0.05$.