Enhancing the Utility of Dietary *Moringa oleifera* Leaf Meal for Sustainable Jumbo quail (*Coturnix* sp.) Production

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Abstract: The effect of pre-treating *Moringa oleifera* leaf powder (MOLP) with different levels of polyethylene glycol (PEG) on the growth performance, serum biochemistry, hematology, and meat quality parameters of Jumbo quail was evaluated. Two-week-old quail chicks (*n* = 432; 239.6 ± 6.48 g live-weight) were randomly allocated to six diets formulated by incorporating (10% *w*/*w*) untreated MOLP (PEG0) or MOLP pre-treated with PEG at 2.5% (PEG25), 5% (PEG50), 7.5% (PEG75), and 10% (PEG100) (*w*/*w*) into a standard grower diet (CON). Overall feed intake linearly increased with PEG levels. At week 4, significant quadratic trends were recorded for weight gain and feed conversion efficiency (FCE) but, at week 5, FCE linearly declined as PEG levels increased. Hemoglobin, phosphorus, and albumin showed quadratic trends, while calcium and chroma (1 h post-mortem) linearly declined in response to PEG levels. Diet PEG50 promoted a higher shear force value (2.41) than diets PEG0 and PEG25. The PEG50 diet promoted a similar (*p > 0.05*) shear force as diet CON. Based on the quadratic response for weight gain, the optimal PEG pre-treatment level was calculated to be 5.9%. It was concluded that MOLP condensed tannins negatively affect growth performance and should be ameliorated to enhance the utility of this nutraceutical source for Jumbo quail.

Keywords: avian birds; blood indices; feed additives; growth traits; meat quality; phytogenics

1. Introduction

The use of phytochemicals could be a long-term strategy for achieving sustainable Jumbo quail (*Coturnix* sp.) intensification for enhanced food and nutrition security. The Jumbo quail is a subspecies of the Japanese quail (*Coturnix coturnix japonica*) that was recently introduced in South Africa for meat production [1]. It is a fast-growing, large-framed (weighing up to 300 g) brownish bird [1,2]. Moreover, quail farming has the capacity to revolutionize the South African poultry industry, which relies heavily on imports to meet local consumer demand. Quail production also provides an opportunity to diversify the poultry industry to increase the supply of animal protein [3]. Currently, quail birds are steadily evolving around the world as an excellent source of protein [4]. Their evolution could be attributed to their low maintenance, early sexual maturity, high prolificacy, short generation intervals, fast growth rates, and resistance to numerous avian diseases [5,6]. However, sustainable intensification of quail birds could be restricted by high feed costs, disease outbreaks, and poor performance. Indeed, the cost of poultry feeds has remained high, especially in the tropics, due to rising prices of soybeans and maize grain, which are conventional nutrient sources in poultry diets [7]. The competition between humans and livestock for these conventional nutrient sources [8] contributes to rising demand that fuels price increases on the world market. It is, therefore, imperative that non-conventional feedstuffs that have nutraceutical properties be identified for use in quail diets to allow...
for sustainable intensification and reduce production cost. One such potential feedstuff is *Moringa oleifera* leaf powder (MOLP), which contains a variety of nutrients and bioactive compounds that could be beneficial to the Jumbo quail.

*Moringa oleifera* Lam is a nutrient-rich plant that is widely distributed in tropical and subtropical countries. It is widely used in the animal, food, and pharmaceutical sectors [9,10]. *Moringa oleifera* by-products have bioactive agents (flavonoids and other phenolics compounds such as caffeic, ferulic, and coumaric) with antimicrobial, antioxidant properties, and hypcholesterolemic effects that can enhance growth performance, health status, meat shelf life, and product quality [11,12]. *Moringa oleifera* leaves have been used as a source of nutrients in poultry [13,14] because they contain high concentrations of protein, vitamins (C, K, and B complex), beta-carotene, and manganese [15]. Moreover, the leaf powder has detergent and anti-septic properties due to the presence of different phytochemicals [16]. The use of MOLP as a dietary supplement in broilers and layers has been shown to improve growth performance and egg quality [17]. However, the amount of MOLP that can be added into Jumbo quail diets is limited by the presence of condensed tannins (CT) (12 g/kg tannins in a dry matter basis) and fiber (19.3% crude fiber) [18]. Indeed, other scholars have reported that the inclusion of MOLP in poultry diets should not exceed 25 g/kg due to the presence of antinutritional factors [19,20]. Further reports have shown that high levels of CT reduce feed utilization efficiency, growth rate, and protein digestibility in chickens [21]. High levels of tannins are harmful to the lining of the small intestines because they disturb normal absorptive function of the gut, resulting in poor performance.

Therefore, there is a need to ameliorate the negative effect of CT to allow the birds to fully benefit from the bioactive components of MOLP. One potential strategy is the use of polyethylene glycol (PEG), a tannin-inactivating compound, which has been reported to have high affinity for CT [22]. Pre-treatment of tannin-rich feeds with PEG has the potential to reduce the negative effects of CT in the gastrointestinal tract of birds and to improve protein digestibility [23]. Several studies have investigated the effect of PEG treatment in poultry [24–26] and ruminant feeds [27,28]. However, the effectiveness of PEG in improving the feed value of MOLP in Jumbo quail diets has not been investigated, possibly because this bird is relatively new to the South African poultry industry. Moreover, the application of PEG to ameliorate the negative effects of CT may enable the inclusion of MOLP at high levels (e.g., 100 g/kg) in Jumbo quail diets without compromising their productivity and meat quality. Therefore, this feeding trial evaluated the effect of pre-treating MOLP with different levels of polyethylene glycol on feed intake, physiology, and meat quality responses of Jumbo quail. We tested the hypothesis that PEG treatment of MOLP would improve the growth performance, blood parameters, and meat quality attributes in Jumbo quail.

2. Materials and Methods

2.1. *Moringa Source and Chemical Composition*

*Moringa oleifera* leaf powder (MOLP) was purchased from Origin Organics Investments (PTY) LTD (Gauteng, South Africa). The MOLP (2 mm) was chemically analyzed for dry matter (DM), ash, organic matter (OM), and crude protein (CP) using guidelines by Association of Official Analytical Chemists [29]. The fiber detergent method by Van Soest et al. [30] was used to determine the neutral detergent fiber (NDF) and acid detergent fiber (ADF). The methods by Makkar [31] were used to determine the total soluble phenolics (TsPh) and soluble condensed tannins (sCT) of the MOLP. Minerals (calcium, phosphorus, sodium, potassium, magnesium, and sulfur) were analyzed using Agri-Laboratory Association of Southern Africa guidelines [32]. Metabolizable energy was calculated using the equation described by Khalil et al. [33].
2.2. Polyethylene Glycol Treatment of Moringa

The PEG (Mr 4000) was purchased from Agro-Enviro Solutions (Gauteng, South Africa). It is a biocompatible, synthetic, hydrophilic polyether compound for which the molecular structure is \( \text{H}-(\text{O}-\text{CH}_2-\text{CH}_2)_n-\text{OH} \) [34]. Initially, four PEG solutions were made by dissolving 150, 300, 450, and 600 g of PEG in 6 L of distilled water. Subsequently, each PEG solution was sprayed onto 6 kg of MOLP, thus producing PEG treatment rates of 2.5, 5, 7.5, and 10% (w/w) before inclusion into the experimental diets. Untreated MOLP was also sprayed with 6 L of distilled water without PEG. The mixing process was conducted as described by Van Niekerk et al. [26]. The untreated and treated MOLP samples were kept at an average room temperature of 25 °C for a duration of 12 h so that the PEG would react with MOLP tannins. The untreated and treated MOLPs were thereafter air-dried to a constant weight and then milled (Polymix PX-MFC 90 D, Kinematica AG, Malters, Switzerland) before being incorporated into a standard grower diet.

2.3. Formulation of Experimental Diets and Analyses

In a mash form, six isonitrogenous and isocaloric experimental diets were formulated by incorporating (10% w/w) untreated MOLP (PEG0) or MOLP pre-treated with PEG at 2.5% (PEG25), 5% (PEG50), 7.5% (PEG75), and 10% (PEG100) (w/w) into a standard grower diet (CON), as shown in Table 1. Nutrient composition of the experimental diets were determined as described in Section 2.1 above and are indicated in Table 2.

| Ingredients                          | CON | PEG0 | PEG25 | PEG50 | PEG75 | PEG100 |
|--------------------------------------|-----|------|-------|-------|-------|--------|
| Polyethylene glycol (%)              | 0.0 | 0.0  | 2.5   | 5.0   | 7.5   | 10.0   |
| *Moringa oleifera* leaf powder       | 0.0 | 100.0| 100.0 | 100.0 | 100.0 | 100.0  |
| Yellow maize-fine                    | 698.6| 626.9| 626.9 | 626.9 | 626.9 | 626.9  |
| Choline powder                       | 0.8 | 0.8  | 0.8   | 0.8   | 0.8   | 0.8    |
| Full fat soya powder                 | 50.7| 148.6| 148.6 | 148.6 | 148.6 | 148.6  |
| Grower-phytase                       | 1.7 | 1.7  | 1.7   | 1.7   | 1.7   | 1.7    |
| Limestone powder                     | 14.5| 14.5 | 14.5  | 14.5  | 14.5  | 14.5   |
| L-Threonine                          | 0.4 | 0.4  | 0.4   | 0.4   | 0.4   | 0.4    |
| Lysine                               | 2.8 | 2.8  | 2.8   | 2.8   | 2.8   | 2.8    |
| Methionine                           | 1.9 | 1.9  | 1.9   | 1.9   | 1.9   | 1.9    |
| Monocalcium phosphate                | 7.2 | 7.2  | 7.2   | 7.2   | 7.2   | 7.2    |
| Olaquindox                           | 0.4 | 0.4  | 0.4   | 0.4   | 0.4   | 0.4    |
| Prime gluten 60                      | 18.0| 18.0 | 18.0  | 18.0  | 18.0  | 18.0   |
| Salt-fine                            | 3.2 | 3.2  | 3.2   | 3.2   | 3.2   | 3.2    |
| Sodium bicarbonate                   | 1.7 | 1.7  | 1.7   | 1.7   | 1.7   | 1.7    |
| Soybean powder                       | 196.7| 70.5 | 70.5  | 70.5  | 70.5  | 70.5   |
| Vitamin and Mineral Premix           | 0.5 | 0.5  | 0.5   | 0.5   | 0.5   | 0.5    |

1Diets: CON = control diet (a standard grower diet); PEG0 = control diet containing 10% MOLP; PEG25 = PEG0 pre-treated with 2.5% polyethylene glycol; PEG50 = PEG0 pre-treated with 5% polyethylene glycol; PEG75 = PEG0 pre-treated with 7.5% polyethylene glycol; PEG100 = PEG0 pre-treated with 10% polyethylene glycol.

2.4. Feeding Trial

The feeding trial was conducted from December to January 2020 at the North-West University’s Farm (Molelwane, 25°86′00″ S; 25°64′32″ E) in South Africa. During this period, ambient temperatures ranged from 27 °C to 37 °C. Mixed-gender Jumbo quail chicks (n = 432; one-week old) were purchased from Golden Quail Farm (Randfontein, South Africa). The chicks were randomly and evenly allotted to 36 pens deemed as the experimental units. The experimental diets were replicated six times per experimental unit. The pens (60 cm W × 100 cm L × 30 cm H) were built using wire mesh, and the floor was covered with removable polythene plastics used as bedding. The birds were adapted to the six experimental diets until two weeks of age while a stress pack containing water-soluble vitamins and electrolytes was given in the first three days. The experiment was conducted
under natural lighting (12 h of daylight) with house temperatures ranging between 25 °C and 30 °C and an average indoor humidity of 60%. For the 4-week feeding period, the birds had unrestricted access to clean water and experimental diets. Initial live weights were measured at 2 weeks of age and thereafter measured weekly until 6 weeks of age to determine average weekly body weight gain (ABWG). Average weekly feed intake (AWFI) was measured by subtracting the weight of the feed refusals (which were measured daily from beginning of week 1 to the end of week 6). Feed conversion efficiency (FCE) was calculated by dividing body weight gain by feed consumed. Nine birds died in total, and the growth performance data were adjusted using the mortality values from the study.

Table 2. Nutrient content (g/kg DM, unless stated otherwise) of the dietary treatments.

| Nutrients                              | MOLP     | CON     | PEG0    | PEG25   | PEG50   | PEG75   | PEG100  |
|----------------------------------------|----------|---------|---------|---------|---------|---------|---------|
| Dry matter (g/kg)                      | 923.7    | 916.1   | 906.5   | 914.6   | 913.7   | 920.8   | 921.2   |
| Ash                                    | 7.6      | 4.93    | 5.21    | 4.81    | 4.85    | 5.15    | 4.49    |
| Organic matter                         | 847.2    | 911.2   | 901.2   | 909.8   | 908.9   | 915.7   | 916.7   |
| Calculated metabolizable energy (MJ/kg)| 12.0     | 12.07   | 12.07   | 12.07   | 12.07   | 12.07   | 12.07   |
| Calculated crude protein               | 177.5    | 182.5   | 182.2   | 182.2   | 182.3   | 182.4   | 182.3   |
| Calcium                                | 7.01     | 7.00    | 7.03    | 7.03    | 7.03    | 7.03    | 7.03    |
| Phosphorus                             | 5.05     | 5.34    | 4.77    | 4.77    | 4.77    | 4.77    | 4.77    |
| Potassium                              | 3.19     | 3.74    | 2.66    | 2.66    | 2.66    | 2.66    | 2.66    |
| Magnesium                              | 1.05     | 1.21    | 0.88    | 0.88    | 0.88    | 0.88    | 0.88    |
| Sulphur                                | 0.60     | 0.74    | 0.48    | 0.48    | 0.48    | 0.48    | 0.48    |
| Sodium                                 | 1.68     | 1.69    | 1.68    | 1.68    | 1.68    | 1.68    | 1.68    |
| Neutral detergent fiber                | 211.1    | 150.0   | 142.6   | 142.4   | 139.2   | 105.6   | 140.5   |
| Acid detergent fiber                   | 151.5    | 113.9   | 111.8   | 92.17   | 92.2    | 102.2   | 111.0   |
| Total phenolics (g/TAE kg DM)          | 41.8     | 9.22    | 19.90   | 20.90   | 20.39   | 18.23   | 18.83   |
| Condensed tannins (AU550 nm/200 mg)    | 0.80     | 0.04    | 0.45    | 0.23    | 0.20    | 0.18    | 0.13    |

1Diets: CON = control diet (a standard grower diet); PEG0 = control diet containing 10% MOLP; PEG25 = PEG0 pre-treated with 2.5% polyethylene glycol; PEG50 = PEG0 pre-treated with 5% polyethylene glycol; PEG75 = PEG0 pre-treated with 7.5% polyethylene glycol; PEG100 = PEG0 pre-treated with 10% polyethylene glycol.

2.5. Slaughter and Hemato-Biochemical Analyses

At day 42 of age, all the birds were weighed to determine their final body weights (FBWs) and then transported to a local poultry abattoir, where they were stunned and then slaughtered by cutting the jugular vein. Blood samples (4 mL) were collected into two sets of sterilized whole blood and serum tubes at slaughter. Hematological and serum biochemical parameters were determined using the Hematology and Vet Test Chemistry Analyzers (IDEXX Laboratories S.A. PTY, Gauteng, South Africa), respectively.

2.6. Carcass and Meat Quality Parameters

Carcass yield, hot carcass weight (HCW), cold carcass weight (CCW), carcass cuts (breast, wing, drumstick, and thigh) and internal organs (liver, proventriculus, gizzard, small intestine, caecum, and colon) of the Jumbo quail were measured as described in our previous work [2,5]. Breast meat pH was determined 1 h and 24 h post-mortem using a Corning pH meter (Model 4 Corning Glass Works, Medfield, MA, USA). Breast meat lightness (L*), redness (a*), yellowness (b*), hue angle, and chroma were taken 1 h and 24 h post-mortem using a spectrophotometer (CM 2500 c, Konika Minolta, Osaka, Japan) following the guidelines by the Commission Internationale de l’Eclairage [35]. Drip and cooking losses were determined following the methods described by Honikel [36]. Shear force, a measure of meat tenderness, was performed on raw breast meat samples according to the method described in our previous work [2]. The water-binding capacity (WBC) was determined using breast meat samples held under 60 kg pressure following the filter-paper press method [37].
2.7. Statistical Analysis

The coefficients for linear and quadratic effects of PEG levels were determined using the response surface regression procedure of SAS (PROC RSREG; SAS [38]). The data for CON were excluded for the regression analysis. Repeated measures analysis by means of General Linear model (GLM) of SAS [38] were used to determine the interaction effects between diet and time (in weeks) on weekly feed intake, weight gain, and FCE. The data for overall feed intake, physiological responses, and meat quality traits were analyzed using one-way analysis of variance (PROC GLM; SAS [38]) with the dietary treatment as the only factor. Significance was set at \( p < 0.05 \), and treatment means were separated using the probability of difference option in SAS.

3. Results
3.1. Growth Performance and Indices

Repeated measures analysis showed significant week \( \times \) diet interaction effects on ABWG (\( p = 0.031 \)) and FCE (\( p = 0.017 \)), except on AWFI (\( p = 0.341 \)). Table 3 shows that PEG pre-treatment levels linearly increased overall feed intake (\( y = 676.2 (\pm 15.95) + 0.198 (\pm 0.763) x; R^2 = 0.329, p = 0.004 \)). Pre-treatment of dietary MOLP with PEG resulted in quadratic trends for weight gain (\( y = 37.22 (\pm 3.17) + 0.471 (\pm 0.152) x - 0.004 (\pm 0.001) x^2; R^2 = 0.305, p = 0.007 \)) and FCE (\( y = 0.223 (\pm 0.016) + 0.002 (\pm 0.0008) x - 0.00002 (\pm 0.000007) x^2; R^2 = 0.374, p = 0.002 \)) in four-week-old quail birds, from which the optimal PEG pre-treatment level was calculated to be 5.9% for weight gain. Five-week-old quail birds showed a linear decrease in FCE (\( y = 0.132 (\pm 0.017) - 0.001 (\pm 0.0008) x; R^2 = 0.172, p = 0.046 \)) as PEG levels increased. Birds reared on PEG75 and PEG100 diets had higher (\( p < 0.05 \)) overall feed intake than those reared on CON, PEG0, and PEG25, for which the overall feed intake did not differ (\( p > 0.05 \)). In week 4, diet PEG50 (57.02 g/bird) promoted the highest (\( p > 0.05 \)) AWG compared with diets CON, PEG0, PEG100, which were statistically similar (\( p > 0.05 \)). The PEG0 diet promoted a similar (\( p > 0.05 \)) AWG as diet PEG25. There were dietary influences (\( p < 0.05 \)) observed for FCE in weeks 4 and 5. In week 4, birds on diet PEG50 (0.232) had the highest FCE when compared with those on diets PEG0 (0.232) and PEG75 (0.231). Diet PEG50 promoted the same (\( p > 0.05 \)) FCE as diets CON, PEG25, and PEG75. In week 5, diets PEG0 (0.135) promoted higher FCE than diets PEG50 (0.087), PEG75 (0.087 g/bird), and PEG100 (0.080), which did not differ (\( p > 0.05 \)). The PEG0 diet had similar (\( p > 0.05 \)) FCEs as diets CON and PEG25.

Table 3. Effect of pre-treating dietary *Moringa oleifera* leaf powder with different levels of polyethylene glycol on growth performance of Jumbo quail.

| 1Diets | CON | PEG0 | PEG25 | PEG50 | PEG75 | PEG100 | 2SEM | p Value |
|--------|-----|------|-------|-------|-------|--------|------|---------|
| Overall feed intake | 644.5 c | 679.8 bc | 666.9 bc | 710.6 ab | 711.5 a | 745.1 a | 14.6 | 0.004 | 0.538 |
| Average weekly weight gain (g/bird) | 47.6 | 39.3 | 37.1 | 37.1 | 46.7 | 48.3 | 4.27 | 0.139 | 0.179 |
| Average weekly feed conversion efficiency | 0.371 | 0.289 | 0.287 | 0.269 | 0.004 | 0.330 | 0.031 | 0.771 | 0.450 |

\(^{abc}\) Means in the same row with different superscripts are significantly different (\( p < 0.05 \)). \(^{1}\)Diets: CON = control diet (a standard grower diet); PEG0 = control diet containing 10% MOLP; PEG25 = PEG0 pre-treated with 2.5% polyethylene glycol; PEG50 = PEG0 pre-treated with 5% polyethylene glycol; PEG75 = PEG0 pre-treated with 7.5% polyethylene glycol; PEG100 = PEG0 pre-treated with 10% polyethylene glycol. \(^{2}\)SEM = standard error of the mean.
Table 4 shows that there was a significant quadratic trend for hemoglobin \((y = 6.99 (\pm 1.08) + 0.126 (\pm 0.049) x - 0.001 (\pm 0.0004) x^2; R^2 = 0.151, p = 0.036)\), which increased with PEG levels and then decreased. Similarly, no significant dietary effects were observed on all hematological parameters of Jumbo quails except for hemoglobin. Birds reared on diet PEG0 had the least \((p < 0.05)\) amount of hemoglobin \((6.84 \text{ g/dL})\) compared with those on diets PEG50 and PEG75, which did not differ \((p > 0.05)\).

### Table 4. Effect of pre-treating dietary *Moringa oleifera* leaf powder with different levels of polyethylene glycol on hematological parameters in Jumbo quail.

| Parameters \(10^9/\text{L} \) | CON | PEG0 | PEG25 | PEG50 | PEG75 | PEG100 | \(^2\)SEM | \(^3\)p Value | Linear | Quadratic |
|-----------------------------|-----|------|-------|-------|-------|--------|---------|-----------|--------|-----------|
| Basophils \(10^9/\text{L}\)  | 0.102 | 0.196 | 0.309 | 0.194 | 0.328 | 0.136 | 0.067 | 0.633 | 0.188 |
| Eosinophils \(10^9/\text{L}\) | 0.182 | 0.801 | 0.811 | 0.432 | 0.582 | 0.395 | 0.196 | 0.115 | 0.825 |
| Erythrocytes \(10^{12}/\text{L}\) | 4.76 | 3.85 | 3.75 | 4.96 | 4.97 | 3.64 | 0.091 | 0.091 | 0.462 |
| Hematocrits \(\text{L/L}\) | 34.1 | 26.6 | 25.2 | 34.6 | 34.6 | 31.6 | 4.7 | 0.212 | 0.410 |
| Hemoglobin (g/dL) | 9.39 \(^\text{ab}\) | 6.84 \(^\text{b}\) | 9.76 \(^\text{ab}\) | 10.9 \(^\text{a}\) | 10.2 \(^\text{a}\) | 9.57 \(^\text{ab}\) | 1.12 | 0.122 | 0.036 |
| Lymphocytes \(10^9/\text{L}\) | 37.75 | 57.27 | 82.24 | 79.24 | 66.8 | 83.3 | 16.6 | 0.514 | 0.720 |
| MCH (pg) | 18.8 | 14.8 | 22.0 | 23.5 | 21.1 | 20.2 | 3.43 | 0.395 | 0.116 |
| MCV (fl) | 65.9 | 55.6 | 58.3 | 68.08 | 70.4 | 66.1 | 7.47 | 0.156 | 0.388 |
| Monocytes \(10^9/\text{L}\) | 0.660 | 1.31 | 1.86 | 1.31 | 1.21 | 1.45 | 0.326 | 0.751 | 0.978 |
| Neutrophils \(10^9/\text{L}\) | 3.48 | 10.2 | 9.03 | 5.31 | 9.77 | 5.25 | 2.46 | 0.259 | 0.868 |
| RDW \(10^9/\text{L}\) | 18.4 | 17.7 | 21.5 | 23.1 | 22.3 | 22.9 | 2.31 | 0.172 | 0.351 |
| Reticulocytes (K/\(\mu\)L) | 3.32 | 5.25 | 1.85 | 2.37 | 3.10 | 3.41 | 1.61 | 0.659 | 0.203 |
| WBC \(10^9/\text{L}\) | 42.1 | 69.9 | 94.2 | 85.6 | 78.7 | 90.5 | 17.6 | 0.663 | 0.771 |

\(^a\)Means in the same row with different superscripts are significantly different \((p < 0.05)\). \(^b\)Diets: CON = control diet (a standard grower diet); PEG0 = control diet containing 10% MOLP; PEG25 = PEG0 pre-treated with 2.5% polyethylene glycol; PEG50 = PEG0 pre-treated with 5% polyethylene glycol; PEG75 = PEG0 pre-treated with 7.5% polyethylene glycol; PEG100 = PEG0 pre-treated with 10% polyethylene glycol. \(^2\)Parameters: MCV = mean corpuscular volume; MCH = mean corpuscular hemoglobin; RDW = red blood cell distribution width; WBC = white blood cells. \(^3\)SEM = standard error of the mean.

Serum calcium linearly declined \((y = 3.94 (\pm 0.346) - 0.018 (\pm 0.015) x; R^2 = 0.158, p = 0.035)\) as PEG levels increased (Table 5). However, serum phosphorus \((y = 3.31 (\pm 0.613) + 0.076 (\pm 0.028) x - 0.0006 (\pm 0.0002) x^2; R^2 = 0.189, p = 0.018)\) and albumin \((y = 27.6 (\pm 4.14) - 0.379 (\pm 0.189) x + 0.004 (\pm 0.001) x^2; R^2 = 0.165, p = 0.030)\) quadratically responded to incremental levels of PEG by first decreasing and then increasing. The diets had no \((p > 0.05)\) effect on serum biochemical parameters, except on phosphorus and albumin. However, diet CON promoted statistically similar \((p > 0.05)\) albumin and phosphorus levels as the other treatment groups.

### 3.2. Carcass and Meat Quality Characteristics

Pre-treatment of dietary MOLP with PEG had no \((p > 0.05)\) linear or quadratic trends for carcass characteristics and internal organ weights in Jumbo quail (Table 6). Similarly, no significant dietary effects were observed on internal organ weights and carcass traits of the birds, except on thigh weights with birds reared on diet CON having lighter \((p < 0.05)\) thigh weights (6.03%HCW) than those reared on diet PEG0 (6.90%HCW).
Table 5. Effect of pre-treating dietary *Moringa oleifera* leaf powder with different levels of polyethylene glycol on serum biochemical parameters in Jumbo quail.

| 2Parameters            | CON     | PEG0    | PEG25   | PEG50   | PEG75   | PEG100  | 3SEM     | Linear  | Quadratic |
|------------------------|---------|---------|---------|---------|---------|---------|----------|---------|-----------|
| Albumin (g/L)          | 25.9ab  | 26.6ab  | 22.7ab  | 17.6b   | 21.6ab  | 31.0a   | 4.64     | 0.492   | 0.030     |
| ALKP (U/L)             | 244.3   | 82.8    | 212.1   | 150.5   | 180.5   | 122.6   | 54.85    | 0.864   | 0.143     |
| ALT (U/L)              | 65.5    | 31.8    | 43.8    | 50.6    | 56.1    | 55.2    | 12.38    | 0.089   | 0.487     |
| Amylase (U/L)          | 284.1   | 274.8   | 384.2   | 330.5   | 441.4   | 363.9   | 99.79    | 0.462   | 0.559     |
| Calcium (mmol/L)       | 3.71    | 3.87    | 3.69    | 3.09    | 3.05    | 2.94    | 0.361    | 0.035   | 0.584     |
| Creatine (µmol/L)      | 26.6    | 31.4    | 17.4    | 39.5    | 18.0    | 29.5    | 9.77     | 0.954   | 0.854     |
| Globulin (g/L)         | 42.9    | 49.8    | 56.5    | 44.5    | 45.08   | 39.9    | 8.61     | 0.232   | 0.742     |
| Glucose (mmol/L)       | 0.885   | 1.75    | 1.57    | 1.38    | 1.06    | 1.00    | 0.450    | 0.154   | 0.941     |
| Lipase (U/L)           | 264.4   | 125.0   | 168.7   | 186.8   | 172.9   | 148.9   | 54.89    | 0.767   | 0.328     |
| Phosphorus (mmol/L)    | 4.68ab  | 3.12ab  | 5.20a   | 5.20a   | 4.33a   | 0.599   | 0.307    | 0.018   | 0.167     |
| Total protein (g/L)    | 63.2    | 41.6    | 79.3    | 63.5    | 62.9    | 60.9    | 11.41    | 0.661   | 0.167     |

1Diets: CON = control diet (a standard grower diet); PEG0 = control diet containing 10% MOLP; PEG25 = PEG0 pre-treated with 2.5% polyethylene glycol; PEG50 = PEG0 pre-treated with 5% polyethylene glycol; PEG75 = PEG0 pre-treated with 7.5% polyethylene glycol; PEG100 = PEG0 pre-treated with 10% polyethylene glycol.

2Parameters: ALKP = alkaline phosphatase; ALT = alanine transaminase.

3SEM = standard error of the mean.

There were significant linear and quadratic trends for breast meat hue angle24 (R² = 1.00, p = 0.0001) as PEG levels increases (Table 7). Chroma values measured 1 h post-mortem showed a linear decrease (y = 22.4 ±1.64 − 0.207 ±0.077 x; R² = 0.436, p = 0.049) in response to PEG pre-treatment levels. The dietary treatments had significant effects on chroma, hue angle24, and shear force of the meat. Birds reared on PEG0, PEG25, PEG50, and PEG100 diets had higher (p < 0.05) meat chroma1 than those reared on CON and PEG75, for which the chroma1 did not differ. Diet PEG100 promoted the highest chroma24 value (17.87) compared with diets CON, PEG0, PEG25, PEG50, and PEG75, which did not differ (p > 0.05). Meat from birds reared on diet PEG100 had a lower (p < 0.05) hue angle24 than meat from those in PEG0 and PEG 75, in which the hue angle24 did not differ. Diet PEG50

Table 6. Effect of pre-treating dietary *Moringa oleifera* leaf powder with different levels of polyethylene glycol on carcass characteristics and internal organ weights (%HCW, unless stated otherwise) of Jumbo quail.

| 2Parameters         | CON     | PEG0    | PEG25   | PEG50   | PEG75   | PEG100  | 3SEM     | Linear  | Quadratic |
|---------------------|---------|---------|---------|---------|---------|---------|----------|---------|-----------|
| Carcass yield (%)   | 67.3    | 66.2    | 60.5    | 64.0    | 65.3    | 63.9    | 2.03     | 0.794   | 0.391     |
| FBW (g)             | 234.3   | 232.4   | 233.1   | 239.6   | 235.9   | 231.3   | 6.487    | 0.766   | 0.366     |
| HCW (g)             | 157.8   | 153.7   | 142.4   | 152.2   | 153.6   | 147.5   | 4.20     | 0.741   | 0.957     |
| CCW (g)             | 154.5   | 149.6   | 142.5   | 149.1   | 122.6   | 166.9   | 14.94    | 0.866   | 0.951     |
| Breast              | 21.2    | 21.2    | 19.9    | 20.8    | 21.6    | 18.94   | 1.57     | 0.537   | 0.569     |
| Wing                | 7.46    | 7.27    | 7.72    | 7.51    | 7.35    | 7.41    | 0.239    | 0.839   | 0.721     |
| Thigh               | 6.03b   | 6.90a   | 6.52ab  | 6.34ab  | 6.20ab  | 6.21ab  | 0.280    | 0.050   | 0.404     |
| Drumstick           | 4.26    | 4.05    | 4.17    | 4.27    | 3.90    | 4.82    | 0.319    | 0.223   | 0.345     |
| Ceacum              | 0.979   | 1.36    | 1.33    | 1.50    | 0.824   | 1.18    | 0.153    | 0.136   | 0.911     |
| Colon               | 0.620   | 0.255   | 0.224   | 0.395   | 0.564   | 0.322   | 0.160    | 0.258   | 0.352     |
| Gizzard             | 2.25    | 2.09    | 2.37    | 2.14    | 2.06    | 2.33    | 0.102    | 0.532   | 0.661     |
| Liver               | 2.93    | 2.89    | 3.05    | 3.01    | 3.13    | 0.204   | 0.310    | 0.973   |           |
| Proventiculus       | 0.541   | 0.571   | 0.582   | 0.647   | 0.585   | 0.719   | 0.063    | 0.175   | 0.645     |
| Small intestine     | 3.90    | 3.630   | 3.70    | 3.70    | 3.62    | 3.94    | 3.68     | 0.253   | 0.291     | 0.238     |

1Diets: CON = control diet (a standard grower diet); PEG0 = control diet containing 10% MOLP; PEG25 = PEG0 pre-treated with 2.5% polyethylene glycol; PEG50 = PEG0 pre-treated with 5% polyethylene glycol; PEG75 = PEG0 pre-treated with 7.5% polyethylene glycol; PEG100 = PEG0 pre-treated with 10% polyethylene glycol.

2Parameters: FBW = final body weight; HCW = hot carcass weight; CCW = cold carcass weight.

3SEM = standard error of the mean.
promoted a higher shear force value (2.41 N) than PEG0 and PEG25 diets, which did not differ ($p > 0.05$). The CON diet promoted similar ($p > 0.05$) shear force values as all the other treatment groups.

**Table 7.** Effect of pre-treating dietary *Moringa oleifera* leaf powder with different levels of polyethylene glycol on breast meat quality parameters in Jumbo quail.

| Parameters | CON  | PEG0 | PEG25 | PEG50 | PEG75 | PEG100 | $p$ Value |
|------------|------|------|-------|-------|-------|--------|-----------|
| pH         | 5.9  | 6.00 | 6.02  | 5.97  | 5.96  | 6.03   | 0.033     |
| $L_*$      | 53.4 | 52.9 | 51.5  | 52.9  | 53.6  | 51.9   | 1.05      |
| $a_*$      | 3.73 | 3.93 | 4.05  | 4.18  | 3.80  | 4.15   | 0.226     |
| $b_*$      | 9.66 | 11.6 | 11.5  | 11.8  | 10.8  | 11.7   | 0.603     |
| Chroma$_a$ | 10.3 | 12.2 | 12.2  | 12.5  | 11.4  | 12.4   | 0.564     |
| Hue angle$_a$ | 1.19 | 1.23 | 1.23  | 1.22  | 1.22  | 1.23   | 0.027     |
| pH$_{24}$  | 5.92 | 5.99 | 5.95  | 5.93  | 5.95  | 5.90   | 0.897     |
| $L_*$$_{24}$ | 48.77 | 49.37 | 47.45 | 47.22 | 40.21 | 34.91 | 3.91     |
| $a_*$$_{24}$ | 5.50 | 5.43 | 6.11  | 6.16  | 5.40  | 9.03   | 0.786     |
| $b_*$$_{24}$ | 11.8 | 14.7 | 14.5  | 13.4  | 13.06 | 15.03  | 0.611     |
| Chroma$_{24}$ | 13.06 | 15.7 | 15.7  | 14.8  | 14.1  | 17.8   | 0.629     |
| Hue angle$_{24}$ | 1.13 | 1.21 | 1.16  | 1.13  | 1.17  | 1.04   | 0.046     |
| Cooking loss (%) | 23.9 | 19.6 | 21.4  | 24.6  | 21.7  | 24.6   | 1.88      |
| Drip loss (%)   | 33.9 | 30.7 | 30.8  | 31.6  | 31.3  | 31.4   | 1.48      |
| Shear force (N) | 2.30 | 2.21 | 2.21  | 2.41  | 2.25  | 2.23   | 0.049     |
| WBC (%)      | 87.9 | 86.9 | 87.5  | 87.0  | 87.3  | 87.4   | 0.978     |

$a,b$ Means in the same row with different superscripts are significantly different ($p < 0.05$). $^1$Diets: CON = control diet (a standard grower diet); PEG0 = control diet containing 10% MOLP; PEG25 = PEG0 pre-treated with 2.5% polyethylene glycol; PEG50 = PEG0 pre-treated with 5% polyethylene glycol; PEG75 = PEG0 pre-treated with 7.5% polyethylene glycol; PEG100 = PEG0 pre-treated with 10% polyethylene glycol. $^2$Parameters: $L^*$ = lightness; $a^*$ = redness; $b^*$ = yellowness; WBC = water-binding capacity. $^3$SEM = standard error of the mean.

4. Discussion

4.1. Feed Intake and Physiological Responses

*Moringa oleifera* leaf powder has nutraceutical properties that can be used in poultry diets to enhance performance, antioxidant capacity, and product quality [20,21]. However, high levels of condensed tannins (CT) in MOLP could restrict its utilization at higher inclusion levels in Jumbo quail diets. Consequently, PEG, a tannin-binding agent, can be applied to negate the antinutritional effects of *Moringa* CT on quail performance [22]. The PEG does not interfere with digestion processes but binds all the polyphenolic compounds including flavones, lignin, and tannins, although it has a higher affinity for tannins [39]. However, the use of PEG to improve the feed value of MOLP at higher inclusion levels in Jumbo quail diets has not been investigated. Pre-treatment of dietary MOLP with incremental levels of PEG had no effect on the concentrations of total soluble phenolics, suggesting that most phenolics in MOLP are not CT. However, pre-treatment with PEG tended to reduce the concentrations of CT. This is because PEG binds to CT, forming strong PEG-tannin complexes that do not react with butanol-HCl mixture during CT assay [31].

Most importantly, the CT in these complexes become inactive and do not reduce crude protein digestibility. In this study, repeated measures analysis showed a significant diet × week interaction effect for weight gain and FCE, indicating that the efficacy of the birds in converting the dietary treatments into body mass varied with the age of birds. The quadratic responses observed for weight gain and FCE in week 4 only were surprising and the reasons are unknown. The significant linear increase in overall feed intake as PEG levels increased could indicate that the anti-nutritional effects of CT were successfully ameliorated, resulting in improved feed utilization. The untreated MOLP promoted the lowest weight gain compared with the standard control diet and the PEG pre-treated MOLP diets, further confirming that the antinutritional effects of CT were ameliorated. These findings corroborate a report that PEG enhanced nitrogen digestibility in broilers fed
high-tannin sorghum [39]. In contrast, pre-treating tannin-containing rapeseed meal with PEG at a rate 1.5% PEG had no influence on male broiler performance [40]. The response of the quail reared on MOLP treated with less than 5.9% PEG may indicate that the amount of PEG administered to them was insufficient to inactivate the harmful effects of CT on quails.

Blood parameters offer a clearer diagnosis of toxicosis and clinical surveillance of disorders as well as indicators of pathogenic and nutritional state of animals [41]. No diet-induced changes were observed for all hematological parameters except hemoglobin, which exhibited a positive quadratic trend as PEG levels increased. However, all the hematological parameters fell within the normal ranges reported for a healthy quail [2,4,5]. The fact that the albumin initially increased and then declined confirms that PEG treatment must be capped at 5.9%. Moreover, no differences were observed particularly on serum total protein as well as the liver enzymes (ALT and ALKP), further verifying that the pre-treating MOLP with PEG did not compromise the health status of the birds.

4.2. Carcass and Meat Quality Traits

Pre-treating MOLP with PEG had no influence on the size of internal organs, carcass, or meat quality attributes except chroma, hue angle, and shear force. These findings agreed with those of Kumanda et al. [25], who indicated a lack of dietary effect on meat lightness ($L^*$), redness ($a^*$), and yellowness ($b^*$) in broilers fed diets containing red grape pomace. Nonetheless, as the PEG levels increased, the redness of the meat decreased, indicating that the highest PEG treatment of MOLP may have interfered with anthocyanin and lowered the myoglobin content of the meat. Because of the degradation of myofibrillar proteins, meat softness improves substantially as muscles age. Tenderness is an important factor that consumers evaluate when making a purchase [42]. The shear force value reveals how delicate the meat is, with a lower value indicating tenderness and a higher value showing toughness.

As such, meat from birds reared on the diet pre-treated with 5% PEG had a higher shear force value than the meat from the birds reared on the other treatments (PEG0 and PEG25) indicating tougher meat in the former group. In comparison with the control diet, the chroma values increased considerably with the addition of PEG, which could be attributable to an increase in $a^*$ values. As a result, PEG treatment of MOLP increased the color intensity of Jumbo quail meat. The ability of meat to hold water is referred to as its water binding capacity (WBC) [43]. It is a critical quality metric that impacts the amount of water lost during transit, storage, processing, and cooking as well as the visual attractiveness of meat [44]. Juices are released during cooking because of protein denaturation and muscle atrophy [45]. In this investigation, there was no change in WBC, cooking loss, or drip loss, indicating that utilizing untreated or treated MOLP did not impact meat quality in Jumbo quail birds.

5. Conclusions

Inactivating condensed tannins with polyethylene glycol in Moringa oleifera leaf powder boosted overall feed intake. In week 4, the average weekly weight gain and feed conversion efficiency of quail initially increased in response to polyethylene glycol pre-treatment levels before decreasing. However, blood parameters, internal organs, carcass characteristics, and meat quality attributes were not influenced by PEG treatment. We concluded that pre-treating Moringa oleifera leaf powder with PEG at 5.9% maximizes weight gain in Jumbo quail.

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**Data Availability Statement:** The data presented in this study are available on request from the corresponding author. The data are not publicly available because the diet formulae used in this study are proprietary brands.

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