Zamorano University

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Special Graduation Project

Evaluation of conditioning temperature and retention time on pellet durability index in poultry feed manufacturing at Auburn University

Student

Aarón Lando Rivera Soria Galvarro

Advisors

Patricio E. Paz, Ph.D.

Wilmer J. Pacheco, Ph.D.

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Authorities

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Abstract

Pellet quality is a critical parameter in feed manufacturing, directly influencing feed efficiency, nutrient stability, and animal performance. This study evaluated the effects of two retention times during conditioning (45 and 90 seconds) and three conditioning temperatures (77 °C, 82 °C and 88 °C) on the Pellet Durability Index (PDI) of broiler feed under commercial-like conditions. A 3 × 2 factorial arrangement was implemented, resulting in six treatments, each replicated during two independent production runs. Pellet durability was measured using a Holmen NHP100 tester at 30 and 60 seconds (Holmen 30 and Holmen 60). There was not an interaction ($P > 0.3$) between retention time in the conditioner and conditioner temperature on PDI. However, results indicated that conditioning temperature influenced PDI ($P < 0.0001$), with diets conditioned at 88°C resulting in the highest PDI. In contrast, retention time in the conditioner did not influence pellet durability ($P > 0.3$). These findings suggest that increasing conditioning temperature enhances pellet durability, while extending retention time beyond 45 seconds provides no additional benefit. This study contributes to the optimization of pelleting parameters in feed mills, emphasizing the role of temperature as a primary driver of pellet quality and process efficiency.

Keywords: Conditioning temperature, feed manufacturing, pellet durability, poultry feed, retention time.

Resumen

La calidad del pellet es un parámetro crítico en la fabricación de alimento balanceado, ya que influye directamente en la eficiencia alimenticia, la estabilidad de los nutrientes y el rendimiento animal. Este estudio evaluó los efectos de dos tiempos de retención durante el acondicionamiento (45 y 90 segundos) y tres temperaturas de acondicionamiento (77 °C, 82 °C y 88 °C) sobre el Índice de Durabilidad del Pellet (PDI) en dietas para pollos de engorde bajo condiciones similares a las comerciales. Se utilizó un diseño factorial 3 × 2, que resultó en seis tratamientos, cada uno replicado en dos corridas de producción independientes. La durabilidad del pellet se midió utilizando un equipo Holmen NHP100 a 30 y 60 segundos (Holmen 30 y Holmen 60). No se encontró interacción significativa ($P > 0.3$) entre el tiempo de retención en el acondicionador y la temperatura de acondicionamiento sobre el PDI. Sin embargo, los resultados indicaron que la temperatura de acondicionamiento sí tuvo un efecto significativo en el PDI ($P < 0.0001$), siendo las dietas acondicionadas a 88 °C las que presentaron el mayor valor. En contraste, el tiempo de retención no tuvo efecto significativo sobre la durabilidad del pellet ($P > 0.3$). Estos hallazgos sugieren que incrementar la temperatura de acondicionamiento mejora la durabilidad del pellet, mientras que extender el tiempo de retención más allá de 45 segundos no aporta beneficios adicionales. Este estudio contribuye a la optimización de los parámetros de peletización en plantas de alimento balanceado, destacando el papel de la temperatura como factor principal en la mejora de la calidad del pellet y la eficiencia del proceso.

Palabras clave: Alimento avícola, durabilidad del pellet, manufactura de alimento, temperatura de acondicionamiento, tiempo de retención.

Introduction

The global poultry industry continues to expand rapidly, driven by increasing population, higher purchasing power, and accelerated urbanization. These factors have not only boosted demand but have also led to significant transformations in poultry production systems. According to (FAO, 2025), world poultry meat production increased from nine to 133 million tons between 1961 and 2020, reflecting the industry's critical role in meeting global protein needs. By 2020, poultry meat represented almost 40% of global meat production, consolidating its position as a cornerstone of animal protein supply worldwide (FAO, 2025).

Poultry production is, however, a demanding and highly competitive industry, frequently characterized by tight profit margins. One of the most influential economic factors is feed cost, which accounts for approximately 60–70% of total production expenses in poultry and livestock operations. As feed constitutes the largest operational input, optimizing its efficiency is essential for improving profitability and ensuring the sustainability of production systems. In recent years, rising feed prices have placed significant financial pressure on producers, intensifying the need for innovative strategies to maximize feed utilization and reduce waste (Intelia, 2025). Consequently, enhancing feed manufacturing practices, particularly those related to pellet quality, has emerged as a key area of focus within modern poultry production.

Pelleted feed has become a standard in intensive poultry production systems due to its capacity to enhance animal performance and feed conversion when compared to mash diets. The transition from mash to pellet feeding has consistently demonstrated positive outcomes in growth rates, feed intake uniformity, and overall production efficiency. According to (Behnke, 2001), feeding pelleted diets improves performance by reducing feed wastage, minimizing selective feeding, decreasing ingredient segregation, and lowering the time and energy birds spend in feed prehension. Moreover, the pelleting process contributes to the destruction of pathogenic organisms, thermal modification of nutrients such as starch and protein, and enhanced palatability, all of which further support productive efficiency and flock health.

While early research focused primarily on the advantages of pelleted diets over mash, the current focus has shifted toward the quality of the pellets themselves. As integrated poultry and swine operations continue to scale, the value of delivering consistently high-quality pellets has become increasingly evident. In this context, pellet quality is no longer viewed as a secondary trait but rather as a key driver of animal performance and feed efficiency (Behnke, 2001). Consequently, evaluating and improving pellet durability and integrity has become a critical objective in feed mill operations aiming to support the nutritional and economic goals of modern poultry systems.

To quantify pellet quality, the Pellet Durability Index (PDI) is widely used as a standard metric within the feed manufacturing industry. This index provides a numerical value that reflects the structural integrity of pellets after they are subjected to mechanical stress during handling, storage, and feeding. Pellet durability is defined as the percentage of the weight of intact pellets remaining after a standardized durability test commonly through tumbling (e.g., Tumbler Box) or air blowing (e.g., Holmen Tester) relative to the initial sample weight (American Society of Agricultural and Biological Engineers [ASABE], 2002). These methods simulate physical impacts that pellets experience during handling and transportation. A high PDI value indicates stronger pellets with lower susceptibility to breakage, which helps reduce fines generation, improves feed intake consistency, and preserves the intended nutrient profile of the ration.

Determining pellet quality at the commercial feed mill before shipping is a common practice to assess and predict the performance of pelleted feeds during storage, transportation, and delivery to the farm. Routine PDI testing enables feed manufacturers to monitor processing outcomes and make timely adjustments in formulation or conditioning parameters to achieve optimal durability (Muramatsu et al., 2015). Given the close link between physical feed quality and animal performance, improving the mechanical stability of pellets has become a priority in commercial feed production.

Pellet durability is a critical parameter in evaluating pellet quality, and it is highly influenced by feed formulation and processing conditions during feed manufacturing. Studies have shown that increasing conditioning temperature and extending retention time can significantly improve PDI, reduce fines, and enhance the physical quality of pellets. However, these benefits may come at the expense of nutrient digestibility and growth performance in broilers, especially when excessive thermal exposure alters feed structure (Maiorka et al., 2020). In this context, determining optimal conditioning parameters is essential to achieve a balance between pellet integrity and animal productivity. As highlighted in a review by Muramatsu et al. (2015), key factors such as moisture content, pellet die specifications, and thermal conditioning directly impact pellet quality, making it necessary to understand the interactions between processing variables and their biological consequences.

Given the critical role of pellet durability in feed efficiency and the known influence of conditioning variables, this study aims to evaluate the effect of conditioning temperature and retention time on the PDI of poultry feed under commercial production conditions. Although the individual impact of these factors has been previously studied, there remains a need to understand their combined effects and practical implications within integrated feed manufacturing systems. This project was conducted at the Poultry Research Unit of Auburn University and involved six treatments combining three conditioning temperatures (77 °C, 82 °C and 88 °C) with two retention times (45 seconds and 90 seconds). Pellet durability was assessed using air blowing methods (Holmen NHP100) at two durations (30 and 60 seconds) to capture the physical integrity of pellets under different stress intensities. By identifying optimal conditioning parameters that maximize PDI without compromising processing efficiency, this research contributes to the ongoing effort to improve pellet quality and economic sustainability in poultry feed manufacturing.

Materials and Methods

Location

The experiment was conducted during April 2025 at the experimental feed mill of the Department of Poultry Science at Auburn University, located in Auburn, Alabama, United States. The city sits at an average elevation of 216 meters above sea level. During April 2025, Auburn recorded an average monthly temperature of 19.4 °C and a total precipitation of 160.8 mm. These conditions are characteristic of a humid subtropical climate, typical of the southeastern United States, and are relevant to feed manufacturing and pellet quality evaluations.

Feed Formulation and Pelleting Process

The base diet used in this study was a typical grower phase formulation for broiler chickens. The diet consisted primarily of ground corn (59.83%) and soybean meal (28.56%), with additional ingredients such as dried distillers grains with solubles (DDGS, 5.00%), soybean oil (3.33%), limestone, salt, DL-methionine, and a vitamin-mineral premix. The complete ingredient and nutrient composition is provided in Table 1.

Table 1

Ingredient composition for the grower phase in broilers used at Auburn University

Ingredient	Percentage (%)	Weight (kg)
Corn	59.83	1196.60
Soybean meal, 46% Crude Protein	28.56	571.20
Distillers dried grains with solubles (DDGS)	5	100.00
Soybean oil	3.33	66.60
Dicalcium phosphate, 18% P	0.97	19.40
Calcium carbonate	1.16	23.20
Sodium chloride	0.37	7.40
D-L Methionine	0.25	5.00
L-Lysine	0.17	3.40
Trace mineral premix 1	0.1	2.00
Vitamin premix 2	0.1	2.00
Choline chloride	0.07	1.40
L-Threonine	0.06	1.20
Enspira phytase	0.008	0.16
Total	100	2000

The diet was formulated to meet or exceed the nutritional requirements for grower broilers, supplying 3,117 kcal/kg of apparent metabolizable energy (AME_n), 20.45% crude protein, 1.02% digestible lysine, 0.68% digestible threonine, 0.19% digestible tryptophan, and 0.78% total sulfur amino acids.

The mash feed underwent standard feed processing operations including grinding, mixing, steam conditioning, pelleting, and cooling. During conditioning, steam was injected to raise mash temperature to the designated levels. Retention time during conditioning was controlled using the automation system (Beta Raven) and by adjusting the speed of the hygieniser. The objective of the conditioning process was to soften feed particles, promote starch gelatinization, and activate inherent binding properties of proteins and starches. After conditioning, the mash was pelleted using a 4.4 mm die and cooled for 8 minutes with ambient air prior to sample collection.

Experimental Design, Sampling, and Statistical Analysis

This study was conducted to evaluate the effect of two retention times during conditioning (45 and 90 seconds) and three conditioning temperatures (77 °C, 82 °C and 88 °C) on pellet quality, measured as PDI. The experimental design followed a 2 × 3 factorial arrangement, resulting in six treatments. Each treatment was produced twice in separate production runs: Run 1 (Treatments 1–6) and Run 2 (Treatments 6–1), to account for process variability. An overview of the six treatments used across both production runs is shown in Table 2.

Table 2

Description of experimental treatments by conditioning temperature (CT), retention time (RT) and number of samples collected after pelleting for Run 1 and Run 2

Run 1				Run 2			
Treatment	Conditioning Temperature (°C)	Retention Time (s)	Samples after pelleting	Treatment	Conditioning Temperature (°C)	Retention Time (s)	Samples after pelleting
T1	77	45	4	T6	77	90	4
T2	82	45	4	T5	82	90	4
T3	88	45	4	T4	88	90	4
T4	88	90	4	T3	88	45	4
T5	82	90	4	T2	82	45	4
T6	77	90	4	T1	77	45	4
Total samples			24	Total samples			24

All diets were conditioned using a dual-stage system composed of a conditioner and a hygieniser with adjustable settings for temperature and retention time. A constant production rate of 0.7 tons/hour was maintained during all treatments, and a pellet die with a diameter of 4.4 mm was used.

After mixing, diets were placed into the mash bin and conditioned at 77 °C, 82 °C and 88 °C with retention times of 45 and 90 seconds. Once the target conditioning temperature was reached, four samples per treatment were collected at three-minute intervals during steady-state production. Sampling occurred after pelleting followed by eight minutes of ambient air cooling. After cooling, pellets reached a final moisture content of approximately 12.0%. Each of the four post-cooling samples was used to perform four Holmen tests (two Holmen 30 and two Holmen60), resulting in a total of 16 PDI analyses per treatment.

Pellet quality was evaluated using a Holmen NHP100 pellet durability tester. For each test, 100 g of whole pellets were weighed and screened using a U.S. No. 6 sieve (4 mm) to remove fines.

Only intact whole pellets retained on the sieve were used for pellet durability analysis. Two PDI measurements were performed per sample: one at 30 seconds and another at 60 seconds. Each test was conducted in duplicate. After the Holmen test, the pellets were re-sieved and reweighed to quantify the final weight of whole pellets. The Pellet Durability Index (PDI) was calculated using equation 1:

$$\text{PDI (\%)} = (\text{Final weight of retained pellets} / \text{Initial 100 g}) \times 100 \quad [1]$$

This method allowed for standardized and consistent comparisons of pellet mechanical durability across treatments. A general linear model (GLM) was used to evaluate the influence of conditioning temperature (CT) and retention time (RT). The data were analyzed using a factorial design model (3 × 2), which allowed for the evaluation of the individual effects of conditioning temperature (CT) and retention time (RT), as well as their interaction, on pellet durability. This approach provided a clearer understanding of how each factor independently influenced the PDI response. Tukey's HSD test was used to separate treatment means at a significance level of $\alpha = 0.05$. All statistical analyses were performed using SAS Studio.

Results and Discussion

Pellet durability, measured through Holmen tester at 30 and 60 seconds (Holmen 30 and Holmen60), exhibited clear and consistent trends across all treatments, reinforcing the robustness of the experimental design. Both indicators followed similar response patterns, with higher conditioning temperatures resulting in increased PDI values. The results confirmed that conditioning temperature had a highly significant effect ($P < 0.0001$) on pellet durability, while retention time ($P > 0.3$) and the interaction between temperature and time were not significant. The PDI values for Holmen 30 ranged from 78.5% to 85.7%, and for Holmen60 from 60.6% to 73.0%, with the highest values observed in treatments conditioned at 88 °C.

Further analysis using a 3 × 2 factorial GLM showed that temperature alone explained over 70% of the variation in pellet durability ($R^2 = 0.703$ for Holmen 30; $R^2 = 0.670$ for Holmen60), while retention time had negligible contribution, confirming its limited impact under the tested conditions. Sampling effects were minimal but statistically significant ($P < 0.05$), likely reflecting inherent variability in pellet consistency across collection points within each run, whereas no significant differences were found between production runs, indicating high operational consistency.

Duncan’s test grouped treatments conditioned at 88 °C (with either 45 or 90 seconds) as the top-performing in terms of PDI, while those at 77 °C consistently showed the lowest values. Importantly, Holmen 30 and Holmen60 not only followed the same ranking across treatments, but also preserved the relative differences, confirming that pellet structure was resistant to increasing agitation times and suggesting true internal cohesion. This consistency reinforces the reliability of the observed treatment effects, summarized in Tables 3, 4, and 5.

Table 3

Effect of conditioning temperature and retention time on pellet durability index (PDI), measured using the Holmen tester at 30 and 60 seconds. Each treatment represents a specific combination of temperature and time applied during feed conditioning

Treatment	Conditioning Temperature (°C)	Retention Time (s)	Holmen 30 (%)	Holmen 60 (%)
T1	77	45	78.51 ± 1.82	59.41 ± 5.30
T2	77	90	79.02 ± 2.84	60.53 ± 5.38
T3	82	45	81.78 ± 1.05	65.07 ± 2.91
T4	82	90	83.24 ± 2.82	68.03 ± 5.31
T5	88	45	85.73 ± 1.18	73.83 ± 2.57
T6	88	90	85.43 ± 1.12	72.83 ± 1.80
P Value			0.4520	0.4120

Note. T1 = 77°C / 45 s; T2 = 77°C / 90 s; T3 = 82°C / 45 s; T4 = 82°C / 90 s; T5 = 88°C / 45 s; T6 = 88°C / 90 s.

In the present study, retention time (RT) did not influence pellet durability, as assessed by Holmen 30 and Holmen 60 tests (P = 0.3297 and 0.3975, respectively). Although the numerical values showed slightly higher PDI at 90 seconds (82.57% and 67.13%) compared to 45 seconds (82.01% and 66.10%), these differences were not statistically significant (Table 3). This trend is consistent across both Holmen 30 and Holmen 60, whose curves followed similar patterns, suggesting that longer retention times may offer only marginal physical improvements in pellet integrity under the conditions tested.

These findings are in contrast to those reported by Salahshour et al. (2023), where significantly higher PDI values were observed with increased retention times, particularly between 30 and 90 seconds, and especially when coupled with higher conditioning temperatures. Similarly Maiorka et al. (2020) reported that extending retention time from three to 20 seconds under 85 °C conditioning improved pellet quality, with the highest PDI achieved at 20 seconds. This discrepancy may be due to differences in the range of retention times applied (i.e., 3 to 20 s in Maiorka et al. 2020 vs. 45 to 90 s in this study), suggesting that the positive effects of retention time may be more pronounced at lower baseline values and may plateau or diminish beyond a certain threshold.

Overall, this study's results suggest that, under the tested conditions and RT window (45 to 90 seconds), extending retention time does not confer a significant advantage in pellet durability. Therefore, from a feed mill efficiency standpoint, shorter retention times may be preferred unless further improvements in quality are justified by other processing or nutritional goals. These outcomes are summarized in Table 4, which compares mean Holmen PDI values between retention times.

Table 4

Effect of retention time on pellet durability (Holmen 30 and Holmen 60)

Retention Time (s)	Holmen 30 (%)	Holmen 60 (%)
45	82.01 ±3.04	66.10 ±6.18
90	82.57 ±3.11	67.13 ±6.09
P-Value	0.3297	0.3975

The results from the present study demonstrate that conditioning temperature influences pellet quality, as measured by the PDI. As shown in Table 4, increasing the conditioning temperature from 77 °C to 88 °C led to improvements in pellet durability across all PDI measurement methods (Holmen 30, Holmen 60). The highest PDI values were obtained at 88 °C, suggesting enhanced feed agglomeration and mechanical stability. These findings are consistent with the work of Rueda et al. (2022), who reported that increasing the conditioning temperature from 71 °C to 88 °C improved PDI by nearly 10 percentage points while simultaneously reducing the percentage of fines in both grower and finisher diets. Similar results were documented by Loar et al. (2014), who observed that higher conditioning temperatures (85 to 96 °C) improved pellet quality parameters under low mixer-added fat conditions.

From a mechanistic perspective, the improved pellet quality observed at higher conditioning temperatures can be attributed to several factors. Elevated temperatures enhance starch gelatinization, solubilize natural binders, and increase moisture penetration, all of which facilitate better particle binding during compression (Behnke, 2001; Teixeira Netto et al., 2019). However, it is important to note that excessive heat can degrade thermolabile nutrients and reduce amino acid availability, as emphasized by Abdollahi et al. (2010) and Loar et al. (2014). In the current study, the benefits of increased temperature on pellet durability appear to outweigh the potential risks associated with nutrient degradation, especially since no detrimental effects on PDI were detected up to 88 °C. This reinforces the notion that, within the tested range, conditioning temperature is a critical factor for optimizing pellet integrity in poultry feed.

The trends observed in the present trial are supported by previous research. For instance, W. G. Cui et al. (2024) confirmed a linear improvement in pellet quality metrics with increasing conditioning temperature up to 90 °C, while noting that digestibility may decline beyond certain thermal thresholds. Hernandez Garcia (2024) reported that increasing the conditioning temperature led to a higher PDI, with the highest values observed at 88 °C. These improvements in physical quality occurred consistently across different diets and were not associated with changes in broiler performance. Although some reductions in mineral digestibility were noted, the overall findings reinforce that higher conditioning temperatures are effective in enhancing pellet structural integrity. The data presented in Table 5 summarizes the effect of conditioning temperature on pellet quality and serves as a reference for this discussion.

Table 5

Effect of conditioning temperature on pellet durability index PDI (Holmen 30 and Holmen 60)

Conditioning Temperature (°C)	Holmen 30 (%)	Holmen 60 (%)
77	78.76 ± 2.36^{c}	59.97 ± 5.31^{c}
82	82.51 ± 2.21^{b}	66.55 ± 4.23^{b}
88	85.57 ± 1.15^{a}	73.33 ± 2.21^{a}
P-Value	<0.0001	<0.0001

Conclusions

The conditioning temperature is a critical factor influencing the pellet quality in poultry feed manufacturing under commercial-like conditions.

Increasing conditioning temperature from 77 °C to 88 °C improved pellet durability, highlighting the importance of thermal input in enhancing physical pellet integrity.

Retention time, within the tested range (45 to 90 seconds), did not affect pellet durability, indicating that extending residence time beyond 45 seconds offers no added benefit under current operational conditions.

No interaction occurred between conditioning temperature and retention time, thus supporting the independent impact of temperature as the dominant variable.

Recommendations

Poultry feed manufacturers should prioritize higher conditioning temperatures (e.g., 88 °C) to improve pellet durability, especially in formulations with high fiber or challenging ingredients.

Retention time beyond 45 seconds may not be necessary under the tested conditions, as no significant improvements in pellet durability were observed. It is recommended to conduct further research to determine the minimum retention time required to achieve comparable PDI values, optimizing conditioner efficiency without compromising pellet quality.

Additional studies should include nutrient digestibility and bird performance metrics, to determine whether the improvements in PDI at higher temperatures translate into biological and economic benefits.

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