

Pelleting on the Nutritional Quality of Broiler Feeds

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Abstract

In the pelleting process, mash feed passes through a conditioner where it is exposed to steam under high pressure and pushed through the die to form pellets. To determine the effect of adding different amounts of water and different thermal processing parameters on the pellet conversion percentage, pellet durability index (PDI) and solubility of protein in KOH of broiler feed. The processing factors were combined in a 4x2 factorial scheme: four moisture

addition levels (0%; 0.7%; 1.4%; 2.1%), and two thermal processes (conditioning-pelleting or conditioning-expanding-pelleting). Eight samples of each treatment were collected to evaluate quality parameters. The feed used in this study was a typical corn-soybean broiler diet processed in a commercial feed mill. The pellet conversion percentage and PDI responded linearly and positively in the range of 0 to 2.1% moisture addition. Positive and linear equations relating moisture addition in the conditioner with pellet conversion percentage and PDI were obtained ($p < 0.001$). Expansion improved PDI and pellet percentage respectively by 18% and 21% when compared to simple conditioning-pelleting feed processing. However, an adverse effect on protein quality was observed when higher processing temperature was used. No particle size effect was observed for conditioned-expanded-pelleted feed. Medium particle size resulted in better PDI and higher pellet conversion percentage ($p < 0.001$) compared to coarse grinding (% pellets – 66.97% versus 64.96%; PDI – 77.30% versus 66.10%).

Keywords: coarse, expanded, feed mill, medium, pelleted

1. Introduction

In the pelleting process, mash feed passes through a conditioner where it is exposed to steam under high pressure and pushed through the die to form pellets. Since pelleting is a costly stage in a feed mill, it is important to achieve the maximum effectiveness of this process. This means a maximum amount of unbroken pellets at the mill and sufficient resistance to withstand typical handling during transport to farms (Melo *et al.*, 2016).

Pellet quality can be expressed as percentage of pellets produced and the pellet durability index (PDI, a measure of pellet resistance against fragmentation and impact forces). Franke and Rey (2006) and Mendez *et al.* (2008) reported that fracture points may occur when particles bigger than 1.00-1.50 mm are incorporated into the pellet structure. The use of annular gap expanders in feed mills also has a positive effect on PDI (Vukmirovic *et al.*, 2017). In some feed mills, a certain amount of water is added in the mixer in order to increase the moisture content of mash feed prior to conditioning (Boemo *et al.*, 2016). Attar *et al.* (2017) reported that the addition of 2.5% and 5.0% water in the mixer prior to pelleting increased the PDI. Kanmani *et al.* (2018) observed improvements on pellet quality when 2% and 4% tap water were added in the mixer.

In addition, parameters such as starch gelatinization and protein solubility can be monitored in order to check the effect of thermal processing on the feed ingredients. Muramatsu *et al.* (2013) evaluated the effect of an annular gap expander at 130-136°C on corn and soybean meal and observed that 29.67% and 19.19% of the starch contents were gelatinized. The high temperature, pressure and shearing forces present during the heat treatment of the feed can lead to formation cross-links in the protein structure that cannot be degraded by enzymatic activities (Röhe *et al.*, 2014; Prestlokken & Fôrutvikling, 2012). Protein solubility in 0.2% potassium hydroxide solution (KOH) is a useful tool to measure protein quality of heat processed feed ingredients.

The objective of the experiment reported here was to determine the effect of feed particle size,

different moisture addition to the mash feed in the conditioner and two thermal processes (conditioning-pelleting or conditioning-expanding-pelleting) on the pellet quality and protein solubility of corn-soybean broiler feeds.

2. Material and Methods

Feed processing. An experimental feed containing 2.5% added fat was formulated (Table 1) in order to evaluate the effects of particle size, moisture addition and processing parameters pellet quality and protein solubility. A commercial feed mill, located in Rio Grande do Sul state, Brazil, was used to produce the experimental feeds.

The ingredients were first passed through a 5.0 mm mesh sieve, and all coarse ingredients (whole corn kernels and coarse soybean meal fragments) were ground in a hammer mill (Buhler vertical hammer mill with 16 hammers - 10 tons/hour output/unit x 6 units) to achieve medium and coarse particle size of the final feed. The different particle sizes were attained by changing the hammer tip speed, since the hammer mill was equipped with a variable hammer rotation control (3600 rpm for medium size grinding and 1800 rpm for coarse size grinding). All the feed components were blended in a paddle mixer (Buhler DFML 8000L, 6000 kg capacity). The mixing time was divided in three phases: dry mixing (45 seconds), liquid addition (60-90 seconds) and wet mixing (25 seconds).

Table 1. Composition of the experimental feeds

Ingredients	Quantity (g/Kg)
Cornmeal	662.00
Soybean meal	239.00
Poultry byproducts meal	40.00
Soybean oil	25.00
Feather meal	10.00
Limestone	8.20
Liquid l-lysine (50%)	4.00
Salt	4.00
Monobicalcium phosphate	2.00
DL-methionine	1.70

Vitamin premix ^a	1.00
Betaine-HCl	0.90
Trace mineral premix ^b	0.85
Liquid choline chloride (75%)	0.70
L- threonine	0.60
Liquid phytase	0.05

Total	
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Calculated levels

Calcium %	3.00
EM kcal/kg	2.800
Available Phosphor %	0.30
Lysine Dig. birds %	1.04
Met + Cist Dig. birds %	0.71
Methionine Dig. birds %	0.47
Crude protein %	18.00
Sodium %	0.14
Threonine Dig. birds %	0.62

^a Supplied per kg of complete diet: 7000 IU of vitamin A, 2000 IU of vitamin D3, 25 IU of vitamin E, 2.0 mg of menadione, 4.0 mg of riboflavin, 25.0 mg of niacin, 12.0 mg of d-pantothenic acid, 4.0 mg of vitamin pyridoxine, 0.01 mg of vitamin B12, 1.0 mg of folic acid and 0.08 mg of biotin. ^bSupplied per kg of complete diet: 10 mg of copper as copper sulfate, 1 mg of iodine as calcium iodate, 60 mg of iron as ferrous sulfate, 70 mg of manganese as manganese sulfate, 0.3 mg of selenium as sodium selenite, and 70 mg of zinc as zinc sulfate.

The feed was steam-conditioned for 15 seconds at 80-82°C under steam pressure of 1.5-2.0 bar. Then the feed was directed either to an expander (Kahl expander, model 38.2, 40 tons/hour output, with average feed retention time of 5 seconds, annular gap pressure of 11-13 kwatt/ton/hour, 2,000 mm length, 400 mm width and 600 hp) or directly to the pellet mill (Buhler model DPAS, 30 tons/hour output, die specifications: 660 mm diameter, die holes with 60 mm depth and 4.5 mm diameter and with no relief, 350 hp and 1.0 mm gap between die and roll). The moisture addition levels in the conditioner were controlled by means of a water apportioning system (Kahl WD-GLI15, water temperature 60 °C and water pressure 3-6 bar). After the feed passed through the press, it was cooled in a Buhler model DFKG 30 cooler with cooling capacity of 30 tons of feed/hour.

Sampling. In order to evaluate the effect of different moisture addition levels (0% 0.7%; 1.4% and 2.1% water addition), thermal processing (pelleted x expanded-pelleted) and particle size (medium and coarse), four batches of four tons of feed (total of 16 tons) were mixed in sequence for each particle size (2 x 16 tons). The feed was tested for particle size by sampling the mash feed delivered by the mixer. Three samples of approximately 500 grams (composite sample) were collected for particle size determination. The particles sizes were determined according to the method referenced by the American Society of Agricultural and Biological Engineers (ASABE, 2006). The average result of the three samples was used to define the average particle size of the four batches.

The treatments were organized to fit the different moisture addition levels in each thermal process. The moisture addition in the conditioner was done from the lowest to highest level initially for pelleted feed ingredients. For each moisture addition level, 8 samples of approximately 500g were collected directly from the discharge of the pellet press. These samples were cooled in room temperature 24 hours before they were submitted to physical and chemical analysis. Sample collections were conducted after the conditioner-expander-pellet press achieved stable operating parameters (production rate, temperature and energy consumption). Once all the moisture addition was tested for pelleted diets, the different moisture levels were tested for expanded-pelleted feed following the same procedures described previously. Finally, all these procedures were repeated for coarse and medium particle size.

Feed Analysis. The feed from different treatments was analyzed for the following physical and chemical parameters: Pellet durability index (PDI): determined according to Method S269.4 from ASAE Standards (Mina-Boac *et al.* 2006); Percentage of pellets: 200 grams of feed were passed through a sieve with 3.0 mm round holes and the portion of feed retained in this screen was considered to be pellets; Protein solubility in KOH: determined according to the method described by Parsons *et al.* (1991); Moisture content: determined according to Method 930.15, referenced by the Association of Official Analytical Chemists International (1998).

Statistical analysis. The general linear model procedures of Statgraphics Centurion XVI (Stat Point Technologies, Inc) were used to analyze the data. The statistical model included the replicates, particle size, type of heat treatment and level of moisture addition: $Y_{ijkl} = \mu + MA_i$

+HT_j + PS_k + ε_{ijkl} Where: Y_{ijkl} = observation, μ = population mean, MA_i = moisture addition effect (I = 0 to 2.1%), HT_j = heat treatment effect (j = pelleted or expanded-pelleted), PS_k = particle size effect (k = medium or coarse particle size) and ε_{ijkl} = residual error.

3. Result and Discussion

Coarser particle size impaired the pellet conversion percentage in comparison to medium particle size (p<0.001) (Table 2).

The feed particle sizes achieved in the tests were respectively 988 microns for coarse grinding and 656 microns for medium grinding. The average moisture content of mash feed samples prior to conditioning was 12.02 ± 0.62%, and for the pelleted-expanded feed samples taken after cooling was 12.52 ± 0.71%.

Table 2. Effect of heat treatment (HT), particle size (PS) and moisture addition (MA) on pellet durability index, pellet percentage and feed protein solubility (KOH)

Factors	Pellet durability index	Pellets percentage	Protein solubility (KOH)
Moisture addition			
0.0% H ₂ O addition	69.35	76.93	69.19
0.7% H ₂ O addition	77.22	78.63	69.31
1.4% H ₂ O addition	78.83	81.88	67.06
2.1% H ₂ O addition	80.69	85.01	67.27
p-value	0.001	0.001	0.430
Particle Size			
Coarse	76.29	77.56	70.06
Medium	76.75	83.66	66.36
p-value	0.331	0.001	0.004
Heat Treatment			
Expanded-Pelleted	87.08	89.47	66.42
Pelleted	65.96	71.75	70.00

p-value	0.001	0.001	0.005
Interactions			
MA x PS			
p-value	<0.001	<0.001	<0.001
MA x HT			
p-value	<0.001	<0.002	<0.001
HT x PS			
p-value	<0.001	<0.001	<0.389
SEM	2.64	1.51	7.68

In general, the moisture addition improved the pellet quality. The PDI rose linearly ($P < 0.001$) with increasing moisture addition in the conditioner. The protein solubility (KOH) of mash feed samples collected before heat treatment and of soybean meal used in this experiment had average values of 73.76% and 81.92% respectively. (Table 2 and Table 3).

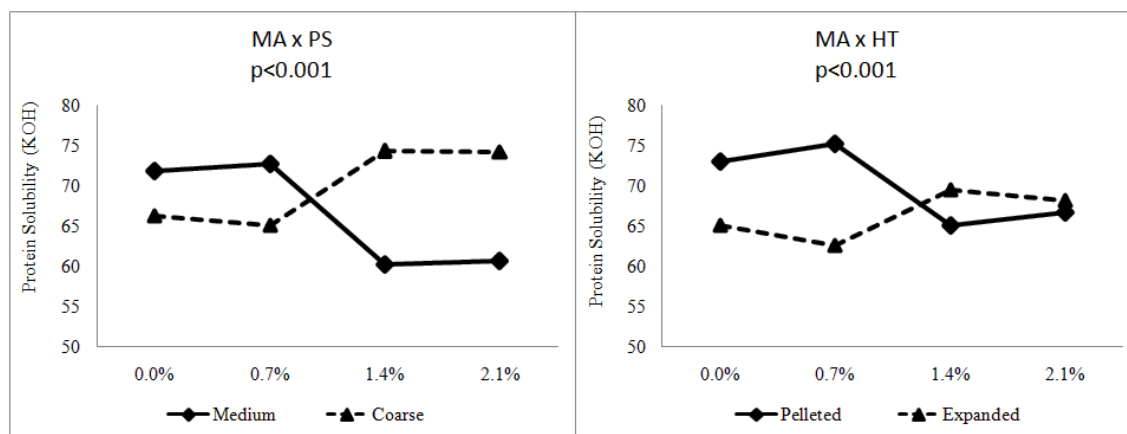


Figure 1. Interaction effects of heat treatment (HT), particle size (PS) and moisture addition (MA) on protein solubility in KOH

The same response was observed for pellet percentage, where different moisture addition levels linearly improved the pellet conversion ($P < 0.001$) (Table 2 and Table 3).

Expanding-pelleting resulted in better pellet percentage and PDI than just pelleting the mash ($P < 0.001$), independent of the particle size.

Protein solubility of the diets decreased in pelleted feeds and with medium particle size as the

moisture addition rose from 0.0% and 0.7% to 1.4% and 2.1% (Table 2 and Figure 1). The opposite response was observed in expanded-pelleted samples and in coarse particle size samples, where the protein solubility rose when moisture addition went from 0.0% and 0.7% to 1.4% and 2.1%.

Although the effect of moisture on pellet quality was more evident in the samples with coarse grinding and in single pelleted feeds, there was a linear and positive response of water addition on PDI and pellet percentage. Similar results were found by Jiménez-Moreno *et al.* (2016), who tested respective additions of 2.5% and 5.0% and 2.0% and 4.0% water in the mixer and observed a positive effect on pellet quality.

The greater effect of moisture addition in single pelleted feeds might be explained by the fact the annular gap expander can homogenize more water in mash feed after conditioning. In general, the conditioner-expander system can add around 1.0% additional water as steam to the feed prior to the pellet press when compared to normal conditioning. In this experiment, the moisture measurements of samples collected just after the pellet press (prior to cooling) showed that the moisture content of conditioned-expanded feed was on average 0.5% higher than single conditioned feed. Probably that is the reason for the smoother response slope of pellet quality to the moisture addition in the conditioned-expanded feed.

Coarser particle size impaired protein solubility regarding medium particle size ($p < 0.004$ respectively) (Table 2).

Table 3. Regression equation for pellet durability index (PDI) and pellet conversion percentage considering the following factors: heat treatment (HT), particle size (PS) and moisture addition (MA) and their interactions

Equation	P	R-Square
$\text{PDI} = 71.179 - 1.867 \cdot \text{PS} + 11.889 \cdot \text{HT} + 5.089 \cdot \text{MA} + 0.771 \cdot \text{PS} \cdot \text{HT} + 1.557 \cdot \text{PS} \cdot \text{MA} - 1.267 \cdot \text{HT} \cdot \text{MA}$	<0.001	97.9
$\% \text{ Pellets} = 76.486 - 4.4789479 \cdot \text{PS} + 10.242 \cdot \text{HT} + 3.930 \cdot \text{MA} + 2.605 \cdot \text{PS} \cdot \text{HT} + 1.361 \cdot \text{PS} \cdot \text{MA} - 1.316 \cdot \text{HT} \cdot \text{MA}$	<0.001	94.9
$\text{Protein solubility in KOH} = 68.752 - 4.539 \cdot \text{OS} - 5.629 \cdot \text{HT} - 0.713 \cdot \text{MA} + 0.5728 \cdot \text{OS} \cdot \text{HT} + 5.889 \cdot \text{PS} \cdot \text{MA} + 3.460 \cdot \text{HT} \cdot \text{MA}$	<0.001	48.3

Again, significant interactions between the processing procedures were observed. Pellet percentage response to moisture addition was higher in pelleted than expanded-pelleted feeds (16% x 7% improvement), and in coarse than medium particle size feeds (15% x 7%). There was an interaction between particle size and heat treatment, since the negative effect of coarser particle size on PDI and pellet percentage was significant only in pelleted feeds.

The addition, of moisture had a more pronounced effect on coarse ground ingredients than on fine ground ingredients. One of the reasons for this response may be the fact that as particle

size increases, the weaker the bonds between the particles become. The capillary property of water helps to keep the particles bound together (Thomas & Poel, 1996). Another possible explanation is that with zero water addition, the coarse ground samples had significantly lower pellet quality, and as a consequence a higher possibility of improvement.

The reduction of the particle size in this study resulted in better pellet quality, as also reported by Castellano *et al.* (2015). The medium particle size (656 microns) resulted in a higher PDI compared to coarse grinding (988 microns). This finding is in accordance with Pacheco-Dominguez (2014), who found that in corn-soybean meal feed for broilers, the ideal particle size is around 650-700 microns. This positive effect of fine grinding on pellet quality was observed only in pelleted samples. The size and shape of the particles influence the nutritional quality of feeds, since they are physical characteristics resulting from different treatment responses (Melo *et al.* 2016; Domingues *et al.* 2014).

Protein solubility was decreased by coarser particles in expanded-pelleted feeds but not in pelleted samples (Table 4 and Figure 2).

Table 4. Interaction effects between heat treatment (HT), particle size (PS) and moisture addition (MA) on pellet durability index, pellet percentage and protein solubility (KOH)

Factors	Pellet durability index		Pellet percentage		Protein solubility (KOH)	
	Pelleted	Expanded	Pelleted	Expanded	Pelleted	Expanded
MA x HT						
0.0% H ₂ O add.*	56.49 b A	82.20 a A	67.43 a A	86.36 b A	73.07 a A	65.13 b A
0.7% H ₂ O add.*	67.94 b B	86.50 a B	68.13 a A	89.08 b B	75.19 a A	62.58 a A
1.4% H ₂ O add.*	68.16 b B	89.51 a C	73.29 a B	90.47 b B	64.99 a B	69.48 b B
2.1% H ₂ O add.*	71.26 b C	90.12 a C	78.03 a C	91.99 a C	66.73 a B	68.18 b B
p-value	0.000		0.000		0.000	
MA x PS	Medium	Coarse	Medium	Coarse	Medium	Coarse
0.0% H ₂ O add.*	71.98 a A	66.72 b A	80.94 a A	72.85 b A	71.92 a A	66.28 b A
0.7% H ₂ O add.*	77.28 a B	77.17 a B	82.78 a B	74.43 b B	72.66 a B	65.11 b A
1.4% H ₂ O add.*	77.69 a B	79.98 b C	84.31 a B	79.45 b C	60.17 a C	74.31 b B
2.1% H ₂ O add.*	80.07 a C	81.30 a D	86.50 a C	83.52 b D	60.68 a C	74.23 b B
p-value	0.000		0.000		0.000	
HT x PS	Medium	Coarse	Medium	Coarse	Medium	Coarse

Pelleted	66.97 a A	64.96 b A	77.34 a A	66.10 b A	68.93 a A	71.07 a A
Expand.-Pel.**	86.54 a B	87.62 a B	89.92 a B	89.03 a B	63.79 a B	68.89 b A
p-value	0.000		0.000		0.033	
SEM	1.04		0.93		0.72	

*add.: addition ** Expanded – Pelleted

In expanded-pelleted feeds, the different particle sizes did not affect the PDI or the pellet percentage. Probably the changes in feed texture by the temperature, pressure and moisture of the annular gap expander overwhelmed the breaking forces of the bigger particles present in coarse grinding

Calculation of the binding strength between solids by Laplace's equation (binding strength = $2 \times (\text{liquid surface tension} / \text{particle diameter} / 2)$) revealed why particle size has a strong impact on the bonds inside the pellets (Thomas & Poel, 1996).

The pellet conversion percentage and PDI were respectively 18% and 21% higher for expanded-pelleted compared to pelleted feed samples. These results are in accordance with Fancher *et al.* (1996), who reported a survey of North American feed mills where the annular gap expander increased the PDI values of chicken feed from 15 to 25% compared to a simple conditioning process.

We observed that pelleted feed had higher ($p < 0.005$) protein solubility in KOH when compared to expanded-pelleted feed (70.0% x 64.2%). Muramatsu *et al.* (2013) also observed that expanding soybean meal at 130-136 °C decreased protein solubility in KOH from 80.57% to 64.12%. However, Lima *et al.* (2016) observed that the thermal processing provided better availability of the protein from the hydrolysis of the starch present in the tested feeds.

Interactions between the different processing factors were significant. Moisture addition was more effective in increasing the PDI values in pelleted than in expanded-pelleted samples (26% x 10% improvement) and in coarse than medium particle size samples (22% x 11%).

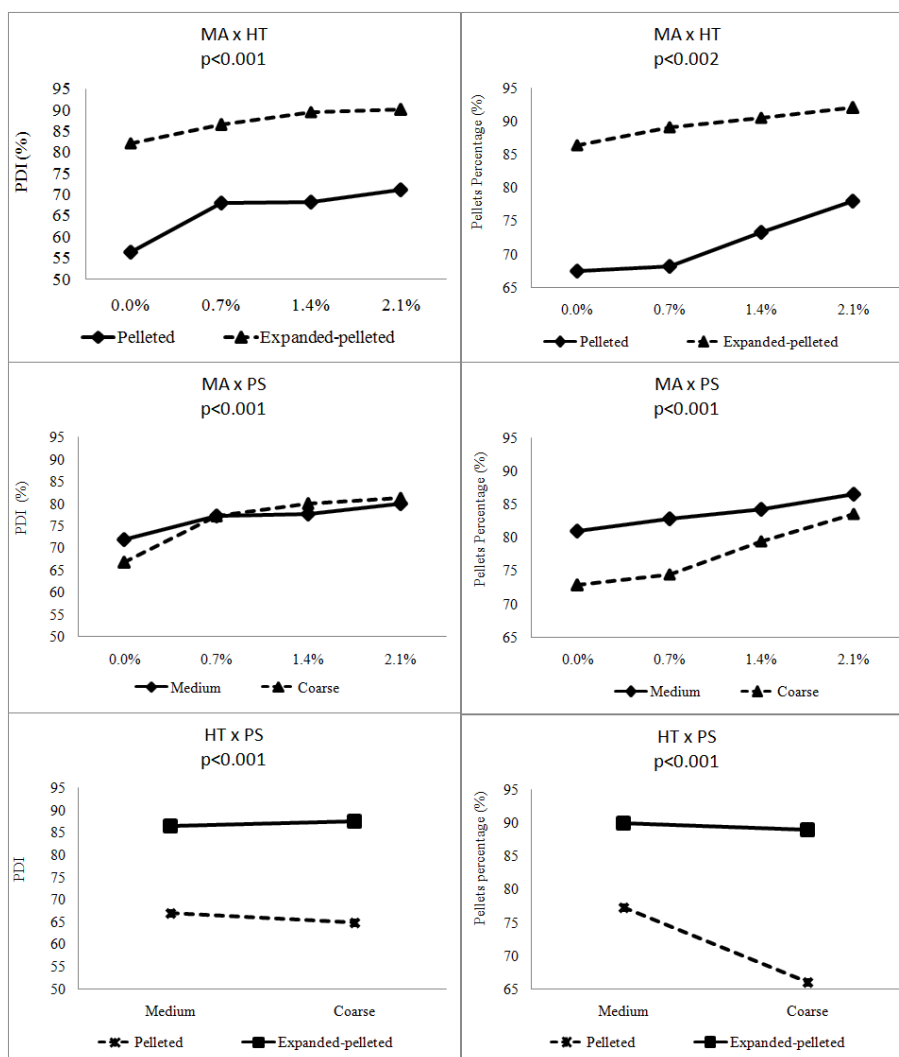


Figure 2. Effect of heat treatment (HT), particle size (PS) and moisture addition (MA) on pellet durability index and pellet percentage

4. Conclusion

Adding moisture in the conditioner up to 2.1% enhanced the pellet quality of the feeds. The addition of moisture proved important mainly with coarse grinding. In the same way, the use of the annular gap expander proved to be a beneficial thermal feed process if the aim is to increase pellet percentage and PDI. The improvements in PDI and % pellets reached, respectively, 18% and 21% in the present study and had an effect on protein quality when higher processing temperature was used.

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