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Impact of physical and nutritional enrichment on Mulard ducks' performance and meat quality

Gehad Eid[1], Fatma Khalil[1], Hosny H. Emeash[1], Amany Abd El-Halim[2], Asmaa K. Abdelghany[1*]

[1]*Animal and Poultry Management and Wealth Development Department, Faculty of Veterinary Medicine, Beni-Suef University, Beni-Suef, 62511, Egypt.*
[2]*Department of Food Science and Technology, Faculty of Agriculture, Fayoum University, Fayoum 63514, Egypt.*

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*Correspondence:

Corresponding author: Asmaa K. Abdelghany
E-mail address: asmaa.kamal@vet.bsu.edu.eg

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ABSTRACT

Poor animal welfare has detrimental impacts on human health and welfare, and damaging effects on the environment. The cultivation of ducks contributes considerably to the production of poultry meat worldwide. Environmental enrichment (EE) approaches have been advantageous for alleviating stress, so housing conditions have prominent effects on animal welfare and, in turn, efficiency of production. Therefore, the objective of this study was to assess and compare the impact of the provision of a tunnel as a physical enrichment (PE) or nutritional enrichment (NE) or combination of both physical and nutritional enrichment on animal welfare, productive performance, and meat quality of Mulard ducks. One hundred and eight 14-day-old Mulard ducklings were distributed at random to 4 groups: Control group (C), Tunnel-enriched group (E): tunnel-based physical environmental enrichment, Moringa-enriched group (Mo): feed *Moringa oleifera* leaves powder, and Moringa + Tunnel-enriched group (Mo+E). The performance and growth parameters measured, carcass properties, meat quality, and economic efficiency were assessed. The data obtained showed that growth performance, weight gain, carcass properties, and meat quality measures, as well as economic efficiency, were positively influenced by the provision of a combination of PE and NE and\ or NE alone. Despite the increase in total costs associated with the addition of MO leaf powder, there was an improvement in economic efficiency, particularly in the MO+E and Mo groups. Thus, the provision of a combination of physical and nutritional enrichment improves animal welfare and consequently increases production efficiency, as well as satisfies consumer needs.

Introduction

The moral implications of actual animal production techniques on farm animal welfare are a clear source of public concern in the contemporary global socioeconomic environment (Eurobarometer, 2007; Fernandes *et al*., 2019). Poor animal welfare, detrimental impacts on human health and welfare, damaging effects on the environment, and inefficient use of the world's natural resources can all render a system or technique unsustainable because people find them intolerable (Broom, 2019). Research is being done on how to satisfy welfare regulations, lessen stress, and improve living conditions as animal welfare in livestock production becomes more prominent (Kim *et al*., 2025). The cultivation of waterfowl, such as ducks, contributes considerably to the production of poultry meat worldwide. Since 2000, the global output of duck meat has been rising substantially (Chen *et al*., 2021). Housing conditions, along with other relevant variables, have prominent effects on animal welfare and, in turn, efficiency of production (Abdel-Hamid *et al*., 2020; Zahoor *et al*., 2022).

Environmental enrichment approaches have been advantageous for alleviating stress while providing ideal raising conditions, with their infrequent application on farms (Kim *et al*., 2025). Physical, tactile, dietary, social, and intellectual enrichment through the environment is all feasible. Expanding the space between feeders and water sources, adding perches, introducing new items, or offering nesting boxes are some of the modifications to the environment that may contribute to bird enrichment (Woods *et al*., 2022). Additionally, nourishment serves as one of the greatest resources for enrichment (Dumonceaux, 2005).

According to da Silva Costa *et al*. (2023) and Cheng *et al*. (2024), duck meat is comparatively low in intramuscular fat and high in desirable proteins, unsaturated fatty acids, vitamins, and minerals. It is a vital source of nutrients that offers plenty of beneficial positive effects, such as boosting immune system performance, cardiovascular health, and muscle building (Cheng *et al*., 2024). Consumers seeking wholesome and well-balanced meat products are increasingly choosing them (Shin *et al*., 2023).

Moringa oleifera Lam. (MO), a member of the *Moringaceae* family, is being studied for its multifaceted health benefits (Worku, 2016), as well as its substantial nutritional value, rapid growth, and application as a product for animal nutrition (Nouman *et al*., 2013). *Moringa oleifera* has been demonstrated to improve appetite, promote carcass yield, induce the synthesis of digestive enzymes, and have antibacterial and immune-boosting properties in poultry (Selim *et al*., 2021).

In poultry, MO leaves meal has been demonstrated to positively impact gut health, liver activity, carcass quality, feed conversion ratio (FCR), weight gain, and feed intake (Mahfuz and Piao, 2019; Tutubalanga *et al*., 2022). The growth efficiency, nutritional digestibility coefficient, and acceptance by consumers of duck meat are all raised when *Moringa oleifera* leaf powder is implemented as a natural growth stimulant (Elsamee *et al*., 2019). Physical enrichment is of great importance in animal rearing environments. In a study on physical enrichment for quails involving various items, a large number of birds selected the tunnel as one of the first things, and it also had a beneficial effect on the rate of fertilization of the eggs (Ramankevich *et al*., 2022).

Therefore, the object of this study is to assess and compare the impact of the provision of a tunnel as a physical enrichment (E) or moringa leaf powder (MO) at 1 % levels as a nutritional enrichment or combination of both physical and nutritional enrichment (MO+E) on animal welfare, productive performance, and meat quality of Mulard ducks.

Materials and methods

Ethics approval

The materials and procedures in this study received approval from the Institutional Animal Care and Use Committee of Beni-Suef University (BSU-IACUC), as documented under number 022-468.

Birds

One hundred and eight 7-day-old Mulard ducklings were purchased

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from a duck farm in El-Fayoum governorate. Ducklings were kept for one week to adapt to new surroundings. Floor pens of similar sizes (2.5 m x 2 m x 3 m), bedded with sawdust as bedding material. Birds were raised in the same surroundings; windows, fans, and exhaust fans were used for proper ventilation. The lighting program was set as a consistent lighting of 23 h of light, and 1 h off. The environmental temperature ranged from 24 to 27°C, and RH% ranged from 45 to 55%. Plastic feeders and drinkers were distributed throughout experimental compartments. Throughout the duration of the experiment, fresh, clean water was provided ad libitum.

Moringa oleifera leaves powder preparation

Recently harvested green Moringa leaves collected from faculty of Agriculture farm, Beni-Suef University were allowed to air dry without being exposed to sunlight. To stop fungus from growing, they were continuously stirred until their leaves were crispy to the touch while remaining green. A fine powder was produced by grinding leaves (Abdel-Raheem *et al*., 2024).

Experimental birds and management

One hundred and eight (108) 14-day-old Mulard ducklings, which had similar average initial weight (420g – 430 g) were distributed at random to 4 groups (n=27 each) in 4 floor pens of similar size (2.5 m x 2m x3 m); each group was subdivided equally into 3 replicates (n=9). The birds were fed a commercial starter diet containing 3000 ME Kcal/kg, and 23.5% CP from 7-day-old to 4 weeks old. Then, the grower diet contained 3100 ME Kcal/kg, and 21.5%CP from 4 weeks up to 10 weeks old, as recommended by NRC (1994) (Table 1).

Table 1. Basal diet composition.

Diet	Starter diet	Grower diet
Cp%	23.5	21.5
CF%	3.35	3.2
Fat%	5.22	6.2
ME (Kcal ME/kg)	3000	3100

Birds grouping: the four groups of ducks (n=27 per group, subdivided equally into 3 replicates, 9 per each) were subjected to one of the following treatments:

Control group (C): Fed basal diet.

Tunnel enriched group (E): Fed basal diet + tunnel-based physical environmental enrichment; each pen was equipped with 3 plastic tunnels (50 cm length, 30.48 cm in diameter), each replicate provided with one tunnel (Ramankevich *et al*., 2022).

Moringa enriched group (Mo): Fed basal diet, *Moringa oleifera* leaves powder was added as a nutritional enrichment (feed additive) at levels of 1% by daily mixing with the ration (Ibrahim *et al*., 2017; Ashmawy and Ibrahim, 2019).

Moringa + Tunnel enriched group (Mo+E): feed basal diet + tunnel + *Moringa oleifera* leaves powder at levels of 1% (Ibrahim *et al*., 2017; Ashmawy and Ibrahim, 2019; Ramankevich *et al*., 2022).

Performance measurement

Every week, birds were weighed, and their feed intake was recorded to determine the average live bird body weight. Many indices, such as weight gain (WG), average daily gain (ADG) (Chen *et al*., 2015), feed intake (FI), feed conversion ratio (FCR), and relative growth rate (RGR) (Khalel, 2022), and performance index (PI) (Nguyen *et al*., 2024), have been computed as indicators of duck performance depending on feed consumption and live body weight.

Carcass properties

Following an overnight fasting, six randomly chosen birds from each group (two per replicate) were weighed and euthanized. The carcass's live weight, hot carcass weight, and dressed carcass weight were all measured. Internal organs, including the heart, spleen, liver, and gizzard, as well as the weights of the thighs, breast, and wings, were also recorded. The relative weight of live body weight was used to express the data. By dividing the dressed carcass's weight by the live body weight and multiplying the result by 100, the dressing percentage was determined (Batta, 2004). For additional analysis, breast samples were stored at -80°C.

Measurement of the quality of meat

Fresh duck breast meat (2 g) was blended with 20 mL of distilled water solution, homogenized, and pH was measured. pH reading was recorded using a pH meter (AD111; Delta Scientific Services, Egypt). The electrode was placed inside the homogenate. Every sample was measured twice as described by Hulankova *et al*. (2018). The pH was measured following euthanization and then after 24 h by placing samples on a refrigerator shelf at 4°C to assess shelf life and microbial spoilage of meat.

Water Holding Capacity (WHC)

The procedures mentioned by Sorour *et al*. (2021) were used to determine the water holding capacity (WHC). One kg weight was used to press the minced sample (0.3 g) under ashless filter paper (Watman, No. 41) for ten minutes. On the filter paper, two zones developed, and their surface areas were measured using a planimeter. The WHC in cm^2 was shown by the area of the outer zone, which was created when the water split from the compressed tissues. For every 1 cm^2 of outer zone area, 8.4 mg of free water is needed. This is how the expressible water percentage and W.H.C. percentage were computed:

Expressible water %= (cm^2x8.4/0.3x1000)x100; WHC%= Moisture%- Expressible water%

Cooking loss

Before cooking, each breast fillet was precisely weighed. According to Li *et al*. (2013), the breast fillets were promptly weighed after cooling and wiping with blotting paper to eliminate any remaining water. Cooking loss (%) was computed as follows: [(raw weight−cooked weight)/raw weight] × 100.

Cooking Yield

According to Yun *et al*. (2025), the cooking yield was calculated by noting the sample weight both before and after cooking. The cooking yield (%) is calculated by dividing the weight of cooked meat by the weight of raw meat, then multiplying the result by 100.

Chemical Composition of Duck Breast Meat

Samples of breast meat from each experimental group's carcass were gathered individually and prepared (carefully minced). The official technique of AOAC (2012) was followed to determine the moisture, fat, ash, and carbohydrate content (nitrogen-free extract, or NFE).

Economic efficiency

The following formula was used to calculate the experimental diets' economic efficiency based on the duck's live body weight and ingredient prices on the local market: Total revenue minus total feed cost is net revenue. (Net revenue/total feed cost) x 100 is the formula for economic efficiency (%) (Ibrahim *et al*., 2017).

Statistical analysis

All data were statistically analyzed by SPSS version 22 statistical software using one-way analysis of variance (One-way ANOVA) and Kruskal-Wallis, and data were presented as mean and SE of mean and considered significant at P-value ($P<0.05$).

Results

Performance measures

In Figure 1, no difference was observed between groups in IW. The ADG revealed no meaningful difference between groups in 1st month, while it was remarkably elevated in 2nd month in the MO+E group with respect to the C and E groups. The total ADG over two months improved markedly ($P<0.05$) in the MO+E group compared to the E group. In addition, WG also enhanced remarkably ($P<0.05$) in the MO+E group, contrary to the C and E groups.

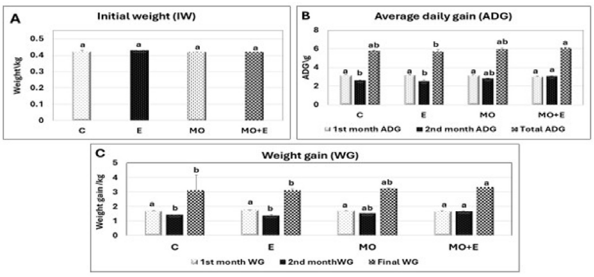

Figure 1. Effect of physical and nutritional enrichment on duck weight gain. Results are expressed as Mean±SE using one-way ANOVA and Kruskal-Wallis (n=27; 9per replicate). a & b superscripts in the same row, values with different letters are significant at P < 0.05 values between groups. FI: Feed intake; FCR: Feed conversion ratio; C: Control group; E: Enriched group; MO: Moringa group; MO+E: Moringa +Enrichment group.

The findings in Table 2 showed that in the 1st month, no statistical significance was noticed in FI between all groups, while the FCR was greatly improved ($P<0.05$) in the E group than in the C and MO+E groups. In the 2nd month, no statistical meaning noticed in FI between all groups, while the FCR was greatly improved ($P<0.05$) in the MO+E group than in the E group. Moreover, total FI over the study period demonstrated a non-significant variation among groups; total FCR was markedly enhanced ($P<0.05$) in the MO group than in the C group.

Following the 1st month of study, it was noticeable that PI was the highest in the E group in relation to the C and MO+E groups. In the 2nd month The PI was the highest in the MO+E group in relation to the C and E groups. The total PI during all periods showed a non-significant increase in all groups with respect to the control group. Furthermore, the RGR% was higher in the MO+E group than in the other groups, while no meaningful variation was observed in the 2nd month, as shown in Figure 2.

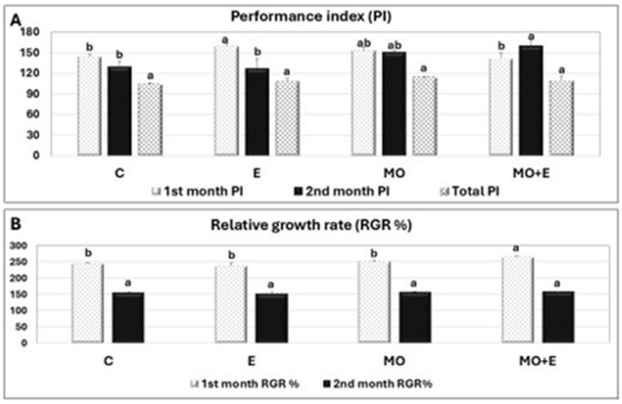

Figure 2. Effect of physical and nutritional enrichment on duck performance (PI, RGR%). Results are expressed as Mean±SE using one-way ANOVA and Kruskal-Wallis (n=27; 9per replicate). a & b superscripts in the same row, values with different letters are significant at P < 0.05 values between groups. FI: Feed intake; FCR: Feed conversion ratio; C: Control group; E: Enriched group; MO: Moringa group; MO+E: Moringa +Enrichment group.

Carcass properties

In Table 3, the dressing % rose greatly ($P<0.05$) in the MO+E group

Table 2. Effect of physical and nutritional enrichment on duck performance (FI, FCR).

Performance measures	Groups			
	C	E	MO	MO+E
1st month FI (kg)	36.69±0.23[a]	34.85±0.63[a]	35.44±1.47[a]	35.89±0.30[a]
1st month FCR	2.42±0.02[a]	2.24±0.04[b]	2.31±0.08[ab]	2.42±0.05[a]
2nd month FI (kg)	57.46±0.67[a]	56.31±0.97[a]	54.90±1.07[a]	57.53±1.11[a]
2nd month FCR	4.51±0.19[ab]	4.67±0.41[a]	4.01±0.02[ab]	3.86±0.08[b]
Total FI (kg)	94.15±0.53[a]	91.16±1.57[a]	90.34±2.26[a]	93.42±0.88[a]
Total FCR	3.37±0.07[a]	3.29±0.10[ab]	3.11±0.05[b]	3.14±0.07[ab]

Results are expressed as Mean±SE using one-way ANOVA and Kruskal-Wallis (n=27; 9per replicate). a & b superscripts in the same row, values with different letters are significant at P < 0.05 values between groups. FI: Feed intake; FCR: Feed conversion ratio; C: Control group; E: Enriched group; MO: Moringa group; MO+E: Moringa +Enrichment group.

Table 3. Effect of physical and nutritional enrichment on duck carcass properties.

Carcass quality parameters	Groups			
	C	E	MO	MO+E
Live weight (kg)	3.17±0.07[a]	3.37±0.12[a]	3.36±0.04[a]	3.35±0.11[a]
Dressing %	56.80±0.96[b]	58.33±0.32[b]	56.59±0.32[b]	67.63±0.35[a]
Wing weight (kg)	0.36±0.01[a]	0.35±0.01[a]	0.37±0.02[a]	0.37±0.02[a]
Breast weight (kg)	1.27±0.04[a]	1.38±0.05[a]	1.30±0.02[a]	1.26±0.04[a]
Thigh weight (kg)	0.88±0.01[a]	0.94±0.03[a]	0.78±0.17[a]	1.03±0.02[a]
Liver weight (kg)	0.06±0.00[b]	0.07±0.00[a]	0.07±0.01[a]	0.07±0.00[a]
Heart weight (g)	27.33±1.45[a]	28.33±1.67[a]	25.97±1.25[a]	26.67±1.67[a]
Spleen weight (g)	2.63±0.15[a]	2.37±0.39[a]	2.73±0.13[a]	2.97±0.72[a]
Gizzard weight (kg)	0.10±0.01[a]	0.12±0.01[a]	0.12±0.00[a]	0.11±0.01[a]

Results are expressed as Mean±SE using one-way ANOVA (n=12; 3per group &1per replicate). a & b superscripts in the same row, values with different letters are significant at P < 0.05 values between groups. C: Control group; E: Enriched group; MO: Moringa group; MO+E: Moringa + Enrichment group.

compared to other groups. There were no obvious differences in the live weight, relative weights of wing, breast, thigh, spleen, heart, and gizzard between all groups, while liver weight showed a notable rise in all treated groups with respect to the C group.

Meat quality measures

The water holding capacity (WHC) and cooking yield expanded, while the cooking loss diminished markedly (P<0.05) in the MO group than other groups. In addition, the E group showed the least WHC and cooking yield, and the highest cooking loss (P<0.05) than other groups. The pH showed a non-significant difference between all groups (Figure 3).

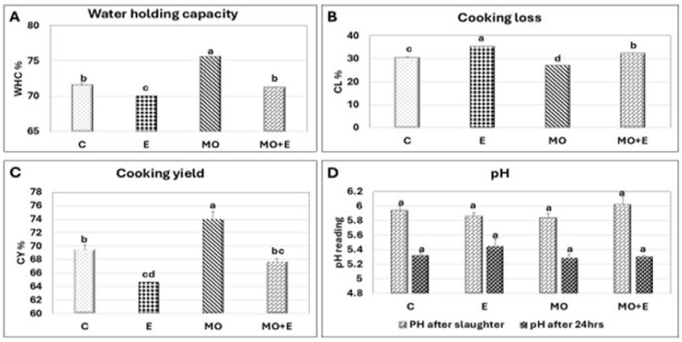

Figure 3. Effect of physical and nutritional enrichment on duck meat quality measures. Results are expressed as Mean±SE using one-way ANOVA (n=12; 3per group &1per replicate). a & b superscripts in the same row, values with different letters are significant at P < 0.05 values between groups. C: Control group; E: Enriched group; MO: Moringa group; MO+E: Moringa + Enrichment group.

Meat chemical composition

The meat chemical composition (Table 4) showed a marked (P<0.05) rise in the moisture and protein % in all treated groups than the C group. The fat and ash % reduced remarkably (P<0.05) in all treated groups with respect to the C group, particularly in the MO and MO+E groups. The NFE% was elevated in the MO and E groups, especially (P<0.05), compared to the C and MO+E groups, while it decreased significantly (P<0.05) in the E group compared to the MO+E group.

Table 5 declared that there was a difference in the total costs among the four groups; it was the highest in MO+E, followed by the MO groups, then the control group. However, the E group was the lowest. Although there is a substantial increase in the total costs, there was an improvement in economic efficiency in the form of elevated net revenue in enriched groups, particularly in the Mo and MO+E groups. Supplementation of MO as a feed additive at 1% achieves superiority in profitability compared with the E group and MO+E group, while the C group revealed the lowest profitability.

Discussion

Although the cost of production has decreased due to the development of duck farming, concerns over the welfare of the birds have also been raised. Housing conditions must be considered in order to maximize animal well-being while sustaining productive performance (Abdel-Hamid *et al*., 2020). *Moringa oleifera* Lam is anticipated to be a useful bio-resource used to produce a widely accessible herbal formulation that may be just as effective and economical as traditional synthetic medications (Mittal *et al*., 2003). The high cost of ingredients for feed could be mitigated by the substantial nutritional value of MO leaves, which could boost growth performance (Ibrahim *et al*., 2017).

The results obtained showed that adding MO as a nutritional enrichment alone or combined with physical enrichment has a positive effect on the ducks' performance, which appeared as a considerable increase in the ADG, FWG, RGR%, and PI compared to other groups. The FCR also enhanced obviously in the MO group with respect to the C group. These findings are supported by Ibrahim *et al*. (2017); Hassan *et al*. (2019) found that provision of MO leaves at 1% in Mulard and Muscovy ducks mark-

Table 4. Effect of physical and nutritional enrichment on duck meat chemical composition.

Carcass chemical composition (%)	C	E	MO	MO+E
Moisture	74.61±0.11^{b}	75.59±0.13^{a}	75.19±0.01^{a}	75.16±0.11^{a}
Fat	4.68±0.01^{a}	3.76±0.00^{b}	3.16±0.00^{c}	3.16±0.00^{c}
Ash	1.46±0.02^{a}	1.39±0.01^{b}	1.31±0.01^{c}	1.36±0.02^{bc}
Carbohydrate content (NFE)	0.23±0.07^{c}	0.65±0.08^{b}	1.14±0.01^{a}	0.19±0.04^{c}
Protein	19.01±0.01^{b}	19.21±0.01^{a}	19.21±0.01^{a}	19.21±0.01^{a}

Results are expressed as Mean±SE using one-way ANOVA (n=12; 3per group &1per replicate). a & b superscripts in the same row, values with different letters are significant at P < 0.05 values between groups. C: Control group; E: Enriched group; MO: Moringa group; MO+E: Moringa + Enrichment group.

Table 5. Effect of physical and nutritional enrichment on ducks' economic efficiency.

Economic efficiency (EE)	Groups			
	C	E	MO	MO+E
Marketing weight (Kg)	3.13	3.08	3.22	3.29
Feed consumed / duck (kg)	10.46	10.12	10.03	10.38
1Kg feed + additive cost (LE)	22	22	23.3	23.3
Feed cost (LE)	230.12	222.64	233.6	241.85
Management/duck (LE)	2	2	2	2
7-day-old duck cost (LE)	57	57	57	57
Total cost (LE)	289.12	281.64	292.6	300.85
Total revenue (LE)	357.6	369.6	386.4	394.8
Net revenue	86.48	87.96	93.8	93.95
Economic efficiency	29.9	31.2	32.05	31.2
R Relative economic efficiency	100	104.3	107.1	104.3

C: Control group; E: Enriched group; MO: Moringa group; MO+E: Moringa + Enrichment group; LE: Egyptian pound (local money);1Kg feed + additive cost (LE): Based on prices of the year 2025; Management/duck (LE): Involve workers, cleaning, healthcare, and immunization/duck 2 LE; Total cost (LE): Incorporate the experimental duck's feed cost; Total revenue (LE): The body's weight x one kilogram's market value, which was 120LE; Economic efficiency: The ratio of net revenue to total cost; Relative economic efficiency: Considering that the control diet's relative economic efficiency is 100.

edly increased the FWG, the ADG, and FCR than the control group. Furthermore, in comparison with the control group, Elsamee *et al*. (2019) found that 1% and 2% MO leaf meal raised the ducks' body weight and weight gain. These findings could be due to MO's substantial nutrient and antioxidant properties (Karthivashan *et al*., 2013), being an abundant source of protein (Kakengi *et al*., 2007), along with impacts on promoting the absorption of protein (Lu *et al*., 2016). Moreover, the housing system and the incorporation of different enrichment elements (plastic, structural, and visual) encourage the birds to engage in physical activity, thus improving the overall health of ducks and broiler chickens by increasing their ultimate body weight and weight gain (Abdel-Hamid *et al*. 2020; Zahoor *et al*., 2022).

It was observed that MO induced an obvious increase in dressing % and liver weight. Additionally, live weight and relative breast, thigh, and organ weights were elevated in treated groups. With regard to similar findings, the dressing % and live weight were considerably greater following MO administration (Moyo *et al*., 2012). Additionally, Ibrahim *et al*. (2017) and Elsamee *et al*. (2019) noticed that the liver, heart, and gizzard percentages in ducks fed a diet enriched with MO leaves were higher with respect to the control group. The ability of MO to regenerate destroyed hepatic and pancreatic cells via its antioxidant characteristics may be a reason for the above results (Abd El Latif *et al*., 2014). In addition, Abo Ghanima *et al*. (2020) found that duck housing enrichment resulted in notably higher dressing percentage, liver percentage, and breast and thigh percentages than the non-enriched group, which may be attributed to the major impact of enrichment on the development of muscle.

According to Mancini and Hunt (2005) and Qwele *et al*. (2013), moringa oliefera leaves are a beneficial natural feed supplement that improves the quality of meat in the livestock industry, thereby improving both animal well-being and customer experience. Additionally, MO leaves are abundant in antioxidants that prolong the shelf life of meat through minimizing the degradation of lipids (Taváreź *et al*., 2011). In the present study, findings revealed that MO enhanced the meat WHC and cooking yield as well as reduced the cooking loss, which is consistent with Abdoun *et al*. (2024) clarified that MO leaves enhance water retention and reduce moisture loss during cooking. On the contrary, the highest cooking loss and the lowest cooking yield were observed in the E group directly reflects the poor WHC observed in this group, while the combined group (MO+E), MO balanced the negative effects of enrichment on meat quality, that may attributed to antagonistic or compensatory effect when nutritional and physical enrichments are combined; this result agrees with Safwat *et al*. (2023).

Our analysis showed that MO, E, and MO+E elevated moisture, protein, and NFE %, while reducing fat and ash %, that supported by Cui *et al*. (2018); Sukria *et al*. (2025) mentioned that the bioactive constituents, such as polyphenols and flavonoids, present in the *Moringa oleifera* leaf meal (MOLM) may modulate lipid metabolism by inhibiting lipogenic enzymes or enhancing beta oxidation. Hassan *et al*. (2019); Abdoun *et al*. (2024) reported that ducklings and lambs fed MO leaf meal recorded the lowest lipid % and lower intramuscular fat content. Furthermore, Abo Ghanima *et al*. (2020) found that duck housing enrichment resulted in a reduction in the abdominal fat percentage, which results from the higher level of activity in enriched ducks. In addition, Abdel-Raheem *et al*. (2024) reported high protein content in the meat of ducks fed MO leaf meal and attributed this to the role of *M. oleifera* in boosting protein absorption and protein retention. Dougnon *et al*. (2012) reported that inclusion of MO leaves in the rabbit diet resulted in increased moisture content. According to Olivo and Olivo (2006); Ladeira *et al*. (2014) reported an adverse relationship between the moisture and fat contents. In addition, Elsamee *et al*. (2019) found that duck meat's NFE, nutritional digestibility efficiency, and consumer acceptance are all boosted through the application of MO leaf powder as a herbal growth promoter.

In the present study, providing ducks with environmental enrichment in the form of dietary and/or physical enrichment had a positive effect on their economic efficiency. This improvement could be attributed to higher final body weight and greater conversion rate for feed than the control group. Unless consumers are ready to pay a premium or the enrichment is both efficient and economical and enhances welfare or well-being, most environmental enrichment could have an adverse economic effect due to greater intervention expenses. In the study, tunnel enrichment (as a thing from the surrounding environment) incurred no additional costs and was profitable compared to the control (Jones *et al*., 2020). Despite the marked increase in the total costs, there was an improvement in the economic efficiency in the form of increased net revenue in enriched groups, particularly in the Mo and MO+E groups. The increased total costs are associated with the addition of moringa leaf powder (Ibrahim *et al*., 2017). Higher ultimate body weight and an improved conversion rate of feed may be contributing factors to the increase in economic efficiency in enriched groups compared to control groups. These improvements directly contributed to a reduction in feeding cost per kilogram of body gain, which is the main determinant of economic efficiency in duck production systems.

Conclusion

The cultivation of ducks contributes considerably to the production of poultry meat worldwide. In ducks, the provision of MO leaves as a nutritional enrichment has been demonstrated to positively impact gut health, liver activity, carcass quality, feed conversion ratio (FCR), weight gain, and feed intake. Also, physical enrichment is of great importance in animal rearing environments. Both nutritional and physical enrichment have a great impact on duck growth and production by enhancing their performance, improving the quality of meat through reducing cooking losses, fat and ash content in duck meat, and elevating ducks' weight and protein content of meat. It was clear that higher ultimate body weight and an improved conversion rate of feed may be contributing factors to the increase in economic efficiency in enriched groups compared to control groups. These improvements directly contributed to a reduction in feeding cost per kilogram of body gain, which is the main determinant of economic efficiency in duck production systems, as well as satisfying the consumer needs.

Conflict of interest

The authors have no conflict of interest to declare.

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