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Research Article

Critical Amino Acid and Energy Balancing to Address Maize Grade Variation in Broiler Performance

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Abstract: This study aimed to evaluate the effects of maize grade variation in broiler performance. A total of 189 Cobb500 broilers were randomly and evenly assigned to three dietary treatments having three replications of 21 birds each. The treatments were: T_0 (feed formulated with grade-A maize), T_1 (feed formulated with grade-B maize, with Metabolizable Energy (ME) deficiencies compensated by additional Soybean Oil (SO)), and T_2 (feed formulated with grade-B maize, where deficiencies in Critical Amino Acids (CAA) and ME were addressed with supplemental CAA, SO, multi-enzyme, and toxin binder). Results showed that T_1 exhibited 13.1 Bangladesh Taka (BDT) higher ($p>0.5$) profit margins per bird along with higher ($p>0.05$) final body weight, feed and water intake, and flock uniformity compared to T_0. Additionally, T_1 had a numerically lower ($p>0.05$) production cost and Feed Conversion Ratio (FCR). However, differences in feed intake and FCR between T_1 and T_0 were significant ($p<0.05$) only during days 15-21. The performance metrics, including total production cost and profit margin in T_2, were intermediate between those of T_0 and T_1. The overall results indicated that the broiler feed made with B-grade maize, when properly supplemented to compensate for nutritional deficiencies, can perform parallelly or even better than the feed made with A-grade maize in terms of productions and profitability. This was especially evident in the formulation approach used in T_1. However, its practical application depends on cost of producing feed with different grades of maize, as well as the selling prices of the birds.

Keywords: Critical Amino Acid, Nutrition Balancing, Maize Grade, Profit Margin

Introduction

Maize or corn (*Zea mays*) is the most commonly used cereal grain in animal feeds. In poultry feed, maize alone contributes approximately 65 and 20% of the Apparent Metabolizable Energy (AMEn) and protein contents (Dei, 2017; Cowieson, 2005). Maize ranked as the top-produced food grain worldwide, with a total output of 1.172 billion metric tons in 2022–2023 of which the USA alone accounted for 30.23% (World Grain, 2025). The maize grains of different genotypes and produced in different locations vary in their physical and chemical properties (Rodehutscord *et al.*, 2016). Melo-Durán *et al.* (2021b) reported that the variability in starch (67–76%), protein (7.9–11.7%), oil (3.7–7.5%), amino acids (e.g., lysine: 2.98–4.89% of crude protein, CP) and non-starch polysaccharides (55.6–81.3 g/kg) of maize is influenced by genetic background, growing conditions and post-harvest processing. Variability in physical characteristics of maize, such as hardness (34.9–80.0%) and kernel density is also associated with its genetic background, agronomic practices, post-harvest processing, and drying temperatures (Bhuiyan *et al.*, 2010).

However, depending on physical and chemical variability, maize is graded as grade-1, 2, 3, or 4 in the USA (USGC, 2025). Grading practices are very common in other countries also including African countries (EAC, 2011). Grade variation of maize is directly associated with its nutrient contents (Gehring *et al.*, 2013; Williams *et al.*, 2017). The grade variability parameters of maize like size, shape and structure influence the digestibility and disparity of nutrients, apart from altering feed density, pellet quality, fluidity of ingredients within the mixing system and transportation and supply of diet to feeders (Huart *et al.*, 2020; Lasek *et al.*, 2020; Zhao *et al.*, 2017).

Grade variability of maize affects growth, feed conversion, flock uniformity, digestibility, AMEn, digesta viscosity, gut microbiota composition, intestinal health, and efficacy of exogenous enzymes (Giacobbo *et al.*, 2021; Giacobbo *et al.*, 2021; Córdova-Noboa *et al.*, 2020; Giacobbo *et al.*, 2021; Giacobbo *et al.*, 2021). Sorting of low-grade corn during feed manufacturing is a common practice in many feed mills. Researchers have tried to investigate the impact of additive mixing with low-quality feed ingredients on broiler performance (Melo-Durán *et al.*, 2021b; Williams *et al.*, 2017; Bhuiyan *et al.*, 2011). Broilers fed diets supplemented with enzymes had similar growth performance as control birds when fed with corn dried at 80°C, but body weight gain was increased and feed conversion ratio was decreased when broilers were fed diets with corn dried at 120 or 140°C (Kaczmarek *et al.*, 2014; Bhuiyan *et al.*, 2010).

Methionine (Met) is the first limiting amino acid in commercial corn-soybean meal diets for poultry and poultry diets are commonly supplemented with Met to meet the birds' total sulfur amino acids requirements (Dozier and Mercier, 2013). Broiler feed must be designed in such a way that it meets the entire essential nutrient requirement for growth and development. So far, various methods have been employed by industrialists for the formulation of the best poultry feed aiming to minimize cost or maximize profit as well as working within the dietary requirements of the birds as proposed by researchers and experts in feeding standards. In Bangladesh and other parts of the world, most of the feed millers use maize grain as a major poultry feed ingredient and generally, they use high-grade maize and try to avoid the low grades. The low-grade maize suffers from nutrient deficiencies including protein and energy (Rodrigues *et al.*, 2014). Therefore, a huge portion of the maize produced worldwide is not utilized as a poultry feed ingredient. Hence. There is a scope for using the low-quality corn in poultry diet through minimization of nutrient gaps with supplements which may help reduce feed cost followed by lowering the price of meat and eggs in the market. Keeping all the issues in mind, this study explores the potential of incorporating grade-B maize in broiler feed compensating for its energy and protein deficiencies through Soybean Oil (SO) and Critical Amino Acids (CAA) supplementation along with additional enzymes and toxin binders.

Materials and Methods

The experiment was conducted at Bangladesh Agricultural University (BAU), Mymensingh from 24 August to 27 September 2023. The management and welfare of the birds were assured in accordance with the guidelines of the Animal Care and Ethics Committee of BAU.

Experimental Feeds, Birds, and Management

A total of 189 mixed sex Cobb500 broiler Day-Old-Chick (DOC, Sunny Poultry Breeders, Gazipur, Bangladesh) were used in this experiment. All the chicks were apparently healthy and uniform in body weights. The average body weight of the DOC was 42.5 g/bird. All the chicks were reared on a littered floor open-sided house amidst 27-34°C ambient temperature and 55-80% relative humidity. The brooding was performed under a common brooder starting the temperature at 34°C then gradually down to 29°C on day 7th. For the first 14 days, the bird was fed with breeder company (Kazi Farms Ltd. Bangladesh) recommended starter feed. After 14 days, the birds were randomly and equally allocated to three experimental feeds having three replications each. Thus, nine experimental pens of 1.95 m^2 size each were used for rearing 21 birds. The experimental feeds were, T_0 (feed formulated with grade-A maize), T_1 (feed formulated with grade-B maize, with Metabolizable Energy (ME) deficiencies compensated by additional Soybean Oil (SO)) and T_2 (feed formulated with grade-B maize, where deficiencies in critical amino acids (CAA) and ME were addressed with supplemental CAA, SO, multi-enzyme and toxin binder). The SO and CAA dosages were fixed to compensate exactly for the deficiencies in ME and CAA (sum of Lys, Met, and Thr) caused due to the use of low-grade maize. CAA, such as Lys Met, and Thr, were selected for the supplementation because of their role as limiting amino acids in broiler diets. These limiting amino acids are essential for protein synthesis, growth, and overall performance, making them crucial for addressing the nutritional deficiencies in low-grade maize-based feed. The SO was chosen as the ME source because of its wider and easier availability in Bangladesh. The multi-enzyme and toxin binder were used to mitigate possible anti-nutritional effects of the lower quality (B-grade) maize and the dosages of the multi-enzyme and toxin binder were fixed as per the recommendation of the manufacturer.

Table 1: Proximate composition of the grade-A and grade-B maize used in the experimental feeds

Ingredients	Grade-A (%)	Grade-B (%)
Moisture	11.1	12
Ash	0.93	1.2
Ether extract	5.45	4.8
Crude fiber	0.9	1.5
Crude protein	11	8
Nitrogen-free extract	70.62	72.5

The grade-A and Grade-B maize were purchased from a local feed mill (Bangladesh Feed Mill, Muktagachha, Mymensingh) and the maize grade was identified by their moisture, bulk density, purity, and soundness. These characteristics of grade-A and grade-B maize corresponded to the characteristics of US corn grades No. 1 and 2 (Allen, 2022; United States Department of Agriculture, 2020) respectively. However, the proximate composition of the maize was determined and estimated as shown in Table (1). The ingredient and nutrient composition of T_0, T_1, and T_2 feeds have been shown in Tables (2-3) respectively. Other than maize, all other ingredients and feed additives were of animal feed grades and purchased from local markets. The price of the ingredients has been shown in Table (4).

Table 2: Ratio of the ingredients used in the experimental feeds

Ingredients	% in the feeds		
	T_0	T_1	T_2
Grade-A maize	60.53	0.00	0.00
Grade-B maize	0.00	59.60	59.04
Protein concentrate	3.30	3.30	3.30
Rice polish	5.00	5.00	5.00
Soybean meal	25.00	25.00	25.00
Limestone powder	0.94	0.94	0.94
Di Calcium Phosphate (DCP)	1.68	1.68	1.68
Soybean oil	2.50	3.40	3.60
Lysine (Lys)[1]	0.22	0.22	0.33
Methionine (Met)[2]	0.16	0.16	0.20
Coccidiostat	0.05	0.05	0.05
Toxin binder	0.00	0.00	0.06
Vitamin mineral premix[4]	0.15	0.15	0.15
Multi-enzyme	0.00	0.00	0.06
Choline chloride	0.06	0.06	0.06
Threonine (Thr)[3]	0.00	0.00	0.07
Table salt	0.41	0.41	0.41
Total	100	100	100

[1, 2, 3]Critical amino acids; [4]Each 2.5 kg contains Vitamin A-1000, 10.00 MIU; Vitamin D-500, 2.40 MIU; Copper Sulfate Pentahydrate, 10.00 gm; Vitamin E50, 23.00 gm; Ferrous Sulfate Anhydrous, 60.00 gm; Vitamin K 3 , 2.33gm; Potassium Iodide, 0.40 gm; Vitamin B1, 2.00 gm; Manganese Oxide, 60.00 gm; Vitamin B2 -NBSG, 5.00 gm; Zinc Sulphate Monohydrate, 50.00 gm; Vitamin B6, 3.00 gm; Sodium Selenite, 150.00 mg; Niacin/Nicotinic acid, 30.00 gm; Antioxidant, 5.00 gm; Cal-D-pantothenate, 12.50 gm; Anticaking agent, 12.50 gm; Vitamin B 12 , 12.00mg; Folic acid, 0.80 gm; Biotin, 60.00 mg, Cal-Carbonate to fill to 2.5 kg (Brand: Eskavit® Broiler SPT Premix)

Table 3: Estimated nutrient composition of the experimental feeds

Nutrients	Types of feed		
	T_0	T_1	T_2
Energy (MJ/Kg)	12.769	12.740	12.736
Crude protein [a]	21.00	19.07	19.11
Calcium	0.96	0.95	0.95
Total phosphorous	0.75	0.75	0.75
Available phosphorous	0.46	0.46	0.46
Lysine	1.20	1.11	1.22
Methionine	0.51	0.43	0.46
Cost (BDT/Kg)	56.19	54.49	55.38

[a]The value of the crude protein (%) in T_2 was calculated including the crude protein equivalent value of the added critical amino acids.

Throughout the experimental period, the birds were exposed to similar care and management. Refusals of the feed and water were measured weekly in the morning. A strict biosecurity program was maintained inside and outside the research house as a most effective part of the disease prevention program. The birds were exposed to a continuous lighting period of 23 h. and a dark period of 30 min in each 24 h for the first 3 days then gradually reduced to 20 h of light up to 7 days followed by 16 h of lighting (consisting of both natural and artificial lighting) during rest of the rearing period. The experimental birds were vaccinated against locally prevalent diseases as per the breeder's guidelines.

Table 4: Price of the ingredients used in the experimental feeds

Name of ingredients	Price (BDT/Kg)[a]
Grade-A maize	32.0
Grade-B maize	27.0
Protein Concentrated	180.0
Soybean Meal	69.0
Limestone	13.0
DCP	90.0
Soybean Oil	174.0
Choline Chloride	380.0
Lysine	220.0
Methionine	320.0
Coccidiostat	550.0
Vit-Min-Premix	250.0
Multi Enzyme	420.0
Threonine	280.0
Salt	21.0

[a]BDT = Bangladesh taka equivalent to 0.0091 US Dollar

Assessment of the Performance Parameters and Feed Utilization

Survivability (%): It was calculated by dividing the number of birds alive by the total number of birds and multiplying by 100.

Body weight gain: The body weight gain of the birds in each replication was calculated by deducting the initial body weight from the final body weight on a weekly basis. Body weight gain = Final live weight – Initial live weight.

Feed intake: The amount of feed consumed by the birds in a particular replication of each treatment group was calculated for every week by deducting the amount of leftover feed from the amount supplied for that particular week. Feed intake = Weekly feed supplied-Weekly feed residue.

Feed Conversion Ratio (FCR): The amount of feed consumed per unit of weight gain is called the feed conversion ratio. This was calculated by using the following formula:

$$Feed\ Conversion\ Ratio\ (FCR) = \frac{Feed\ intake}{Weight\ gain}$$

Water intake: The amount of water consumed by the birds in each replication of each treatment group was calculated for every day by deducting the amount of leftover water from the amount supplied on a particular day.

$$Water\ Intake = \frac{Water\ supplied - Surplus\ water}{Number\ of\ birds}$$

Carcass characteristics: At the end of the experiment, one broiler from each replication, possessing average body weight, was slaughtered following the Halal Method (Addeen *et al.*, 2014) and allowed to bleed for two minutes, and the feathers and skin were removed manually. Final processing was performed by removal of the head, shank, viscera, kidney, and lungs. Dressed broilers were cut into different parts, weighed, and recorded separately. The following measurements were recorded: Live weight, dressed weight, bloodless weight, featherless weight, heart weight, liver weight, spleen weight, small intestine length, and caecum length.

Digestibility: During 24-26 days of age, the broilers were fed with acid insoluble ash (AIA, at the rate of 1 g/kg feed). The AIA contents in feeds and feces were determined gravimetrically after drying, ashing, boiling of ash in hydrochloric acid, filtering and washing of the hot hydrolysate, and re-washing as per the slightly readjusted protocol of Siriwan *et al.* (1993). The calculation of the feed and nutrients digestibility through the AIA protocol was done as per Sundu *et al.* (2008). Apparent digestibility of the nutrients (%) = [(Nutrients in feed/ AIA in feed)-(Nutrients in feces/AIA in feces) / (Nutrients in feed/ AIA in feed)]×100. Fresh droppings and litter samples were collected into a zipper polythene bag from three representative locations of the floor under each treatment and stored in a refrigerator until nutrient analysis. The litter moisture level and other proximate components were determined as per AOAC (1990).

Cost-Return and Sensitivity Analysis

Cost was counted from the expenses incurred during the experiment. Production cost was calculated by accounting for the expenses of chicks, feed, litter, equipment depreciation, vaccine cost, etc. Income was calculated as BDT/Kg live weight and BDT/Bird. Taking assistance from ChatGPT in OpenAI, a sensitivity analysis has been conducted to understand how changes in feed cost and sale price of the birds affect profit.

Statistical Analysis

All recorded data were organized, processed, and summarized and statistical analysis was done using One-way Analysis of Variance (ANOVA) followed by Tukey's mean comparison test in Minitab 2017 Statistical Computer Package in accordance with the principles of Completely Randomized Design (CRD) of experiment. The significant difference was considered at $p<0.05$.

Results

Survivability and Flock Uniformity

The rate of survivability in the experimental birds until day 14 of age was 100%. The highest 8.51 % mortality was observed at T_1 followed by 5.13% in T_2 and 3.0% in T_0, respectively. However, these differences were not statistically significant ($p>0.05$). The flock uniformity rates in the broilers were 53, 60, and 60% on T_0, T_1, and T_2, respectively. The uniformity rates in T_1 and T_2 were slightly ($p>0.05$) higher than those of T_0 (Table 5).

Table 5: Flock uniformity in the broilers under different types of feed

Parameters	Types of feed		
	T_0	T_1	T_2
Number of birds weighed	75	75	70
Mean body weight	2191	2238	2183
Mean +10%	2410	2461	2401
Mean–10%	1972	2014	1965
Number of birds outside 2,410 and 1,972 g	35	30	28
Uniformity = ([75-35]/75)×100 (%)	53	60	60
CV = (320.91/2191) ×100 (%)	14.6	12.7	12.7

Feed and Water Utilization

Table (6) demonstrated that there was no significant difference ($p>0.05$) in the feed intake of broilers under different feed types over the day 15-21, 22-28, and 29–35 time-slots. But data revealed that the water intake at T_2 on days 15-21 was significantly ($p<0.05$) lower than that of the two other groups. Data also demonstrated a significantly ($p<0.05$) lower FCR at the T_1 group during ages 15-21 days of the bird in comparison to that of the T_0 and T_2 groups. The FCR data on day 22-28 and 29–35 time-slots were statistically similar ($p>0.05$). BWG were also statistically similar ($p>0.05$) on all the feed groups throughout the experimental periods.

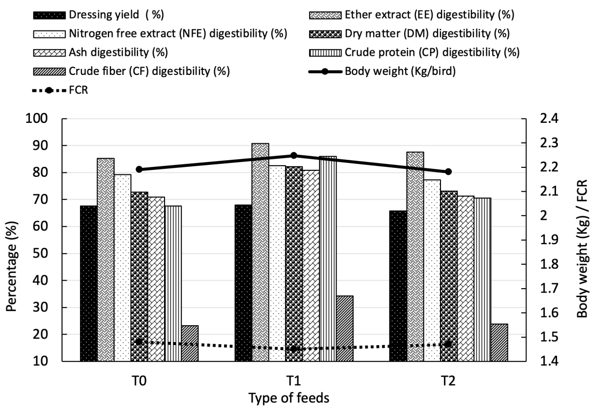

Fig. 1: Comparison of different parameters across feed types T_0, T_1, *and* T_2.

Figure (1) indicates a trend of relatively higher digestibility % of the DM and other proximate components in T_1 along with higher body weight gain and lower FCR value. Results were produced from three observations in each case except body weight, where 57-63 observation data per feed group were used. All the differences for different parameters among feed types were statistically insignificant ($p>0.05$) A similar digestibility pattern, the highest in EE followed by NFE, DM, Ash, CP, and CF, was observed both in T_0 andT_2 groups. In case ofT_1, the = pattern was a bit different, where the CP digestibility rate exceeded that of NFE, DM, and Ash. However, none of the differences in the digestibility and FCR, and body weight were statistically significant ($p>0.05$) across feed types.

Table 6: Effect of grade variation of maize on week-wise average feed intake, water intake, Feed Conversion Ratio (FCR) and Body Weight Gain (BWG) in the broiler chicken

Parameters	Age (Days)	Types of feed			F-value (1-β)	P-Value
		T_0	T_1	T_2		
Feed intake (g/bird)	15-21	768.85±13.37	762.2±40.9	751.5±26.5	0.36 (0.07)	0.707
	22-28	1060.86±13.39	1033.9±23.5	1059.0±26.4	1.91 (0.09)	0.203
	29-35	851.6±70.1	876.0±90.0	911.0 ±83.6	0.54 (0.09)	0.603
Water intake (ml/bird)	15-21	1780.7^{a}±53.4	1801.1^{a}±61.7	1611.6^{b}±57.5	13.03 (0.09)	0.002*
	22-28	2402.5±128.9	2401.4±68.1	2292.6±81.1	1.72 (0.09)	0.233
	29-35	2295.0 ± 296.0	2418.0±238.0	2284.0±196.8	0.36 (0.09)	0.707
FCR	15-21	1.75^{ab}±0.01	1.67^{b} ±0.084	1.84^{a} ±0.05	5.32 (0.09)	0.030*
	22-28	1.77±0.12	1.72±0.12	1.73±0.2	0.46 (0.09)	0.645
	29-35	1.51±0.30	1.60 ± 0.05	1.52 ±0.31	0.04 (0.09)	0.966
BWG (g/bird)	15-21	440.6±28.5	451.7±25.3	411.92±12.2	3.16 (0.09)	0.091
	22-28	604.0 ±37.0	636.8±35.4	603.2±72.2	0.56 (0.09)	0.589
	29-35	580.6±125.7	586.6±51.6	589.7±77.2	0.01 (0.09)	0.989

*Values are Mean ± Standard deviation; (1-β) = Statistical power; *p<0.05 when compared in a row, values in a row carrying uncommon superscripts (ab) are significantly different*

Table 7: Effects of grade variation of maize on carcass characteristics of the broiler chicken

Parameter (%)	Types of feed			F-Value (1-β)	P-Value
	T_0	T_1	T_2		
Carcass weight	67.58±3.25	68.02±1.57	65.73±1.80	0.81 (0.07)	0.485
Breast weight	26.51±1.23	26.72±1.41	25.00±2.69	0.74 (0.07)	0.516
Leg weight	19.48±0.61	20.14±0.22	19.52±0.71	1.31 ().07)	0.335
Liver weight	2.08±0.22	2.081±0.289	2.024±0.134	0.06 (0.07)	0.942
Heart weight	0.35±0.06	0.38±0.05	0.40±0.09	1.21 (0.07)	0.360
Blood weight	2.56±0.051	2.74±0.41	2.72±0.52	0.18 (0.07)	0.841
Spleen weight	0.098±0.005	0.107±0.007	0.10±0.02	0.39 (0.07)	0.695
Length of small intestine (cm)	112.19±9.53	103.30±4.16	110.90±3.89	2.43 (0.07)	0.436
Length of caecum (cm)	17.35±0.74	14.81±1.93	16.94±1.47	6.55 (0.07)	0.155

Values are Mean ± Standard deviation; (1-β) = Statistical power

Carcass Characteristics and Organ Development

Results furnished in Table (7) indicated that all the differences including breast meat and leg meat weights and liver, heart, blood, and spleen weights were statistically similar (p>0.05) across feed groups. The small intestine length and caecum length were also statistically similar (p>0.05) in the feed groups.

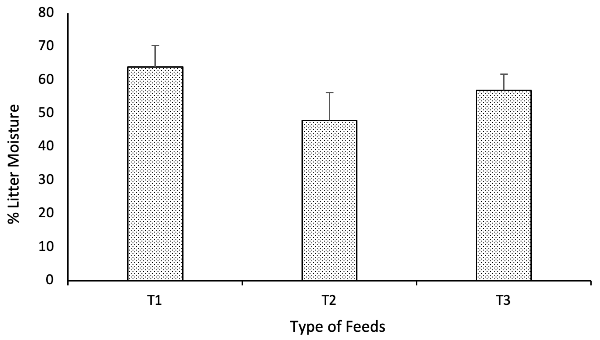

Fig. 2: Effect of grade variation of maize on moisture content in broiler litter

Litter Moisture Content

In Figure (2), a numerically higher (64%) moisture level was observed in the litter of the T_0 group than in T_1 (57%) and T_2 (48%) groups respectively. However, the litter moisture contents were found to be the highest in the highest protein-containing feed (T_0) group.

Economic Analysis

Total costs of production of the broiler on different feed types were statistically equal (p>0.05) (Table 8), while the total sale value was varied by up to 11.0 BDT per broiler. However, the profit was found to be the highest 86.1 BDT / bird in T_1 followed by 74.9 BDT/ bird in T_2 and 73.2 BDT in T_0 respectively. Sensitivity analysis data presented in Fig. (3) indicates that profit increases significantly when the sale price increases, even if the feed cost rises slightly. If feed cost increases sharply (+20%), profit declines, but a sale price increase can compensate. However, at a 20% reduction in bird sale price, all scenarios lead to low or negative profits and T_1 remains the most profitable across different scenarios.

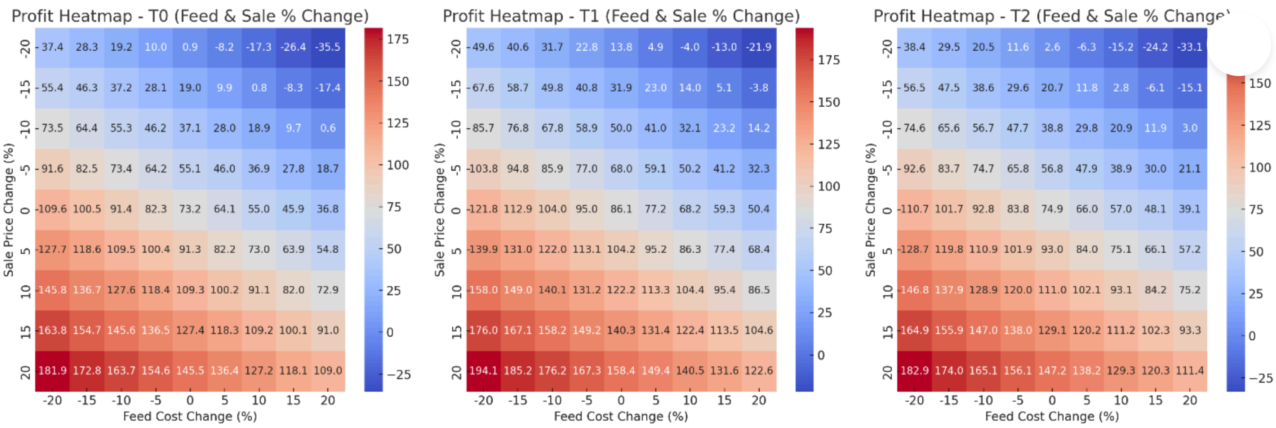

Fig. 3: Sensitivity analysis of the profits based on feed cost and sale price (BDT) across different types of feed

Figue (3) presents heatmaps illustrating the impact of variations in feed cost and sale price on the profit of three different feed types (T_0, T_1, *and* T_2).

Table 8: Cost involvement and return analysis in rearing broiler across different feed types

Items	Values (BDT/Bird) in different types of feed		
	T_0	T_1	T_2
Cost of feed	182.2	178.7	178.9
Cost of chicks	38.5	38.5	38.5
Cost of litter	4.5	4.5	4.5
Cost of vaccine	9.0	9.0	9.0
Disinfection cost	4.0	4.0	4.0
Other costs	50.0	50.0	50.0
Total cost	288.2	284.7	284.9
Sale price (BDT / kg live weight)	165.0	165.0	165.0
Sale price	361.3	370.8	359.8
Profit	73.2	86.1	74.9

Discussion

Insignificant differences in flock uniformity (Table 5), live body weight, and FCR among feed groups (Figure 1) during the whole experimental period were supported by Attia *et al.* (2022), who reported no effect of low-protein diet enhanced by amino acids on the early life of broiler. Similarly, Giacobbo *et al.* (2021) found no significant differences ($p > 0.05$) in the Body Weight Gain (BWG) and FCR of broilers from day one to day 42 of age fed three different types of corn hybrid-based diet. Ojediran *et al.* (2017) also reported no difference in the flock uniformity of broilers fed low low-protein diet fortified with or without Lys. However, the significantly higher water intake and lower FCR value found in the current study during day 15-21 time-slot along with constant trend of numerically higher body weight and nutrients digestibility in T_1 (Table 6, Fig. 1) was disagreed by Liu *et al.* (2017), who reported improved growth of broilers on supplementation of low-protein diet with Lys, Met, Thr and Trp. However, the slightly better performance of T_1 in the present study may be attributed to the broilers' ability to more easily recover Metabolizable Energy (ME) from Soybean Oil (SO), an immediate energy source. In contrast, ME retrieval in T_0 and T_2 involves a more complex digestion process of feed grains. This hypothesis was in agreement with the findings of Moore *et al.* (2008), who reported the impact of physical and chemical characteristics of the feed ingredients and their ME utilization for the growth of birds. However, while previous studies, such as Cowieson *et al.* (2010), have demonstrated the benefits of supplementation, this study uniquely addresses the economic and nutritional challenges of using low-grade maize in broiler diets. By combining oil supplementation with critical amino acid balancing, this study provides a cost-effective solution for feed producers in developing countries.

In a study of Zhao *et al.* (2017), better BWG and FCR were found in broilers from day one to day 42 of age fed on corn–corn-corn-soybean-based diets either with inclusion of flint corn or dented corn. The statistically similar carcass characteristics in our three different types of feeds under the current study were supported by Melo-Durán *et al.* (2021a), who noticed a similar growth rate in broilers from day one to day 42 of age fed on corn–soybean meal-based diets, where the corn came from eight different varieties. Downs *et al.* (2023) concluded that the corn quality has only a small effect on performance, organ weights, and nutrient digestibility. The non-significant differences found in our study in the live weight and FCR across feed groups suggested that the nutritional adjustments made in T_1 and T_2 effectively compensated for the lower quality of grade-B maize. This indicates that feed producers can use grade-B maize without compromising broiler performance, provided that energy and amino acid deficiencies are addressed.

Zhao *et al.* (2008) also found no difference ($p > 0.05$) on whole breast weight of broilers fed a corn–soybean meal-based diet with the inclusion of either dent or flint corn at fixed amounts, even though they had differences of 0.18% and 0.16% within their contents of Lys and Met, respectively. Similar results were obtained by Giacobbo *et al.* (2021), who did not report differences

($p > 0.05$) in carcass, whole breast, wing, and leg yield of 42-day-old broilers subjected to diets with the inclusion of three different corn varieties. Carter and Kim (2013) reported that excess nitrogen excretion by poultry arises mainly from dietary amino acids and may increase the volatilization of ammonia from animal production systems, which can affect air quality. A reduced crude-protein diet has also been reported to improve litter quality by reducing the litter moisture content (van Harn *et al.,* 2019) what have rightly been validated in our current findings of litter moisture content (Fig. 2). Lower litter moisture content in T_1 suggests improved litter quality, which is critical for broiler welfare and environmental sustainability. High moisture levels can lead to ammonia emissions and footpad lesions, negatively impacting both bird health and farm profitability. Therefore, the use of low-grade maize with appropriate supplementation may also contribute to better litter management and reduced environmental impact. Matching and mismatching of our results with the previous findings can be explained by the fact that the overall performance of broilers is not the outcome of nutrition only, but rather it is an aggregated manifestation of the effects of all management, genetic, and environmental factors.

The relatively higher profit-gaining formula of T_1 feed (Table 8) might result from variations in the body weights of the broiler. And, the variation in body weight of broiler under T_1 was the outcome of relatively better FCR (Fig. 1) of the bird. The relatively wider sensitivity of profit margins to feed cost and broiler sale price in T_1 also suggested its superiority over the feed formulae used in T_2 and T_0. However, while T_1 showed a marginal profit advantage in this study, long-term reproducibility under varying economic conditions (e.g., fluctuating maize and soybean oil prices) should be investigated. Additionally, the broader economic impact of using low-grade maize, including potential effects on broiler health and consumer perception, warrants further exploration.

Conclusion

Feed producers can use B-grade maize as an alternative to grade-A maize in broiler feed upon compensating for the grade variation created ME gaps through SO supplementation. Fulfilling both the ME and CAA gaps through SO and CAA supplements respectively together with additional multienzyme and toxin binder supplementation can be chosen as the second option for profitable broiler farming in a resource-constrained setting, like in Bangladesh. The findings of this study could be adapted for other livestock industries, such as swine or dairy, where low-grade maize is often underutilized.

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Author's Contributions

Md. Shahidur Rahman: Conceptualization, Resources arrangement, Methodology development, Investigation, Data analysis, Manuscript drafting and editing.

Mohammad Farhad Hossain: Participated in laboratory analysis.

Million Maksuda: Participated in laboratory analysis and field experiments, data gathering, and processing of raw data.

Md. Kamruzzaman: Advised during planning and constructing the research design and writing up the manuscript.

Md. Rakib Hassan: Reviewing and improving the readability of the manuscript.

Conflict of Interest

The authors have no conflict of interests related to this manuscript.

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