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Original Article

Effects of Dietary Composite Bakery Waste on Productive Performance and Egg Quality Traits of Laying Hens in a Temperate Environment

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ABSTRACT

Introduction: High costs of conventional feed ingredients, along with climate change impacting crop growth, result in shortages of conventional feeds. The present study aimed to determine the effects of different levels of composite bakery waste (CBW) as a maize replacement on the productive performance and egg quality of laying hens in a temperate environment.
Materials and methods: A total of 150 laying hens aged 26 weeks, with an average body weight of 1.704 kilograms, were randomly allocated to five treatment groups, with three replicates of ten chickens each. The CBW was air-dried, ground, and analyzed for proximate composition, then replaced with maize in laying hens' diets at levels of 0% (T1), 5% (T2), 10% (T3), 15% (T4), and 20% (T5). The feeding trial duration was 49 days. Productive performance, such as body weight, mortality, and egg quality indices, including egg weight, shell weight, shell thickness, yolk height, yolk index, yolk color, albumen length, albumen width, albumen height, albumen weight, albumen index, and Haugh unit of the experimental laying hens, was determined at alternate weeks (weeks 1, 3, 5, 7), except hen-day egg production, which was recorded daily.
Results: The CBW contained 93.17% dry matter, 5.67% crude protein, 0.24% crude fiber, 0.31% ether extract, 83.30% nitrogen-free extract, 0.29% calcium, 0.53% phosphorus, and 3192.43 kcal/kg metabolizable energy. Dietary CBW had no significant effect on final body weight, hen-day egg production, or mortality. Dietary CBW demonstrated a significant positive correlation with eggshell thickness across all treatment groups. Adding CBW demonstrated a positive, statistically significant correlation with albumen length in T4 compared to other groups. However, including CBW did not significantly affect yolk length, yolk height, yolk index, yolk color, albumen width, albumen height, albumen weight, or albumen index across all treatment groups.
Conclusion: The current findings suggest that CBW can serve as a substitute for maize in laying-hen diets. Shell thickness increased with CBW at 15% and 20% inclusion levels and did not adversely affect productive performance and egg quality traits. Albumen length was the only internal trait affected, increasing significantly at the 15% CBW replacement of maize.

1. Introduction

Animal products provide vital nutrients, including high-quality proteins, vitamins, and minerals such as iron and zinc. Animal agriculture offers employment and income to millions globally. Livestock farming sustains farmers, herders, and workers involved in processing, transportation, and retailing of animal products[1]. In many developing countries, such as Lesotho, Nigeria, and Kenya, livestock is an important agricultural industry that empowers vulnerable households to escape poverty and build long-term financial stability. Farm animals produce valuable by-products that have economic and environmental benefits[2]. Manure, for example, is a natural fertilizer that improves soil health and crop yield[1]. Animal products are rich in essential nutrients that are either absent or present in smaller amounts in plant-based feeds. Animal products are abundant sources of essential nutrients including methionine, lysine, threonine, and tryptophan, as well as calcium, phosphorus, and vitamin B12, which are comparatively limited in plant-based feeds[1].

Animal protein sources, such as eggs, play a significant role in human health. Animal protein sources supply essential amino acids in the proportions the human body requires. These amino acids are vital for muscle growth, repair, and

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maintenance[3]. Animal-derived protein generally offers greater nutritional value than plant-based protein, which can aid appetite regulation and support weight management[4]. Livestock require adequate, balanced levels of macronutrients such as fiber, non-fiber carbohydrates, proteins, and lipids, along with micronutrients including minerals and vitamins, all of which interact synergistically to influence the growth, development, and overall health of livestock and poultry[5]. Adequate protein intake is essential for preserving muscle mass and strength, especially in older animals[2]. As a result, optimal human growth, development, and health require appropriate consumption of high-quality animal protein[3]. Poultry diets are often costly because they rely on conventional feedstuffs also used for human consumption; therefore, there is a need to explore readily available, less expensive agro-industrial by-products that can be used as animal feed. The present study aimed to evaluate the effects of different levels of composite bakery waste (CBW) as a replacement for maize on the productive performance in laying hens.

2. Materials and Methods

2.1. Ethical approval

The study proposal and protocol were presented and approved by the Departmental Board of the National University of Lesotho on March 5, 2025.

2.2. Animals and study design

A total of 150 Hy-Line brown laying hens aged 26 weeks, with an average body weight of 1.704 kg, were used in a 7-week feeding trial. The chickens were obtained from the Grange, Almur Smit Pluimvee company in the Republic of South Africa. The study was conducted at the National University of Lesotho, Roma, Lesotho (Longitude 27° 43′13.79″E and Latitude 29 ° 27′1.19″S)[6], from April to June 2025. Laying hens were randomly allocated into five groups based on similar body weight. The experiment used a completely randomized design, and each group was randomly assigned to one of the experimental diets. Each treatment had three replicates, with ten laying hens per replicate. The treatment groups included a basal diet without CBW as the control (T1), whereas T2, T3, T4, and T5 contained 5%, 10%, 15%, and 20% CBW as a maize substitute, respectively (Table 1). The treatment groups were designed and modified based on the study of Olafadehan et al.[7]. The laying hens were raised in a 3-tier battery cage system (0.5 × 0.36 × 0.24 m), with 3 hens per compartment, in a three-quarter-walled, well-aerated house. During the feeding trial, the prevailing temperature and relative humidity ranged from -2°C to 20.3°C (environmental temperature) and 67-49%, respectively. Supplementary heating was supplied via infrared brooders, and adjustable curtains were employed to close the open side of the house during nighttime, ensuring that the internal temperature remained above 15°C. Laying hens had unrestricted access to feed and fresh drinking water via automatic nipple drinkers. Laying hens were fed twice daily at 07.00 and 17.00 to avoid overload of the linear feeders. The house was cleaned daily, while manure was removed weekly. Biosecurity measures were strictly followed according to Chi Farms Limited guidelines to ensure a disease-free trial[8]. The chickens had already been vaccinated against Gumboro disease at day of age (HVT-Gumboro, Merial, Lyon, France), infectious bursal disease at day 14 (IB4/91, MSD, USA and Canada), and Newcastle disease at weeks 4, 12, and 16 of age (ND Clone 30, MSD TRT/SHS, Hipra, Spain) before the start of the experimental trial. Chickens were vaccinated against *Mycoplasma gallisepticum* at week 6 (FVA x MG Avipro, USA) and *Salmonella Gallinarum* at weeks 8, 10, and 14 (MSD, Europe). Visual observation of the chickens was conducted daily for health monitoring.

Table 1. Dietary ingredients of composite bakery waste in 26-week-old laying hens during a 7-week feeding trial

	Experimental diets				
Feed ingredients (%)	**T1**	**T2**	**T3**	**T4**	**T5**
Maize	60.25	55.25	50.25	45.25	40.25
Soybean meal	27.00	27.00	27.00	27.00	27.00
Bakery waste	0	5	10	15	20
Wheat bran	7.50	7.50	7.50	7.50	7.50
Sawdust	2.00	2.00	2.00	2.00	2.00
Feed lime[1]	2.50	2.50	2.50	2.50	2.50
Layer micro ingredients[2]	0.45	0.45	0.45	0.45	0.45
Common salt	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00
Chemical analysis					
Crude protein (%)	18.15	18.06	17.97	17.88	17.79
Crude fiber (%)	5.01	4.95	4.80	4.84	4.79
Metabolizable energy[3] (kcal/kg)	2737.99	2733.54	2729.09	2724.65	2720.20
Lysine (%)	0.94	0.93	0.93	0.92	0.91
Methionine (%)	0.33	0.32	0.32	0.31	0.30
Calcium (%)	1.10	1.11	1.12	1.12	1.13
Phosphorus (%)	0.49	0.49	0.50	0.51	0.52

T1: Diet containing 0% composite bakery waste, T2: Diet containing 5% composite bakery waste, T3: Diet containing 10% composite bakery waste, T4: Diet containing 15% composite bakery waste, T5: Diet containing 20% composite bakery waste. [1]Feed lime: Calcium: 320 g/kg, fluorine: 1 g/kg, aluminum: 20 g/kg. [2]Layer micro medicated: Lysine: 40 g/kg, methionine: 30 g/kg, moisture: 120 g/kg, fibre: 0 g/kg, calcium: 300 g/kg, phosphorus: 100 g/kg, salt: 164 g/kg, cobalt: 25 mg/kg, copper: 500 mg/kg, Iodine: 50 mg/kg, Iron: 2000 mg/kg, manganese: 4500 mg/kg, selenium: 10 mg/kg, zinc: 4500 mg/kg, vitamin B1: 20 mg/kg, vitamin B2: 150 mg/kg, vitamin B6: 100 mg/kg, folic acid: 25 mg/kg, vitamin B12: 1 mg/kg, vitamin E: 500 mg/kg, choline: 8000 mg/kg, Niacin: 1000 mg/kg, Pantothenic acid: 250 mg/kg, vitamin K: 100 mg/kg, Biotin 2: mg/kg, Phytase Enzyme: 3000 mg/kg, vitamin A: 0.3 mill IU/kg, vitamin D3: 0.1 mill IU/kg. [3]Metabolizable energy = (37 × crude protein%) + (81.8 × ether extract%) + (35.5 × nitrogen-free extract%)

2.3. Composite bakery waste and experimental diets

The CBW was sourced from a popular bakery in Maseru, Lesotho. The CBW was completely air-dried immediately after collection to eliminate moisture and prevent mold infestation. About 70 kg of CBW was collected and air-dried, ground, and mixed with other feed ingredients, replacing maize at graded levels of 0%, 5%, 10%, 15%, and 20% to obtain experimental diets T1, T2, T3, T4, and T5, respectively. The laying hen diet was balanced according to National Research Council Nutrient Requirements of Poultry guidelines (NRC)[9]. The feed ingredients for feed compounding and the gross composition of the experimental diets are presented in Table 1.

2.4. Data collection

Data were collected when the hens were 26 weeks old, at the start of the feeding trial. Egg production data were recorded daily from week 1, while body weight was measured at alternate weeks. Three eggs were randomly collected at alternate weeks (1, 3, 5, 7) on Wednesdays and Sundays from each replicate (n =18/treatment) to determine internal and external characteristics in the Animal Science Laboratory, National University of Lesotho, Lesotho. Mortality was recorded and expressed as a percentage of the chickens' initial population. The external and internal egg indices were determined using the methods recommended by Haugh[10]. The Hen-day egg production was recorded daily from each replicate and expressed as a percentage using Formula 1[7]. The following internal and external egg characteristics were determined weekly. Albumen height, Albumen weight, Haugh unit (HU), Albumen index, Albumen length, yolk height, yolk diameter, yolk weight, yolk index, egg weight, shell thickness, and shell weight were measured weekly. Albumen height was measured by cracking the egg open on a white flat surface, and the micrometer screw gauge was used to record the height of the albumen at approximately 1 cm from the egg yolk. Haugh unit (HU) was calculated using Formula 2[7]. Albumen weight was calculated using Formula 3[7]. The albumen index was determined using Formula 4[7]. Yolk height was measured with a Vernier caliper from the base to the top of the yolk. Yolk diameter was measured with a Vernier caliper at the widest point of the intact yolk. Yolk weight was determined after separating the egg white from the yolk, placing the yolk in a tared bowl, and weighing it on a precision scale (model XY10002C) with an accuracy of 0.01g. The yolk index was determined using Formula 5[7]. Egg weight was measured using a precision electronic weighing balance Model XY10002C with a sensitivity of 0.01 g. Shell thickness was assessed with a micrometer screw gauge to an accuracy of 0.01 mm at three points (broad end, equatorial plane, and narrow end) after oven-drying the shell for 24 hours at 105°C; the average value was then calculated. Shell weight was ascertained after removing the inner membrane, oven-drying for 24 hours at 105°C, and cooling in a desiccator. Yolk color was determined using the DSM yolk color fan (yolk fan), which was placed on a white, non-reflective surface, observed vertically from above, and matched to the fan accordingly.

$$\text{Hen-day egg production (\%)} = \frac{\text{Number of eggs produced in a day}}{\text{Number of pullets per replicate}} \times 100 \quad \text{(Formula 1)}$$

$$\text{HU} = 100 \log (h - 1.7w^{0.37} + 7.6)^{7} \quad \text{(Formula 2)}$$

Where HU means Haugh unit, h is the height of albumen (in millimeters), and w is the weight of the egg (in grams)

$$\text{Albumen weight} = \text{Egg weight} - (\text{shell weight} + \text{yolk weight}) \quad \text{(Formula 3)}$$

$$\text{Albumen index} = \frac{\text{Albumen height}}{\text{Albumen length} + \text{Albumen width}} \times 100 \quad \text{(Formula 4)}$$

Where the albumen length was measured using a Vernier caliper from one end to the other point of the spread-out albumen, while the width was measured using a Vernier caliper at the widest point perpendicular to the albumen length.

$$\text{Yolk index} = \frac{\text{Yolk height}}{\text{Yolk diameter}} \quad \text{(Formula 5)}$$

2.5. Chemical analysis

The proximate composition of CBW was determined using the standard methods of AOAC[11], recommended by the Association of Official Agricultural Chemists, and the energy content of the bakery waste and diets were calculated according to the methods of Pauzenga[12]. Calcium and phosphorus were determined using the procedure of Zaklouta et al.[13].

2.6. Data analysis

The collected data were entered into a Microsoft Excel spreadsheet and transferred to SPSS[14] version 20 for statistical analysis. All analyses used one-way analysis of variance, and means were separated using least significant difference (LSD). A p-value of less than 0.05 was considered significant ($p \leq 0.05$). Data were presented as mean ± standard error of mean (SEM). Pearson correlation was used to measure the linear strength and direction between two continuous variables.

3. Results

3.1. Chemical composition of composite bakery wastes

The chemical composition of CBW used in feed formulation was 93.17% dry matter, 6.83% moisture, 3.15% ash, 0.31% ether extract, 0.24% crude fiber, 5.67% crude protein, and 83.30% nitrogen-free extract. Phosphorus and calcium levels were 0.53% and 0.29%, respectively. The phosphorus and calcium levels reported in this study were for the bakery waste, not the diet used. The calculated metabolizable energy (ME) of the CBW was 3192.43 Kcal/kg.

3.2. Performance of laying chickens

All experimental diets (T1-T5) exhibited no statistically significant impact on initial body weights (ranging from 1636 to 1746 g), final body weights (ranging from 1753.33 ± 37.12 g to 1833.33 ± 23.33 g), hen-day egg production rates (from 68.47 ± 2.72% to 74.20 ± 1.62%), and mortality rates ($p > 0.05$; Table 2). Final body weight of laying hens across all treatments positively correlated with dietary CBW ($r = 0.19$), whereas hen-day egg production demonstrated a negative correlation ($r = -0.16$) with dietary CBW. Mortality had a negative correlation with dietary CBW ($r = -0.38$).

Table 2. Effects of composite bakery waste on the growth performance of laying hens at 26-33 weeks of age

	Experimental diets						
Indices	**T1**	**T2**	**T3**	**T4**	**T5**	**r**	**P-value**
Initial body weight (g)	1636.67 ± 65.66	1730.00 ± 15.28	1730.00 ± 10.00	1676.67 ± 31.80	1746.67 ± 29.06	-	0.24
Final body weight (g)	1753.33 ± 37.12	1833.33 ± 23.33	1820.00 ± 10.00	1763.33 ± 17.64	1820.00 ± 17.32	0.19	0.10
Hen-day egg production (%)	71.66 ± 2.21	70.20 ± 4.20	74.20 ± 1.62	71.93 ± 1.86	68.47 ± 2.72	-0.16	0.65
Mortality (%)	*3.33 ± 3.33	0.00	0.00	0.00	0.00	-0.38	0.45

T1: Diet containing 0% composite bakery waste, T2: Diet containing 5% composite bakery waste, T3: Diet containing 10% composite bakery waste, T4: Diet containing 15% composite bakery waste, T5: Diet containing 20% composite bakery waste, r: correlation coefficient, P-value: Probability at the 5% level of significance. *: only one hen died in T1.

3.3. External and internal egg indices

The effects of dietary CBW on the external and internal egg indices are presented in Table 3. Shell thickness varied significantly in T4 and T5 (both 0.35 ± 0.00 mm) compared to T1, T2, T3 all of which have shell thickness of 0.34 ± 0.01 mm ($p < 0.05$), while egg weight (60.16 g to 60.77 g) and shell weight (5.18 g to 5.32 g) did not differ significantly in all the groups ($p > 0.05$). Shell thickness ranged from 0.33 mm (T3) to 0.35 mm (T4 and T5) and demonstrated a positive correlation with CBW ($r = 0.47$). T4 significantly increased albumen length compared to other groups ($p < 0.05$). The values for albumen length ranged from 72.55 to 74.55 mm. The other internal egg parameters, namely yolk length (39.08 - 39.78 mm), yolk diameter (36.12 - 36.81 mm), yolk weight (14.84 - 15.05 g), yolk height (13.95-14.24 mm), albumen width (62.23-63.57 mm), albumen height, (8.76-8.79 mm), albumen weight (40.30-40.64 g) albumen index (6.28-6.48), yolk index, yolk color, and Haugh unit (92.63- 93.48), did not vary significantly across all the treatment groups ($p > 0.05$). The Haugh unit ranged from 92.63 to 93.48, and yolk color remained consistent at 7.00 across all treatment groups. Yolk length ($r = 0.33$), yolk diameter ($r = 0.56$), yolk weight ($r = 0.29$), yolk height ($r = 0.12$), yolk color ($r = 0.00$), and albumen length ($r = 0.30$) had a positive correlation with the dietary CBW, but were non-significant across all treatment groups. Albumen width ($r = -0.07$), albumen height ($r = -0.22$), albumen weight ($r = -0.22$), yolk index ($r = -0.13$), albumen index ($r = -0.21$), and Haugh unit ($r = -0.23$) had a non-significant negative correlation with the dietary CBW.

Table 3. Effects of composite bakery waste on external and internal egg indices of laying hens at 26-33 weeks of age

	Experimental diets						
Parameters	**T1**	**T2**	**T3**	**T4**	**T5**	**r**	**P value**
Egg weight (g)	60.77 ± 0.34	60.69 ± 0.35	60.16 ± 0.16	60.49 ± 0.27	60.52 ± 0.32	-0.22	0.65
Shell weight (g)	5.30 ± 0.02	5.32 ± 0.03	5.18 ± 0.10	5.23 ± 0.08	5.21 ± 0.09	-0.33	0.61
Shell thickness (mm)	0.34 ± 0.01^{b}	0.34 ± 0.00^{b}	0.33 ± 0.00^{b}	0.35 ± 0.00^{a}	0.35 ± 0.00^{a}	0.47	0.05
Yolk height (mm)	14.07 ± 0.10	14.13 ± 0.07	13.98 ± 0.20	13.95 ± 0.07	14.24 ± 0.07	0.12	0.41
Yolk index	0.39 ± 0.01	0.39 ± 0.00	0.38 ± 0.00	0.38 ± 0.00	0.39 ± 0.01	-0.13	0.42
Yolk color	7.00 ± 0.00	7.00 ± 0.00	7.00 ± 0.33	7.00 ± 0.00	7.00 ± 0.00	0.00	0.45
Albumen length (mm)	72.99 ± 0.41^{b}	72.55 ± 0.35^{b}	73.34 ± 0.38^{b}	74.55 ± 0.56^{a}	72.93 ± 0.34^{b}	0.30	0.05
Albumen width (mm)	62.79 ± 0.33	62.73 ± 0.05	62.65 ± 0.44	63.57 ± 0.48	62.23 ± 0.21	-0.07	0.16
Albumen height (mm)	8.76 ± 0.06	8.79 ± 0.09	8.60 ± 0.03	8.64 ± 0.03	8.74 ± 0.08	-0.22	0.27
Albumen weight (g)	40.64 ± 0.23	40.42 ± 0.50	40.40 ± 0.23	40.36 ± 0.26	40.30 ± 0.31	-0.22	0.96
Albumen index (%)	6.48 ± 0.05	6.46 ± 0.11	6.33 ± 0.02	6.28 ± 0.07	6.48 ± 0.07	-0.21	0.21
Haugh unit	93.38 ± 0.35	93.48 ± 0.42	92.63 ± 0.18	92.73 ± 0.25	93.25 ± 0.48	-0.23	0.36

T1: Diet containing 0% composite bakery waste, T2: Diet containing 5% composite bakery waste, T3: Diet containing 10% composite bakery waste, T4: Diet containing 15% composite bakery waste, T5: Diet containing 20% composite bakery waste, r: correlation coefficient. ^{a,b} Means with different superscript letters in the same row are significantly different ($P < 0.05$).

4. Discussion

4.1. Chemical composition of composite bakery wastes

The bakery waste used in the feed formulation contained 93.17% dry matter, and this result was similar to the 91.00-100.00% level found by Macgregor[15]. Dry matter ensures an accurate nutrient supply, which helps hens consume the nutrients needed for growth and egg production[16]. Moisture in feed is crucial for diet palatability, but it should be maintained at low levels to avoid microbial growth and mycotoxin contamination, as reported by Jalilzadeh et al.[17], which was consistent with the present results. Ash content in CBW was higher than the 1.83% reported by Al-Tulaihan et al.[18]. Ash represents the total mineral matter in feed after complete combustion of organic material, and these minerals are crucial for eggshell quality and egg production[19]. Ash content is crucial for assessing feed quality because it directly dictates the laying hens' productive performance and eggshell strength, ensuring the diet has the required mineral balance for optimal egg formation[20]. The ether extract content of CBW was lower than 1.8% reported by Melini et al.[21]. Perez-Bonilla et al.[22] observed that the ether extract had no negative impact on the performance and egg quality of laying hens, which was consistent with the present results, in which dietary inclusion of CBW had no adverse effect on the overall performance and egg quality of the laying hens. The CBW fiber level in the present study was higher than the 0.18% reported by Al-Tulaihan et al.[18]. Crude fiber is essential for digestive tract health and helps reduce cannibalism in laying hens[23]. Composite bakery waste contained 5.67% crude protein, which was lower than the 11.34% and 7% reported by Al-Tulaihanet al.[18] and Chauhan et al.[24], respectively. The amino acid balance is necessary for normal growth, and dietary protein supports normal growth in laying hens[25]. Dietary protein provides amino acids necessary for tissue development, feather growth, and continuous egg formation, which helps hens efficiently convert nutrients into egg mass and high-quality albumen to optimize laying rates[7]. The nitrogen-free extract content of CBW was 83.30%, higher than the 66.25% reported by Nwosu et al.[26]. Variation in nitrogen-free extract may reflect differences in the ingredient composition of bakery wastes across geographical locations. The CBW in the present study contained 0.53% phosphorus, compared with 0.15% phosphorus level reported by Al-Tulaihan et al.[18]. The calcium level of CBW was 0.29%, higher than the 0.14% previously reported by Macgregor[15]. The most probable reason for differences in mineral levels across studies is the source of the bakery waste. Phosphorus and calcium deficiencies affect eggshell thickness, strength, and overall egg quality and health[27]. The ME of CBW in the present study was 3192.43 kcal/kg ME, which was higher than the 2981 kcal/kg ME reported by Mavromichalis[28]. It has been observed that the higher energy content of bakery waste is crucial for sustaining laying hens' energy requirements for egg production[25]. The proximate constituents, minerals, and ME of the CBW indicated its rich nutrient content and, thus, its feed value for laying hens' nutrition.

4.2. Growth performance of laying hens

The slight variation in final body weight relative to initial body weight observed in the present study might be due to the prevailing low environmental temperature during the feeding trial, which likely increased the chickens' energy requirements to help them cope with cold weather. Therefore, the hens allocated a greater proportion of nutrients to heat production rather than weight gain. Consequently, the hens used more nutrients for body heat increment instead of body gain. Hen-day egg production in the present study was lower than the 85.5-89.5% obtained by Hy-line International[29]. These differences can be attributed to the cold winter weather during the present study. Li et al.[30] reported that cold weather can reduce egg production, consistent with the present results. The low hen-house egg production in the present study may be due to the shorter day length during the winter when the feeding trial was conducted, which reduced egg production, especially because the experimental house was dark at night. The present study was carried out in winter, when day length was shorter, which could impair follicle-stimulating hormone activity and egg laying. Furthermore, laying hens might have used nutrients to produce body heat to maintain the physiological temperature required for different metabolic activities, rather than for egg production. Live body weight of laying hens was positively correlated with dietary CBW. The laying hens fed CBW had higher live body weight than the control group. This finding was supported by Alagawany et al.[25], who reported higher final body weights and body weight gain in laying hens fed diets containing 10-30% dried bakery waste as a partial replacement for maize. The present results suggested that bakery waste can increase dietary ME to support maintenance and growth requirements, as well as energy utilization by laying hens. Hen-day egg production decreased as the amount of CBW-based diets increased. Hen-day egg production was negatively correlated with the use of CBW-based diets. This observation was consistent with the findings of Dao et al.[31], who incorporated 50% blended recycled food-waste diets fed to Hy-Line laying hens. Additionally, Alagawany et al.[25] reported that including up to 30% dried bakery waste did not compromise egg production in ISA Brown laying hens, consistent with the present results. These findings indicated that CBW can be used in the diet of laying hens without affecting hen-day egg production. The current results indicated that only the control group experienced low mortality. Consequently, CBW can be included in the diets of laying hens at levels up to 20% without negatively impacting productivity or profitability. This finding was consistent with those of Dao et al.[31] and Alagawany et al.[25], who reported that including food waste or dried bakery waste did not increase mortality in laying hens.

4.3. External and internal egg indices

Dietary CBW notably affected shell thickness, whereas egg weight and eggshell weight were not affected. The correlation between dietary CBW and egg weight was negative, indicating that increasing dietary bakery waste did not notably decrease egg weight. It has been reported that bakery waste can be included at up to 30% in laying hens' diets without adversely affecting egg weight[25]. Shell weight was negatively correlated with dietary CBW. The shell weight in the present study was lower than the 6.69-6.96 g reported by Grigorova and Penkov[32]. Shell thickness had a positive correlation with the dietary CBW, which was lower than 0.40-0.41 mm reported by Grigorova and Penkov[32]. These differences may reflect the variations in management practices. The positive correlation between dietary CBW and albumen length suggested that increasing levels of bakery waste in the diet contributed to a less intact albumen. The positive correlation between diet and yolk length, yolk diameter, yolk weight, yolk height, and yolk color in the present study indicated that using CBW as a replacement for maize had only a marginal improvement effect on these internal egg quality parameters. The current results indicated that CBW can be incorporated into laying hens' diets without detrimental effects on the yolk characteristics. Similar findings were reported by Dao et al.[33], who found that feeding recycled food wastes to laying hens did not notably alter yolk quality. Yolk length and composition are essential factors that contribute to the energy available for embryonic growth and development[34]. Yolk diameter is an important indicator of an egg's freshness and contributes to the calculation of the yolk index[35]. Liu et al.[36] reported that higher yolk weight corresponded to a greater value of an egg nutrient-wise. The negative correlation between dietary CBW and albumen width, height, weight, index, and Haugh unit in the present study indicated that CBW did not adversely affect internal egg indices. The current results were consistent with those of Dao et al.[33], who found that incorporating recycled food waste into laying hens' diets did not affect albumen quality traits. Haugh unit determines the freshness and quality of an egg[37], and albumen weight is an indicator of the freshness and nutritional value of eggs[38]. The Haugh unit was very high across all treatment groups, regardless of CBW replacement of maize. These findings suggested that CBW diets maintained albumen quality, especially since the negative correlation values were weak.

5. Conclusion

Replacing maize with CBW had a similar effect on growth response and all egg traits, except albumen length and shell thickness, which increased at higher replacement levels. The present findings indicated that CBW can replace up to 20% of dietary maize to improve eggshell thickness, thereby reducing the incidence of egg cracks and consequent economic losses. The small sample size and shorter light duration were limitations of the present study; these could be addressed in future studies using artificial lighting and a larger sample size.

Declarations

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Availability of data and materials

All data supporting the findings of the present study are available from the corresponding author upon reasonable request.

Authors' contributions

Lebalang Manyali conceived the study, collected the data, and drafted the first manuscript. Oluwabiyi Oluremi designed the study, supervised data collection, analysis, and interpretation, reviewed the manuscript, and approved the final version for publication. Mary Molefe assisted with data collection and revision of the manuscript. All authors read and approved the final edition of the manuscript for publication.

Competing interests

The authors declared no competing interests.

Ethical considerations

The article has been checked for plagiarism; the data are original, and it has not been submitted to another Journal for publication. No AI tool was used. The authors take full responsibility for the originality of the present study's data before submission and during the peer review process up to publication.

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