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Research Article

Combination of Corn, Wheat Pollard and Maggot Steamed at Different Times as Functional Feed Ingredients for Poultry

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Abstract | The study aimed to assess the effects of combining corn, wheat pollard, and maggot meal with different steaming durations on the chemical composition and nutrient digestibility in chickens. The appropriate ratio of feed ingredients and steaming method was expected to enhance digestibility. A randomized group design with a 2 × 3 factorial pattern and seven replicates was used. The first factor was the feed composition: L0 (25% corn, 25% wheat pollard, and 50% maggot) and L1 (37.5% corn, 37.5% wheat pollard, and 25% maggot). The second factor was the steaming duration: T0 (no steaming), T1 (121°C for 15 minutes), and T2 (121°C for 20 minutes). Parameters observed included proximate composition (dry matter (DM), ash, crude fat, crude protein (CP), crude fiber, and nitrogen-free extract (NFE)), gross energy, Scanning Electron Microscopy with Energy Dispersive X-ray (SEM-EDX), digestibility (crude protein, crude fiber, and crude fat), True Metabolizable Energy (TME), and Apparent Metabolizable Energy (AME). The results showed a significant interaction ($P<0.05$) between feed composition and steaming duration on ash content, crude fat, crude fiber, crude fat digestibility, AME, and TME, with the highest values observed at 15 minutes of steaming. The optimal treatment was the L1 formulation (37.5% corn, 37.5% wheat pollard, and 25% maggot) steamed for 15 minutes. This treatment preserved levels of DM, CP, NFE, and gross energy; increased ash and crude fat; and reduced crude fiber. It also maintained the digestibility of CP and crude fiber while enhancing the digestibility of crude fat, AME, and TME. The optimized feed contained 91.03% DM, 10.51% ash, 10.44% crude fat, 17.45% CP, 3.09% crude fiber, 58.48% NFE, and 3105.3 kcal/kg of gross energy. It resulted in a CP digestibility of 72.09%, crude fiber digestibility of 85.23%, crude fat digestibility of 90.39%, AME of 2715.89 kcal/kg, and TME of 2983.34 kcal/kg. Steaming for 15 minutes was the most effective treatment, improving the chemical quality and utilization of feed ingredients without compromising their nutritional value.

Keywords | Corn, Wheat pollard, Maggot, Chemical quality, Nutrient utilization

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INTRODUCTION

Corn is an energy source feed ingredient called the king of energy. Corn has an energy content of 3760 kcal/kg, 60%-80% starch, 10% protein, and 5% fat (Lapui *et al.*, 2021). The use of corn in the poultry feed industry ranges from 50-55% of the total ration (Liu *et al.*, 2020). Corn as feed has the disadvantage of being increasingly expensive, which will have an impact on poultry feed production. Therefore, there is a need for other energy source feed ingredients that are used as substitutes for corn. Another energy source feed ingredient that can be used as poultry feed is wheat pollard. Wheat pollard is also referred to as the queen of energy.

Wheat pollard comes from wheat processing industry waste which has the advantage of high food fiber and oligosaccharide content (Li *et al.*, 2022). Oligosaccharides play a positive role as prebiotics that can stimulate the growth of non-pathogenic bacteria in the gut (Johnson *et al.*, 2024). Utilization of wheat pollard as feed is less than optimal due to the presence of non starch polysaccharides (NSP) which are difficult to digest by poultry digestion (Kim *et al.*, 2021). One of the efforts that can be made to utilize wheat pollard is processing by steaming. Steaming can change the chemical structure of wheat pollard to be simpler, making it easy to digest (Sulistiyanto *et al.*, 2019).

Feeding energy sources needs to be balanced with protein source feed. One of the cheap protein source feed ingredients is maggot meal. Maggot is the larva of the Black Soldier Fly (BSF) whose protein content reaches 59-65% (Song and He, 2019). Maggot has a disadvantage because it contains chitin. Chitin in maggot ranges from 3.9 - 14.2% which inhibits the process of digestion and absorption of nutrients in the poultry body (Shin *et al.*, 2019). The steaming process can be a solution in reducing NSP in wheat pollard and chitin in maggot.

Pressure steaming can stretch the surface structure of feed ingredients and reduce anti-nutritional substances, so that feed is easier to digest (Liu *et al.*, 2020). High-pressure steaming can change the structure of chitin to become porous and more brittle (Tan *et al.*, 2015). Heating temperature can also change the structure of NSP, thereby increasing the digestibility of NSP (Dey *et al.*, 2024). The level of nutrient digestibility determines the quality of the ration and the amount of feed that can be utilized to meet the basic needs of life and livestock growth (Moningkey *et al.*, 2019). The digestibility value of feed is influenced by the type of livestock, age of livestock, environmental temperature, feed flow rate in the digestive system, and the form and composition of feed (Puja *et al.*, 2023).

The high energy content of corn and wheat pollard, as well as the protein content of maggot meal, has the potential to be used as a functional feed for poultry. Functional feed is a modified feed that can improve performance, affect immunity, gut health, and resistance to several diseases (Zuberi *et al.*, 2024). Digestibility testing of feed ingredients using culled laying hens aims to measure the digestibility of nutrients in feed ingredients, because the absorption of nutrients for reproduction of old laying hens has changed (Gu *et al.*, 2021). The novelty in this study is the combination of corn, wheat pollard, and maggot processed using pressurized heating to increase its beneficial value.

The purpose of the study was to examine the effect of different ratios of corn, wheat pollard, and maggot and the length of steaming on the chemical quality of feed and digestibility in chickens. The benefit of the research is to know the effect of different ratios of corn, wheat pollard, and maggot and the duration of steaming on the chemical quality of feed and nutrient utility in chickens. The research hypothesis is that combining corn, wheat pollard, and maggot meal with pressurized steaming will enhance feed chemical quality and nutrient digestibility in chickens.

MATERIALS AND METHODS

Material

The materials used in the study included ground corn, dried maggot, selenium, zinc, monosodium glutamate (MSG), 25 90-week-old laying hens of the Lohman Brown strain weighing 1.71 ± 0.055 kg, 0.2 N HCl, distilled water. Equipment used included a 39L capacity autoclave (All American 75x, US), 16 mesh sieve (Yakuma, Indonesia), blender (National Omega BL-T11A, Indonesia), measuring cup (Owl Plast 500 mL, Indonesia), digital scale (Good Wife SF-400, Japan), and analytical balance (AandD EK-300i, Japan), syringe (Terumo Syringe 60 mL, Philippines), battery cage, drink holder, sprayer (Asena 1000 mL, Indonesia) and excreta container.

Methods

The study used a randomized group design factorial pattern of 2 x 3 treatments with 7 replicates. The first factor was the ratio of feed ingredients, namely L0 (25% corn, 25% wheat pollard, and 50% maggot) and L1 (37.5 corn, 37.5% wheat pollard, and 25% maggot) and the second factor was the steaming time T0 (no steaming), T1 (steaming at 121°C, for 15 minutes) and T2 (steaming at 121°C, for 20 minutes). The combination of each feed treatment is as follows:

L0T0= 25% Corn + 25% wheat pollard + 50% maggot (without steaming)
L0T1= 25% Corn + 25% wheat pollard + 50% maggot (121°C, 15 minutes)
L0T2= 25% Corn + 25% wheat pollard + 50% maggot (121°C, 20 minutes)
L1T0= 37.5% Corn + 37.5% wheat pollard + 25% maggot (without steaming)
L1T1= 37.5% Corn + 37.5% wheat pollard + 25% maggot (121°C, 15 minutes)
L1T2= 37.5% Corn + 37.5% wheat pollard + 25% maggot (121°C, 20 minutes)

Research Procedure

Feed preparation stage: The feed preparation stage begins with grinding dried maggot and then mixed according to the treatment combination. The mixture was steamed in an autoclave pressurized at 1.5 atm with a temperature of 121°C for 15 minutes and 20 minutes. The steamed feed ingredients were then aerated to room temperature. Monosodium glutamate (MSG), zinc and selenium were added as much as 0.25% of the weight of each treatment. MSG, zinc and selenium were added to help the growth and immune system. The amount of mineral addition was adjusted to its maximum level before it was added to the actual poultry ration. The feed that had been mixed evenly was then dried in the sun until the moisture content was 12%. The dried samples were ground and analyzed for SEM-EDX profile and proximate components (dry matter (DM), ash, crude fat, crude protein (CP), crude fiber, nitrogen free extract (NFE)) and gross energy (GE)).

Feed ingredient test of corn, wheat pollard and maggot combination in culled laying hens: Digestibility tests were carried out using the force feeding method on culled laying hens (Lo *et al*., 2020). The study began by satisfying the culled laying hens in all experimental units for 6-8 hours, but they were still given water adlibitum. The next day the chickens were fed by force feeding using a syringe into the cache (Mihrani *et al*., 2021). Feeding was carried out for 2 days with a daily consumption of 60 grams, while total excreta collection was carried out for 3 days. During collection, excreta were sprayed with 0.2 N HCl solutions every 2 hours. HCl will react with NH_3 to become the more stable NH_4Cl (Wang Li, 2015). The reaction serves to prevent N volatilization and maintain its presence. Excreta samples were dried, ground and analyzed. Parameters observed were digestibility value and metabolic energy.

Nutrient digestibility values were calculated based on the formula (Moningkey *et al*., 2019):

$$Crude\ protein\ digestibility\ (CP)(\%) = \frac{(\Sigma\ Feed\ consumption\ (g) \times feed\ CP)-(\Sigma\ excreta\ (g) \times excreta\ CP)}{(\Sigma\ Feed\ consumption\ (g) \times feed\ CP)} \times 100\%$$

$$Crude\ fiber\ digestibility\ (\%) = \frac{(\Sigma\ Feed\ consumption\ (g) \times feed\ crude\ fiber)-(\Sigma\ excreta\ (g) \times excreta\ crude\ fiber)}{(\Sigma\ Feed\ consumption\ (g) \times feed\ crude\ fiber)} \times 100\%$$

$$Crude\ fat\ digestibility\ (\%) = \frac{(\Sigma\ Feed\ consumption\ (g) \times feed\ crude\ fat)-(\Sigma\ excreta\ (g) \times excreta\ crude\ fat)}{(\Sigma\ Feed\ consumption\ (g) \times feed\ crude\ fat)} \times 100\%$$

Apparent Metabolizable Energy (AME) and True Metabolizable Energy (TME) values were calculated based on the formulas of Yuniarti and Wahyono (2015) and Nurrohman *et al*. (2015):

$$AME\ (kcal/g) = \frac{(GEf \times A)-(YEf \times B)}{A}$$

$$TME\ (kcal/g) = \frac{(GEf \times A)-(YEf \times B - YEc \times C)}{A}$$

Notes;
GEf= Gross Energy of the Feed (kcal/kg)
YEf= Energy voided by the Fed chicken (kcal/kg)
YEc= Energy voided by the Unfed chicken (kcal/kg)
A= Weight of the Feed Given (g)
B= Weight of Excreta from Fed chickens (g)
C= Weight of Excreta from Unfed chickens (g)

Data Analysis

Data on the compositional profile of corn, wheat pollard, and maggot meal, obtained using Scanning Electron Microscopy coupled with Energy Dispersive X-ray (SEM-EDX) at 10,000× magnification, were presented descriptively and quantitatively in the form of tables and figures. Proximate composition, gross energy, nutrient digestibility values (crude protein, crude fiber, and crude fat), Apparent Metabolizable Energy (AME), and True Metabolizable Energy (TME) were statistically analyzed using analysis of variance (ANOVA). Significance was determined by comparing the calculated F value to the critical F value at the 95% confidence level. When significant differences were found, Duncan's multiple range test was used for post hoc comparison.

RESULTS AND DISCUSSIONS

Proximate and Gross Energy Content of Combination of Corn, Wheat Pollard and Maggot at Different Heating Ratios and Duration

The effect of steaming time on the combined treatment of corn, wheat pollard, and maggot is shown in Tables 1, 2 and 3. Analysis of variance showed a significant effect ($P<0.05$) on ash, crude fat, and crude fiber. There were no significant differences ($P>0.05$) for dry matter (DM), crude protein (CP), nitrogen free extract (NFE), and gross energy (GE) (Table 1). Variations in steaming duration and the ratio of corn, wheat pollard, and maggot resulted in an increase in ash and crude fiber, but a decrease in crude fat.

The results of analysis of variance also showed a significant effect ($P<0.05$) on crude fat digestibility, apparent metabolizable energy (AME), and true metabolizable energy (TME). There was no significant difference ($P>0.05$) for crude protein digestibility and crude fiber digestibility. The variation of steaming time of 15 minutes and the combination ratio of corn, wheat pollard, and maggot increased the digestibility of crude fat, AME, and TME (Table 3).

The results of the analysis of variance calculation showed that there was no interaction between the ratio of feed ingredients with different steaming times on dry matter ($P>0.05$; Table 1). Factors that affect the value of dry matter are the length of heating and moisture content. This can

Table 1: Nutrient composition of corn, wheat pollard, and maggot combinations with varying ratios and steaming durations.

Variables	Material Level (L)	Steaming Duration (T)			Average (L)
		T0	T1	T2	
DM (%)	L0	91.48 ±0.98	92.18±0.16	92.28±0.47	91.98^{a}±0.53
	L1	91.50 ±0.13	91.03±0.24	91.09±0.14	91.21^{b}±0.17
	Average (T)	91.49 ±0.55	91.60±0.20	91.68±0.27	
Ash (%)	L0	10.67^{b} ±0.32	10.79^{b}±0.14	12.53^{a}±0.19	11.33^{a}±1.04
	L1	8.88^{c}± 0.005	10.51^{b}±0.34	10.82^{b}±0.43	10.07^{a}±1.03
	Average (T)	9.77^{c}± 0.162	10.65^{b}±0.24	11.68^{a}±0.31	
Crude Fat (%)	L0	20.08^{a}±0.37	19.56^{a}±0.20	17.00^{b}±0.27	18.88^{a}±0.28
	L1	10.12^{c}±0.39	10.44^{a}±1.31	10.76^{c}±0.27	10.44^{b}±0.65
	Average (T)	15.15^{a}±0.38	15.00^{a}±0.75	13.88^{b}±0.27	
Crude Fiber (%)	L0	4.32^{b}±0.70	5.73^{a}±0.01	5.08^{a}±0.62	5.04±0.44
	L1	4.14^{b}±0.79	3.09^{c}±0.69	2.74^{c}±0.28	3.32±0.58
	Average (T)	4.41^{a}±0.74	4.23^{a}±0.35	3.91^{b}±0.45	
Crude Protein (%)	L0	22.85±0.19	23.18±0.13	22.90±1.31	22.98^{a}±0.54
	L1	18.15±0.36	17.45±0.04	17.34±0.18	17.65^{b}±0.19
	Average (T)	20.50±0.27	20.32±0.08	20.12±0.74	
NFE (%)	L0	42.04±0.57	40.70±0.35	42.44±1.26	41.73^{b}±0.72
	L1	58.66±0.28	58.48±1.91	58.30±0.58	58.48^{a}±0.93
	Average (T)	50.35±0.42	49.59±1.13	50.37±0.92	
GE (Kcal/kg)	L0	3237.33±18.90	3162±25.06	3131±1.73	3176^{a} ±15.2
	L1	3074.33±109.92	3105.33±72.21	2943.67±30.92	3041^{b}±71.00
	Average (T)	3155.8^{a}±64.4	3133.6^{a}±48.63	3037.3^{b}±16.32	

Notes: Different superscripts indicate significant differences (p<0.05). L0 = 25% corn + 25% wheat pollard + 50% maggot; **L1:** 37.5% corn +37.5% wheat pollard + 25% maggot; **T0:** no steaming; **T1:** steaming at 121°C, for 15 minutes; **T2:** steaming at 121°C, for 20 minutes.

be seen from the average of T0 (91.49%), T1 (91.60%), T2 (91.68%) which experienced an increase in DM during heating. The length of heating causes physicochemical changes due to the heating of starch granules with water until gelatinization. Domnez *et al.* (2021) showed that the autoclave process for 20 minutes can affect the water content due to the release of water from the cell due to the rupture of starch granules. This can be seen from the results of the corn-wheat pollard-maggot profile analysis on SEM. Steaming for 15 minutes showed that the starch granules swelled because the pressure during steaming triggered water absorption. The 20-minute steamed treatment experienced cell damage so that some of the water began to escape and the water content decreased.

After 20 minutes of steaming, the average of T2 (91.68%) was higher than T1 (91.60%). Ayamdoo *et al.* (2015) stated that the length of steaming will cause the water content to decrease and the value of dry matter to increase. Moisture content will affect the decrease in dry matter caused by evaporation. Nilasari *et al.* (2017) evaporation occurs due to the difference in vapor pressure between water in the material and water vapor in the air. The water vapor pressure in the material is generally greater than the water vapor pressure in the air, resulting in mass transfer of water from the material to the air.

Our findings showed that the ash content of each treatment was significantly influenced (P<0.05) in the proximate analysis (Table 1). The result of analysis of variance showed that there was an interaction effect between factor L (ratio of feed ingredients) and factor T (steaming time) on ash content (P<0.05). One of the factors that can affect the increase in ash content value is heating time. This can be seen from treatment L0T0 (10.67%), L0T1 (10.79%), L0T2 (12.53%) which will increase along with the heating time. Zhang *et al.* (2023), heating can cause an increase in ash content. The length of heating can cause an increase in ash content, this is because the longer steaming will affect the value of water content. Bija *et al.* (2022) stated that increasing temperature can cause an increase in ash content; this is because the higher the steaming temperature will cause the water content to decrease. So that the mineral content increases this causes the ash content to increase. The ash content value in Table 1 shows that the average value of treatment T0 (9.77%) is lower than T1 (10.65%) and T2 (11.68%). The heating process causes water evaporation, resulting in a change in the concentration of organic matter and triggering an increase in inorganic matter or ash. This can be seen from the SEM-EDX mineral composition changes found in carbon (C), potassium oxide (K_2O), and zinc oxide (ZnO).

The results of the analysis of variance showed that crude fat content in each treatment was significantly affected ($P < 0.05$) as shown in Table 1. The results of the analysis of variance showed that there was an interaction effect between factor L (ratio of feed ingredients) and factor T (steaming time) on the value of crude fat ($P < 0.05$). One of the factors affecting crude fat is the length of steaming. The length of heating will cause the value of crude fat to decrease. This can be seen from the treatment L0T0 (20.08%), L0T1 (19.56%), L0T2 (17.00%) which decreased. This is in accordance with the results of research by Asmaa *et al.* (2015), the length of time steaming will cause the crude fat content of feed ingredients to decrease due to damage to fat molecules. Damaged fat content can cause a decrease in fat can be caused by high temperature treatment. This is in accordance with the research of Zhang *et al.* (2023) stated that a temperature of 100-110°C will cause hydrolysis of triacylglycerols which will produce free fatty acids which result in the value of fat content. The ratio of feed ingredients affects the value of crude fat; a 50% ratio of maggot has a higher crude fat value than a 25% ratio. This is because maggot has high fat, so the heating process will affect the crude fat. The fat content in BSF prepupae consists of saturated fatty acids and lauric acid (Suyati *et al.*, 2023). Lauric acid in feed can improve the quality of poultry eggs for the better (Heuel *et al.*, 2021).

In present study statistical anlysis showed that the crude fiber content was significantly affected ($P<0.05$) by the treatments (Table 1). The results of the analysis of variance showed that there was an interaction effect between factor L (ratio of feed ingredients) and factor T (length of steaming) on the value of crude fiber ($P<0.05$). Factors that can affect the value of crude fiber are steaming time and temperature. Long steaming will cause the value of crude fiber to decrease. This can be seen from the treatment L1T0 (4.14%), L1T1 (3.09%), L1T2 (2.74%) which decreased along with the length of heating. Chao *et al.* (2022), the higher and longer the steaming temperature will cause fiber content to decrease, so that the feed is partially degraded which can reduce fiber bonds. Heating used at autoclave temperature (121°C) or below the temperature of hemicellulose decomposes, so that the hemicellulose content produced cannot be significantly different, it is not optimal to decompose. Chen *et al.* (2018), steaming with an autoclave below the temperature of hemicellulose decomposes (240-300 °C) results in hemicellulose levels that cannot be significantly different because it is not optimal to decompose. With crude fiber in Table 1, the highest crude fiber value was found in the L0T1 treatment (5.73%) and the lowest value in the L1T2 treatment (2.74%).

The results of the analysis of variance showed that crude protein levels differed significantly among treatments ($P < 0.05$), as presented in Table 1. The results of the analysis of variance showed that there was no interaction effect between factor L (feed ingredient ratio) and factor T (steaming time) on crude protein value ($P>0.05$). The factor that affects the value of crude protein is steaming time. This can be seen from the average T0 (20.50%), T1 (20.32%), T2 (20.12%) decreased along with the length of heating. This is in accordance with Bija *et al.* (2022), the length and temperature of heating can cause protein denaturation, and some proteins are damaged.

Syarif *et al.* (2017) the value of protein can decrease due to one of them because the structure of amino acids changes due to heating. Protein degradation causes the formation of short chain peptides, amino acids and volatile ammonia. The L1T1 treatment (17.45%) experienced a decrease in protein in the L1T2 treatment (17.34%) for 20 minutes. Le *et al.* (2019), the formation of carbonyl compounds from amino acid chains that contribute to protein denaturation, thus affecting protein quality. This is evidenced by the decrease in carbon mineral content (C) from SEM-EDX analysis. Some of the heated treatments had lower carbon content than the non-heated treatments.

The current study showed that the nitrogen-free extract (NFE) differed significantly among treatments ($P < 0.05$), as shown in the proximate analysis results (Table 1). The results of the analysis of variance showed no interaction effect between factor L (ratio of feed ingredients) and factor T (length of steaming) on NFE value ($P>0.05$). Factors that can affect NFE value are related to the increase in other nutrient levels such as crude protein, crude fat and crude fiber (Traughber *et al.*, 2021). The average NFE value in T0 (50.35%), T1 (49.59%), T2 (50.37%). Suryani and Luthfi (2022), the size of NFE is related to crude fiber content. This can be seen from the average crude fiber in T1 (4.23%) which is smaller than T0 (4.41%). Crude fiber content affects crude fiber consumption.

The average NFE value in L0 (41.73%) was lower than L1 (58.48%) due to the ratio of energy source feed ingredients. This is evidenced by the number of starch granules in the SEM illustration of treatment L1 which is more than treatment L0. Treatment L0 (50% maggot) was lower than L1 (25% maggot) also due to changes in the structure of some CP. Amor *et al.* (2021), the heating process with autoclave affects the protein which will cause amine and carbonyl groups to change (Maillard reaction).

In the present study, the gross energy (GE) of each treatment varied significantly ($P < 0.05$) in the proximate analysis (Table 1). The results of the analysis of variance showed that there was no interaction effect between factor L (feed ingredient ratio) and factor T (steaming time) on NFE value. Gross energy value on the average T0 (3155.83%), T1 (3133.67%), T2 (3037.33%) decreased along with the length of heating. Khoirunisa and Sjofjan (2022), the decrease in gross energy value is caused by the temperature and duration of heating by autoclave. The decrease in GE content indicates a decrease in the energy content of feed ingredients. This can be seen from the results of SEM analysis which reflects changes in carbohydrate structure after being heated in an autoclave. The L1T2 treatment showed that the steaming duration was too long, causing amylose and amylopectin to diffuse out due to the breakage of starch granules. Gross energy value correlates with the value of crude fiber content. This can be seen from the average of crude fiber in T1 (4.23%) which is smaller than T0 (4.41%). Crude fiber content affects crude fiber consumption. This is in accordance with the research of Dobos *et al.* (2019); differences in crude fiber values in feed constituents can affect the value of energy available in feed. High crude fiber can last a long time in digestion, thus increasing satiety, so gross energy will be consumed by livestock and processed in the body to produce metabolic energy used for basic living needs and production (Fitasari and Santoso, 2015).

SEM-EDX of Corn, Wheat Pollard and Maggot with Different Ratio and Steaming Time

The results of SEM-EDX analysis of corn, wheat pollard and maggot composition with different steaming levels and duration are shown in Figure 1 and Table 2.

The results presented in Table 2 indicate that steaming treatments caused noticeable changes in the morphology of the feed particles. In the SEM images of treatments L0T0 and L1T0 (without steaming), the starch granules appear small and unexpanded. In contrast, the images of treatments L0T1 and L1T1 (steamed for 15 minutes), as well as L0T2 and L1T2 (steamed for 20 minutes), show starch granules that are more expanded. Notably, the granules in the 20-minute treatments (L0T2 and L1T2) appear more swollen compared to those in the 15-minute treatments (Figure 1).

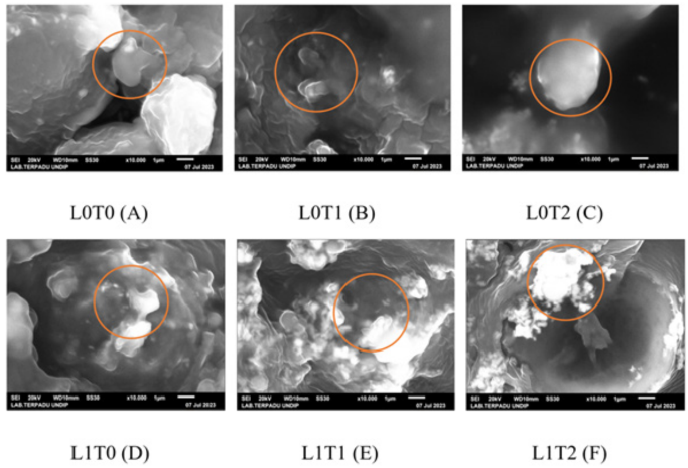

Figure 1: SEM-EDX illustration of feed at 10,000x magnification. **A:** Without steaming, the granules remain unswollen. **B:** Steaming with 15 minutes causes the granules to start swelling. **C:** Steaming with a time of 20 minutes causes the granule to swell even more. **D:** Without steaming the granules remain unswollen. **E:** Steaming with 15 minutes causes the granules to swell. **F:** Steaming with 20 minutes causes the granules to swell even more and then break due to heating.

According to Chen *et al.* (2021), prolonged steaming can cause starch granules to absorb excessive amounts of water, leading to irreversible swelling and reaching the maximum granule expansion. Liu *et al.* (2020) noted that heat-induced gelatinization can cause starch granules to transition into a starch paste, which may eventually form a gel during subsequent storage. The size of the starch granule can increase significantly before it eventually ruptures.

The SEM-EDX method allows for the identification of mineral composition by analyzing both elemental and oxide content, and also provides insights into the physical and chemical properties of these minerals (Julinawarti *et al.*, 2015). Based on the Energy Dispersive X-ray (EDX) analysis presented in Table 2, the mineral composition was dominated by the element carbon (C), ranging from 31.90% to 92.24%. The carbon content increased with longer heating durations, as observed in treatments L0T1 (92.24%) and L0T2 (90.94%). According to Husin and Hasibuan (2020), variations in carbon content can also be influenced by factors such as water content, ash levels, and the presence of volatile substances in activated carbon.

The EDX analysis also showed that the highest zinc oxide (ZnO) content was detected in the L1T1 treatment, reaching 55.93%. Wickramasinghe *et al.* (2020) noted that zinc plays a crucial role in protein and nucleic acid metabolism and functions as a coenzyme in carbohydrate metabolism. Additionally, a reduction in oxygen (O_2) levels was observed in treatments L0T1 and L0T2, which may be attributed to the extended heating duration, as prolonged steaming tends to reduce the oxygen content within the sample.

Table 2: Mineral composition of edx analysis on corn, wheat pollard, and maggot combinations with varying ratios and steaming durations.

Mineral Composition	Material Level (L)	Steaming Duration (T)		
		T0	T1	T2
		---------%--------		
Carbon (C)	L0	89.87	92.24	90.94
	L1	86.97	31.90	80.89
Sodium Oxide (Na_2O)	L0	1.10	2.09	-
	L1	2.03	-	2.80
Magnesium Oxide (MgO)	L0	-	0.26	-
	L1	0.37	-	-
Diphosphorus Pentaoxide (P_2O_5)	L0	-	-	-
	L1	0.97	-	-
Sulfur Trioxide (SO_3)	L0	1.30	2.32	-
	L1	2.17	-	5.18
Chlorin (Cl)	L0	-	-	-
	L1	0.10	-	-
Potassium Oxide (K_2O)	L0	0.51	1.23	0.71
	L1	1.11	0.48	2.68
Calcium Oxide (CaO)	L0	0.23	-	0.13
	L1	-	-	-
Cupric Oxide (CuO)	L0	1.03	-	0.57
	L1	0.78	9.94	0.92
Zinc Oxide (ZnO)	L0	3.96	1.81	5.83
	L1	4.24	55.93	7.53
Tin Dioxide (SnO_2)	L0	-	0.05	-
	L1	-	-	-
Zirconium Dioxide (ZrO_2)	L0	1.81	-	0.74
	L1	1.28	-	-
Aluminum Oxide (Al_2O_3)	L0	0.18	-	-
	L1	-	1.76	-

The highest sodium oxide (Na_2O) content was observed in the L1T2 treatment (2.80%). According to Wickramasinghe *et al.* (2020), sodium plays an important role in maintaining electrolyte balance and supporting the transmission of nerve impulses. Based on the Energy Dispersive X-ray (EDX) analysis in Table 2, calcium oxide (CaO) was present in L0T0 (0.23%) and L0T2 (0.13%) treatments. Quarcoo and Manu (2016) noted that calcium is essential for bone development.

The composition of copper oxide (CuO) decreased with increased heating duration, as seen in the L0T2 treatment (0.57%). This aligns with the findings of Wickramasinghe *et al.* (2020), who reported that copper is essential for enzyme production. Overall, based on the SEM-EDX analysis, steaming for 15 minutes produced optimal results, as it preserved the structural integrity of the material without causing excessive degradation.

Nutrient Digestibility of Corn, Wheat Pollard and Maggot Combination with Different Ratios and Steaming

The results of observations on nutrient digestibility in laying hens fed with combinations of corn, wheat pollard, and maggot meal are presented in Table 3, specifically focusing on the digestibility of crude protein (CP), crude fat, crude fiber, Apparent Metabolizable Energy (AME), and True Metabolizable Energy (TME).

Based on the analysis of variance (ANOVA), there was no significant interaction ($P>0.05$) between the feed ingredient ratios and steaming durations on CP digestibility (Table 3). Individually, the ratio of corn, wheat pollard, and maggot meal had no significant effect on CP digestibility ($P>0.05$); however, steaming time had a significant effect ($P<0.05$). The mean CP digestibility in the T1 treatment (15 minutes of steaming) was significantly higher than in T2 (20 minutes of steaming) and T0 (no steaming). This suggests that moderate steaming enhances CP digestibility, likely due to partial breakdown of complex proteins or anti-nutritional factors. However, excessive heating may degrade protein quality or denature enzymes, ultimately reducing digestibility.

Saroh *et al.* (2019) the digestibility value of feed CP is influenced by the length of heating and is caused by a combination of chemical and physical (physico-chemical) treatments that provide changes in the content of feed substances. Arifudin *et al.* (2023) stated that maggot feed steamed at 121 °C for 20 minutes had the highest CP decrease compared to steaming for 10 and 15 minutes, so that CP was digested less. Saraswati *et al.* (2017) a protein source feed ingredient is said to be of good quality if the percentage of digested protein is high, due to the presence of essential amino acids that can be utilized by livestock. Based on the data in Table 3, it can be seen that the L1T1 treatment has the highest crude protein digestibility value. This shows that the ratio of 37.5% corn, 37.5% wheat pollard, and 25% maggot steamed for 15 minutes is able to change the CP structure of the material to be more digestible and has not experienced excessive damage.

The analysis of variance showed that there was no significant interaction ($P>0.05$) between the ratio of feed ingredients and steaming duration on crude fiber digestibility (Table 3). Separately, the ratio of corn, wheat pollard, and maggot meal had no significant effect on crude fiber digestibility ($P>0.05$). However, steaming time significantly

Table 3: Digestibility of crude protein, crude fat, crude fiber, ame, tme, and digesta rate in late-phase laying hens fed a combination of corn, wheat pollard, and maggot with varying ratios and steaming durations.

Variables	Material Level (L)	Steaming Duration (T)			Average (L)
		T0	T1	T2	
Crude Protein Digestibility (%)	L0	64.84 ±0.56	70.16 ±0.36	65.41 ±1.18	66.80 ±2.62
	L1	65.10 ±3.18	72.09 ±1.00	67.67 ±1.01	68.29 ±3.52
	Average (T)	64.97^{c} ±2.04	71.12^{a} ±1.26	66.54^{b} ±1.58	
Crude Fiber Digestibility (%)	L0	69.56 ±5.51	83.47 ±2.08	73.50 ±2.98	75.51 ±7.03
	L1	71.26 ±6.42	85.23 ±4.10	81.24 ±1.79	79.24 ±7.36
	Average (T)	70.41^{c} ±5.43	84.35^{a} ±3.06	77.37^{b} ±4.78	
Crude Fat Digestibility (%)	L0	87.12^{c} ±0.58	88.66^{b} ±0.29	87.37^{c} ±0.65	87.72^{b} ±0.85
	L1	87.22^{c} ±0.17	90.39^{a} ±0.73	88.61^{b} ±0.15	88.74^{a} ±1.43
	Average (T)	87.17^{c} ±0.39	89.53^{a} ±1.07	87.99^{b} ±0.80	
AME (Kcal/kg)	L0	2352.72^{c} ± 34.01	2658.84^{a} ± 14.02	2528.84^{b} ± 37.44	2513.46^{b} ± 135.62
	L1	2500.37^{b} ± 66.60	2715.89^{a} ± 38.43	2545.47^{b} ± 13.56	2587.24^{a} ± 105.60
	Average (T)	2426.54^{c} ± 93.68	2687.37^{a} ± 40.57	2537.16^{b} ± 26.78	
TME (Kcal/kg)	L0	2620.16^{c} ± 34.01	2926.29^{a} ± 14.02	2796.29^{b} ± 37.44	2780.92^{b} ± 135.62
	L1	2767.8^{b} ± 66.60	2983.34^{a} ± 38.43	2812.92^{b} ± 13.56	2854.69^{a} ± 105.60
	Average (T)	2693.99^{c} ± 93.68	2954.81^{a} ± 40.57	2804.60^{b} ± 26.78	
Rate of Digesta (minute)	L0	314.00 ± 9.84	386.00 ± 7.00	335.00 ± 26.88	345.00^{b} ± 35.29
	L1	336.00 ± 11.53	396.00 ± 15.13	361.00 ± 17.52	364.33^{a} ± 29.13
	Average (T)	325.00^{c} ± 15.40	391.00^{a} ± 11.88	348.00^{b} ± 24.80	

Description: Different superscripts in the same row indicate significant difference (p<0.05%). **L0:** 25% corn + 25% wheat pollard + 50% maggot; **L1:** 37.5% corn + 37.5% wheat pollard + 25% maggot; **T0:** no steaming; **T1:** steaming at 121°C, for 15 minutes; **T2:** steaming at 121°C, for 20 minutes.

affected crude fiber digestibility (P<0.05). This suggests that steaming can improve crude fiber digestibility, but prolonged heating may have the opposite effect. Utama *et al.* (2022) reported that steaming at 121°C for 15 minutes reduced crude fiber content. Similarly, Liu *et al.* (2020) explained that the reduction in crude fiber during extended steaming may be due to the breakdown of cellulose and hemicellulose bonds into simpler sugars. Additionally, crude fiber digestibility is influenced by the chitin content in maggot meal. Steaming may alter the structure of chitin, making it more porous and brittle, thereby improving digestibility. Sipayung *et al.* (2015) also noted that thermal processing can disrupt cell structures, leading to a reduction in crude fiber content and changes in its digestibility.

According to the data presented in Table 3, the L1T1 treatment (37.5% corn, 37.5% wheat pollard, and 25% maggot steamed for 15 minutes) resulted in the highest crude fiber digestibility. This indicates that this specific combination and processing time effectively modified the crude fiber structure, making it softer and more easily digestible.

The results presented in Table 3 showed that there was a significant interaction between the ratio of feed ingredients and steaming duration on crude fat digestibility (P<0.05). Separately, the ratio of corn - wheat pollard - maggot and steaming time had a significant effect on crude fat digestibility (P < 0.05). The L1T1 treatment had higher crude fat digestibility than the other treatments. It is suspected that the low maggot ratio and steaming time of 15 minutes can increase crude fat digestibility. Puja *et al.* (2023) stated that the higher the percentage of crude fat digestibility, the better the metabolism of the livestock body. Lehmali and Jafari (2019) argue that heat processing methods can affect nutrient levels and increase crude fat digestibility.

The L0T0 treatment had the lowest crude fat digestibility compared to other treatments. This is thought to be due to the high maggot ratio and no steaming. Priyadi *et al.* (2016) the higher the maggot content, the higher the chitin content in the feed, so that chitin will bind the nutrients needed by livestock and digestibility is low. Feed that is not steamed, the chitin content will inhibit the absorption of feed nutrients. Safir *et al.* (2020) steaming aims to reduce levels of anti-nutritional substances in feed raw materials and increase feed digestibility. Based on the data in Table 3, it can be seen that the L1T1 treatment has the highest crude fat digestibility value. This shows that the ratio of 37.5% corn, 37.5% wheat pollard, and 25% maggot steamed for 15 minutes is able to increase crude fat digestibility.

The results of analysis of variance presented in Table 3 showed that different ratios of feed ingredients and steaming time had significant effect on AME utility (P<0.05). Separately, the ratio of corn - wheat pollard - maggot and steaming time had a significant effect on AME utility (P<0.05). The L1T1 treatment had higher AME utility than the other treatments. Low maggot ratio and steaming time of 15 minutes can increase AME utility. This is thought to be influenced by nutrient digestibility. Pramudia *et al*. (2016) stated that the metabolic energy of feed is influenced by the increase in crude fat digestibility, crude protein digestibility and crude fiber digestibility which are energy sources. Increasing the digestibility of nutrients and other energy sources can increase the value of corrected metabolic energy. Utama *et al*. (2017) steaming with a long time can increase the resistant starch content in pollard by 8.75 + 1.06% to 15.40 + 1.5%. However, the retrogradation process makes the starch difficult to digest. The L0T0 treatment had the lowest AME value compared to the other treatments. The high maggot ratio and no steaming had a high chitin content, which inhibited the absorption of feed nutrients. Safir *et al*. (2020) steaming aims to reduce levels of anti-nutritional substances and increase feed digestibility, if not steamed, the absorption of nutrients will be disrupted. Based on the data in Table 3, it can be seen that the L1T1 treatment has the best AME value. This shows that the ratio of 37.5% corn, 37.5% wheat pollard, and 25% maggot steamed for 15 minutes is able to change the structure of the energy source material and increase the digestibility of the material.

Our present study showed that the different ratios of feed ingredients and the duration of steaming have a statistically significant effect on TME utility (P < 0.05) as shown in Table 3. Separately, the ratio of corn - wheat pollard - maggot and steaming time had a significant effect on TME utility (P<0.05). The L1T1 treatment had higher TME utility than the other treatments. It is suspected that the low maggot ratio and steaming time of 15 minutes can increase TME utility. Barzegar *et al*. (2020) stated that factors that affect metabolic energy consist of ration energy content, feed consumption, livestock breed and age and the ability of livestock to metabolize in the body. Yang *et al*. (2020) stated that the higher TME value is due to the endogenous energy value being taken into account, while the AME value of endogenous energy value is not taken into account. The L0T0 treatment had the lowest TME utility compared to other treatments. High maggot ratios and no steaming have high chitin content, which inhibits the absorption of feed nutrients. Saroh *et al*. (2019) feed that is not heated by aoutoclave does not change the composition of feed substances and anti-nutritional substances will not decrease. Based on the data in Table 3, it can be seen that the L1T1 treatment has the best TME value. This shows that the ratio of 37.5% corn, 37.5% wheat pollard, and 25% maggot steamed for 15 minutes is able to change the physical-chemical structure while increasing the digestibility of the material.

Our results showed that there was no effect of treatments and steaming time on digesta rate (P>0.05), but separately the level of corn, wheat pollard, and maggot, as well as steaming time had a significant effect on digesta rate (P<0.05; Table 3). The mean of L1 had a higher digesta rate than L0. Providing a low level of maggot, the feed has a low crude fiber content, which will slow down the digesta rate. The longer the feed rate, the better the digestion of the feed, because the absorption of nutrients is more optimal (Saraswati *et al*., 2017). Low-fiber diets can increase the digestibility of protein, gross energy (GE), and dry matter compared with high-fiber diets (Wang *et al*., 2023).

The mean of T1 was significantly different and higher than T2 and T0. Liu *et al*. (2020) stated that steaming can cause the surface structure of the feed to be relatively loose, due to the breakdown of cellulose and hemicellulose bonds, resulting in simple carbohydrates. Steaming can reduce the crude fiber content, so that the digest rate increases, but if steaming is too long the feed will turn into a gel. Utama *et al*. (2017) in steaming the gelatinization process occurs due to the entry of water into the cell, causing starch granules to swell, the longer steaming can cause the release of water from the cell as a result of the rupture of starch granules. Based on the analysis of the best digesta rate, it is found in the L1T1 treatment (396 minutes), because it has the highest value.

CONCLUSIONS AND RECOMMENDATIONS

Based on the findings of this study, it can be concluded that steaming for 15 minutes effectively enhances the digestibility of crude fat, Apparent Metabolizable Energy (AME), and True Metabolizable Energy (TME). The optimal treatment was a feed formulation consisting of 37.5% corn, 37.5% wheat pollard, and 25% maggot meal, steamed for 15 minutes. This combination maintained desirable levels of dry matter (DM), crude protein (CP), nitrogen-free extract (NFE), and gross energy (GE); increased ash and crude fat content; and reduced crude fiber content. Additionally, this treatment preserved the digestibility of crude protein and crude fiber while significantly improving the digestibility of crude fat, AME, and TME. The optimized feed had the following composition: DM (91.03%), ash (10.51%), crude fat (10.44%), CP (17.45%), crude fiber (3.09%), NFE (58.48%), and gross energy (3105.3 kcal/kg). It resulted in a CP digestibility of 72.09%, crude fiber digestibility of 85.23%, crude fat digestibility of 90.39%, AME of 2715.89 kcal/kg, and TME of 2983.34 kcal/kg.

Steaming for 15 minutes proved to be the most effective processing method, enhancing the chemical quality and utilization of the feed ingredients without compromising their nutritional integrity. These results provide a foundation for further development and evaluation of this feed formulation in commercial poultry diets.

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NOVELITY STATEMENT

This study provides the latest scientific information on the combination of corn and wheat pollard as an energy source feed ingredient and maggot as a protein source feed ingredient processed through steaming with an autoclave at a temperature of 121 pressure 1.5 atm. It is hoped that heating can increase the utility of the combination of corn and maggot so that it can be used as a functional poultry feed.

AUTHOR'S CONTRIBUTIONS

Cahya Setya Utama and Bambang Sulistiyanto: Provided guidance on research topics, manuscript preparation, and finalization of the scientific manuscript.
Dilla Mustika Kharisma Putri, Siti Mukaromah and Rahman Wijaya: Conducted the research, performed data processing, and contributed to manuscript preparation.
Nadya Marcelina Cinderawati: Supervised the fieldwork, conducted research and data processing, participated in manuscript preparation, and contributed to editing the final version of the manuscript.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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