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The effect of incorporating dietary green seaweed (*Ulva* sp.) on growth performance, blood parameters, and carcass and meat quality characteristics of Jumbo quail

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ABSTRACT

Seaweeds are functional aquatic plants that can be used in Jumbo quail (*Coturnix* sp.) feeds as sources of phytochemicals and nutrients. However, no studies have investigated the feed value of green seaweed (*Ulva* sp.) meal (SM) for the Jumbo quail. Thus, the impact of different dietary inclusion levels of SM on productive traits, serum biochemistry, haematology, visceral organ sizes, carcass features, and meat quality attributes in Jumbo quail was investigated. In a completely randomised design, one-week-old quail (n = 385; 67.7 ± 3.44 g body weight) were allotted to five treatments, with seven replicate pens (experimental unit). The treatments were produced by including 0 (SM0), 20 (SM20), 40 (SM40), 60 (SM60) and 80 g/kg (SM80) of green SM in a commercial grower diet. Regression results showed no linear or quadratic effects ($P > 0.05$) to different levels of SM for average weekly feed intake, overall weight gain, haematological indices, internal organs, carcass features, and meat quality characteristics of the birds. However, incorporating SM up to 80 g/kg in the diet linearly reduced overall gain-to-feed ratio (G:F) [$R^2 = 0.282$; $P = 0.0001$] and slaughter weights [$R^2 = 0.159$; $P = 0.026$]. Treatment SM80 promoted ($P < 0.05$) higher feed intake than diet SM60 in weeks 3, 4 and 5, but were comparable to the control treatment in weeks 4 and 5. Birds fed with diets SM0 and SM20 had higher ($P < 0.05$) overall weight gain than birds fed with diet SM60. Diet SM80 resulted in lower ($P < 0.05$) overall G:F (0.250) than diet SM0 (0.277). Higher slaughter weights were observed on SM0 and SM20 groups than the SM60 group. We concluded that the use of dietary green SM up to 80 g/kg in Jumbo quail feeds compromises gain-to-feed ratio and slaughter weights but not physiological and meat quality attributes.

1. Introduction

The high demand for animal protein has resulted in an increase in animal production worldwide. This has prompted the expansion of the poultry industry with unconventional bird species like the quail to boost poultry production [1]. Quail farming has been recently hailed as a viable source of income and high-quality protein and micronutrients that can be used to combat food insecurity in developing countries such as South Africa [2]. The Jumbo quail (*Coturnix* sp.) is one example of recently developed meat-type birds, whose production is intended to increase meat supply and economic growth of the poultry industry [3]. It is a large-frame (~250 g at

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five weeks of age) brownish bird that has short generation intervals, excellent adaptability, fast growth rates, high muscle-to-bone ratio, and strong resistance to infectious diseases [3,4]. However, the viability and sustainability of Jumbo quail farming could be limited by high feeding costs, owing to the increasing prices of major ingredients (maize and soybean) that are mostly used during poultry feed formulations [4]. Furthermore, the reliance on antibiotic growth promoters (AGP), which have been publicly denounced due to the presence of antibiotic traces in animal-derived foodstuffs and the formation of antibiotic resistant pathogens that could compromise human health [5], increases production cost because AGPs are expensive.

Thus, the use of naturally available nutraceutical sources in quail diets can deliver profitable and organic quail enterprises and ensure that humans consume safe and high-quality quail products. One putative nutraceutical source, which is largely available across diverse ecological regions and exist globally in intertidal zones of marine environments, is green seaweed (*Ulva* sp., *Chlorophyceae*) [6,7]. Green seaweeds, also known as sea lettuce, forms an integral part of the aquatic habitat [8] and contain numerous biologically active compounds such as phlorotannins, hydrocolloids, polysaccharides, prebiotic substances, terpenes, and polyphenols [9]. These compounds have been reported to exhibit antioxidant, anticoagulant, anticancer, anti-inflammatory, antimicrobial, immunomodulatory, hypocholesterolemic and hypoglycaemic, and neuroprotective activities [10] that could enhance quail performance, health status, and meat quality. Moreover, seaweeds contain essential amino acids, vitamins, pigments, chelated micro-minerals (arsenic, chromium nickel, and selenium), and complex carbohydrates (alginate, agar, laminarin, and fucoidan) [11,12] that could boost the nutritional status of the Jumbo quail.

Apart from their desirable nutritional value, seaweeds are regularly washed to the coastal shorelines where they decay into seaweed heaps that emit hydrogen sulphide that is detrimental to the environment as well as human and animal health [13]. Thus, its incorporation in diets of Jumbo quail would contribute to environmental sustainability and allow for sustainable quail intensification even in feed deficient areas. Recent findings showed that the incorporation of seaweeds in poultry feeds boost immunological responses, enhance meat and egg quality, and reduce gut pathogens [7,14,15]. However, to this end, the feed value of dietary green SM is unknown for the Jumbo quail. Thus, we studied the impact of different inclusion levels of green SM on Jumbo quail performance, serum biochemistry, haematology, carcass characteristics, internal organs, and meat quality. We hypothesized that the incorporation of dietary SM would improve Jumbo quail performance, health status, and meat quality traits.

2. Materials and methods

2.1. Ethical statement

The North-West University's Research Ethics Committee for Animal Production Studies approved all the research protocols used in this study (NWU-01885-19-S5).

Table 1
Nutritional content of seaweed meal (%, unless stated otherwise).

Components	Seaweed meal
Dry matter	90.4
Calculated ME (MJ/kg)	7.40
Ash	9.93
Organic matter	80.4
Crude protein	17.6
Crude fat	6.53
Alanine	1.52
Lysine	1.01
Methionine	0.36
Histidine	0.29
Arginine	0.71
Serine	0.84
Glycine	0.94
Aspartic acid	1.99
Glutamic acid	2.17
Histidine	0.29
Threonine	0.60
Valine	1.01
Isoleucine	0.67
Leucine	1.25
Phenylalanine	0.79
Proline	0.55
Neutral detergent fibre	22.6
Acid detergent fibre	16.6
Acid detergent lignin	5.0

ME = metabolizable energy.

2.2. Harvesting and analyses of the seaweed meal

The seaweed (*Ulva* sp.) was collected by hand from an Abalone farm to form a bulk sample, which was cleaned and then oven-dried at 60 °C until constant weight before milling using a Polymix grinder fitted with a 2-mm sieve (model no: PX-MFC 90D, Switzerland). Triplicate samples of the milled SM were analysed (Table 1) using the Association of Official Analytical Chemist (AOAC) methods [16] for dry mater, ash, organic matter, crude protein, and crude fat. Amino acids were analysed using the Waters Acquity UPLC that was fitted with a photodiode array detector. Neutral detergent fibre (NDF) with an aid of a heat-stable amylase and acid detergent fibre (ADF) were assayed with an ANKOM^{2000} Fibre Analyser (ANKOM Technology, NY, US) following the guidelines by Van Soest et al. [17]. Acid detergent lignin was determined by soaking the ADF residue F57 filter bags in 72% sulphuric acid for 3 h and oven-dried for 6 h. The following formula [$ME\,(kcal/kg) = (35.3 \times CP\,\%) + (79.5 \times EE\,\%) + (40.6 \times NFE\,\%) + 199.0$] was used to calculate metabolizable energy (ME) [18].

2.3. Formulation and analysis of the diets

Five isocaloric and isoproteic diets were produced by blending the ingredients as indicated in Table 2. The diets, in a mash form, were nutritionally balanced to meet the nutrient requirements for grower quail [19]. The treatments were: 1) SM0 = a commercial grower meal with no SM; 2) SM20 = a commercial grower meal with 20 g/kg SM; 3) SM40 = a commercial grower meal with 40 g/kg SM; 4) SM60 = a commercial grower meal with 60 g/kg SM; and 5) SM80 = a commercial grower meal with 80 g/kg SM. The chemical composition and metabolizable energy values of the dietary treatments were determined using the methods described above.

2.4. Experimental design

The 35-day feeding experiment was performed during summer (January–February 2022) in the North-West University Experiential Farm (25°34′58″S, 25°64′32″E) in Mafikeng, South Africa. Seven-day-old, mixed gender quail chicks (n = 385) were acquired from a small-holder quail breeder (Randfontein, South Africa). The chicks were evenly and randomly assigned into 35 pens, which were designated as experimental units (wire-mesh pens; 1.0 m W × 3.5 m L × 1.85 m H). Each experimental unit held 11 birds and was replicated 7 times per treatment. The pen floors were covered with removable polythene plastics and no bedding material was used. The quail house was ventilated by opening windows and the temperature ranged between 27 and 33 °C while humidity ranged from 55 to 65%. The quail were offered free access to the dietary treatments and fresh water and rearing was carried out during daylight from morning (06h00 a.m.) to the evening (18h00 p.m.). There were no mortalities recorded during the feeding trial.

Table 2
Gross ingredient and nutritional composition (g/kg, as fed basis) of the experimental diets.

Ingredients	[a]Diets				
	SM0	SM20	SM40	SM60	SM80
Seaweed meal	0	20	40	60	80
Soybean meal (44%)	360.6	361.9	363.3	365.3	366.0
Maize yellow	556.4	531.1	505.8	477.2	455.5
Dicalcium phosphate	14.7	14.5	14.4	14.3	14.2
Palm oil	48.1	54.2	60.3	67.5	68.6
Limestone	11.1	11.2	11.2	11.2	11.2
Common salt	4.6	2.6	0.5	0	0
[b]Premix	2.0	2.0	2.0	2.0	2.0
DL-methionine	2.0	2.0	2.0	2.0	2.0
Choline Cl70	0.5	0.5	0.5	0.5	0.5
Proximate components and ME values (g/kg DM, unless stated otherwise)					
Calculated [c]ME (MJ/kg)	12.98	12.98	12.98	12.98	12.98
Crude protein	205.1	205.0	205.1	205.1	205.2
Dry matter	910.0	900.7	901.4	894.4	904.5
Ash	50.7	62.0	59.4	54.1	66.7
Organic matter	859.3	838.8	842.0	840.3	837.7
Lysine	12.10	12.20	12.20	12.30	12.30
Methionine	5.40	5.40	5.40	5.50	5.50
Crude fat	65.75	61.95	88.69	83.81	89.46
Neutral detergent fibre	189.0	188.0	194.0	197.3	198.6
Acid detergent fibre	56.6	55.7	65.7	60.1	59.1
Acid detergent lignin	10.7	14.8	15.1	13.5	16.4

[a] Diets: SM0 = a commercial grower diet without SM; SM20 = a commercial grower diet with 20 g/kg SM; SM40 = a commercial grower diet with 40 g/kg SM; SM60 = a commercial grower diet with 60 g/kg SM; SM80 = a commercial grower diet with 80 g/kg SM.

[b] Premix: Ferrous sulphate (80 mg), zinc sulphate (79 mg), folic acid (0.7 mg), copper sulphate (8.0 mg), potassium iodide (0.34 mg), magnesium sulphate (100 mg), sodium selenite (0.25 mg), biotin (0.12 g), niacin (30 mg), vitamin A (11,000 IU), vitamin K3 (2.0 mg), vitamin B1 (2.5 mg), vitamin B6 (5.1 mg), vitamin B2 (4.5 mg), vitamin D3 (2500 IU), vitamin E (25 IU), and pantothenic acid (10 mg).

[c] ME = metabolizable energy.

2.5. Growth performance

Initial body weights (67.7 ± 3.44 g live-weight) were measured in week 1 of age. Thereafter, the birds were weighed every week to obtain average weight gain. Feed intake (feed offered – feed refused) was measured daily and averaged for each bird per week in each experimental unit. Gain-to-feed ratio (G:F) was determined as the ratio of weight gain and feed intake.

2.6. Slaughter and blood analysis

At day 35 of age, every quail in a pen was weighed to determine slaughter weights. The birds were then taken to a nearby abattoir where they were stunned and exsanguinated and allowed to bleed while hanging upside down. Fresh samples of the blood (4 ml) were immediately collected from two birds randomly selected per experimental unit and transferred to sterile haematological tubes (with EDTA) and serum biochemical tubes. The serum tubes were processed using a centrifuge (Cryste Varispin 4 Multi-purpose centrifuge, 4000 rpm; 5 min, Cryste CO., LTD, Korea) to produce the sera [20], which was analysed using an automated Catalyst One Chemistry Analyser (IDEXX Laboratories (Pty) Ltd., Gauteng, South Africa) for urea, symmetric dimethylarginine (SDMA), total protein, alanine aminotransferase (ALT), creatinine, phosphorus, globulin, calcium, cholesterol, albumin, amylase, lipase, alkaline phosphatase (ALKP) and total bilirubin. Haematological parameters (haematocrit, platelets, white cell count (WCC), lymphocytes, heterophils and monocytes) were analysed within 48 h after blood collection [20] with an automated LaserCyte Haematology Analyser (IDEXX Laboratories (Pty) Ltd., Gauteng, South Africa).

2.7. Post-slaughter measurements

After plucking, all the carcasses (devoid of the internal organs, head and feed) were weighed with a platform scale to obtain hot carcass weight (HCW). After, the carcasses (per experimental unit) werestored at 16 °C for 24 h and then weighed again to determine cold carcass weights (CCW). Carcass yield was determined by dividing HCW with slaughter weight and expressed in percentages. The carcasses were subsequently cut into various parts (breast, wing, thigh, and drumstick) for measurement of their lengths or weights. Internal organ sizes (liver, proventriculus, gizzard, small intestines, and large intestines) were also determined.

Breast meat pH, temperature, and colour coordinates [21]: lightness (L^*), yellowness (b^*) and redness (a^*) were all determined 1 h and 24 h post-mortem as described in our previous work [2,3]. The hue angle and chroma values were calculated as described by Priolo et al. [22]. Cooking loss was determined after cooking the breast meat samples at 75 °C for 20 min [23]. The filter-paper press method was used to quantify breast meat water-holding capacity (WHC), where 60 kg pressure was exerted on breast samples (~8 g) that were placed in-between two filter papers for 5 min [24].

2.8. Statistical analysis

Data for all measured parameters were analysed using response surface regression analysis [25] to obtain linear and quadratic coefficients. A single factor analysis of variance was employed to account for dietary effects on the data using PROC GLM in SAS. Data for weekly feed intake, weight gain and G:F were further analysed using repeated measures analysis in PROC GLM [25] to determine the interaction effect of treatment and time (week). Significance was declared at $P < 0.05$ and the least square means were separated using the probability of difference option in SAS.

Table 3
Effect of different levels of dietary seaweed meal on average weekly feed intake (g/bird), overall weight gain (g/bird) and overall gain-to-feed ratio in Jumbo quail (n = 385).

[b]Parameters	[a]Diets					[c]SEM	*P* value	
	SM0	SM20	SM40	SM60	SM80		Linear	Quadratic
Average weekly feed intake								
Week 2	118.4	124.1	120.1	118.97	123.1	2.131	0.662	0.932
Week 3	143.2^{a}	152.9^{b}	147.9^{ab}	143.9^{a}	154.7^{b}	1.897	0.081	0.739
Week 4	182.1^{ab}	191.1^{b}	185.1^{b}	164.4^{a}	195.2^{b}	4.496	0.982	0.197
Week 5	214.2^{ab}	213.8^{ab}	221.0^{ab}	202.9^{a}	235.2^{b}	6.381	0.170	0.136
Overall BWG	182.4^{b}	182.6^{b}	180.3^{ab}	165.9^{a}	177.2^{ab}	3.965	0.053	0.531
Overall G:F	0.277^{b}	0.268^{ab}	0.267^{ab}	0.264^{ab}	0.250^{a}	0.005	0.001	0.567

[a,b]Means in a row with different superscripts denote statistical differences ($P < 0.05$).
[a] Diets: SM0 = a commercial grower diet without SM; SM20 = a commercial grower diet with 20 g/kg SM; SM40 = a commercial grower diet with 40 g/kg SM; SM60 = a commercial grower diet with 60 g/kg SM; SM80 = a commercial grower diet with 80 g/kg SM.
[b] Parameters: BWG = body weight gain; G:F = gain-to-feed ratio.
[c] SEM = standard error of the mean.

3. Results

3.1. Growth and blood parameters

There were no week × diets interaction effects on weight gain (P = 0.194) and G:F (P = 0.387), except on feed intake (P = 0.025). Neither linear nor quadratic effects (P > 0.05) were noted for overall feed intake and weight gain, but overall G:F linearly declined [$y = 0.276 (\pm 0.005) - 0.001 (\pm 0.003) x$; $R^2 = 0.298$; P = 0.0001] with increasing dietary SM levels (Table 3). The GLM results showed significant dietary effects on feed intake in weeks 3, 4 and 5, and on overall weight gain and G:F. Birds fed with the SM0 and SM20 diets had significantly higher overall weight gain than the birds fed with the SM60 diet. The control diet SM0 promoted higher overall G:F (0.277) than diet SM80 (0.250). Three-week old birds fed with diets SM0 and SM60 had lower (P < 0.05) feed intake than those on SM20 and SM80 treatment groups. In week 4, diet SM60 promoted lower feed intake (164.4 g/bird) than diets SM20, SM40, and SM80, which promoted statistically similar feed intake. Five-week-old birds fed with diet SM80 (235.2 g/bird) had significantly higher feed intake than to those fed with diet SM60 (202.9 g/bird). Nonetheless, diet SM0 promoted similar (P > 0.05) feed intake as diets SM20, SM40, SM60 and SM80 in weeks 4 and 5.

Feeding different dietary SM levels induced no linear or quadratic effects on blood parameters (Table 4). Likewise, no dietary effects (P < 0.05) were observed on serum biochemical and haematological parameters of the birds.

3.2. Organs and meat quality

Supplementation of the diet with different levels of SM linearly reduced slaughter weights [$y = 254.0 (\pm 4.281) - 3.51 (\pm 2.535) x$; $R^2 = 0.159$; P = 0.026] (Table 5). Likewise, dietary effects were recorded on slaughter weights only, where diets SM0 and SM20 promoted heavier (P < 0.05) slaughter weights than diet SM60 (232.3 g/bird). Nonetheless, diets SM0 and SM20 promoted comparable (P > 0.05) slaughter weights as diets SM40 and SM80. The supplementation of the diets with SM up to 80 g/kg induced no effects on organ sizes, carcass traits, and breast meat quality of the birds (Table 6).

4. Discussion

4.1. Growth performance and blood parameters

The incorporation of green seaweed in Jumbo quail feeds as a source of protein, minerals, polysaccharides, pigments, polyunsaturated fatty acids, phlorotannins, and carotenoids [26,27] could boost the nutritional status of the birds and, therefore, allow for large-scale intensification. In this study, diet-induced changes on feed intake depended on the age of the birds as shown by the diets ×

Table 4
Blood parameters of five-week-old Jumbo quail (n = 70) fed with diets containing different levels of seaweed meal.

[b]Parameters	[a]Diets					[c]SEM	*P* value	
	SM0	SM20	SM40	SM60	SM80		Linear	Quadratic
Haematocrits (%)	56.57	52.58	55.83	58.25	56.00	2.380	0.609	0.582
[b]WCC ($\times 10^9$/L)	18.57	17.64	21.96	20.07	18.21	3.957	0.905	0.539
Platelets ($\times 10^9$/L)	20.43	19.00	22.17	20.88	21.64	4.486	0.698	0.976
Heterophils (%)	61.79	64.42	61.50	66.63	60.57	5.441	0.899	0.430
Lymphocytes (%)	31.93	28.08	31.83	26.38	33.79	3.865	0.769	0.264
Monocytes (%)	5.71	6.75	6.25	7.00	5.21	1.277	0.723	0.175
SDMA (μg/dL)	40.17	31.64	33.00	40.17	30.29	4.604	0.397	0.835
Urea (mmol/L)	1.15	1.09	1.59	1.61	1.06	0.349	0.788	0.698
Phosphorus (mmol/L)	5.14	5.20	5.03	5.20	5.18	0.090	0.483	0.080
Calcium (mmol/L)	3.07	3.28	8.74	3.31	2.78	2.918	0.448	0.728
Total protein (g/L)	45.93	50.0	41.07	55.75	50.57	6.037	0.494	0.851
ALT (U/L)	46.00	76.86	69.0	49.17	82.71	18.44	0.077	0.400
ALKP (U/L)	185.9	165.8	154.8	206.1	282.8	44.03	0.629	0.660
Total bilirubin (μmol/L)	15.21	43.79	8.70	21.0	38.0	24.61	0.908	0.436
Cholesterol (mmol/L)	4.57	4.10	4.50	4.73	4.96	0.320	0.647	0.084
Amylase (U/L)	228.7	250.6	346.6	267.8	244.1	44.64	0.391	0.547
Lipase (U/L)	141.7	219.4	208.5	264.3	169.0	34.77	0.608	0.141
Albumin (g/L)	16.36	19.57	17.57	21.08	21.21	3.005	0.294	0.199
Creatinine (μmol/L)	9.86	15.33	11.87	13.83	14.93	3.352	0.142	0.984
Globulin (g/L)	29.36	28.93	24.53	31.50	31.21	4.179	0.320	0.539

[a,b]Means in a row with different superscripts denote statistical differences ($P < 0.05$).
[a] Diets: SM0 = a commercial grower diet without SM; SM20 = a commercial grower diet with 20 g/kg SM; SM40 = a commercial grower diet with 40 g/kg SM; SM60 = a commercial grower diet with 60 g/kg SM; SM80 = a commercial grower diet with 80 g/kg SM.
[b] Parameters: ALT = alanine aminotransferase; WCC = white cell count; ALKP = alkaline phosphatase; SDMA = symmetric dimethylarginine; ALB/GLOB = albumin/globulin ratio.
[c] SEM = standard error of the mean.

Table 5
Carcass yield, carcass features, and internal organs (g/100 g HCW, unless mentioned otherwise) of five-week-old Jumbo quail (n = 315) fed different levels of seaweed meal containing diets.

[b]Parameters	[a]Diets					[c]SEM	P value	
	SM0	SM20	SM40	SM60	SM80		Linear	Quadratic
Slaughter weight (g)	251.8[b]	250.9[b]	248.0[ab]	232.3[a]	244.2[ab]	4.233	0.026	0.458
HCW (g)	163.8	163.3	163.4	155.2	162.3	2.783	0.235	0.539
CCW (g)	157.8	155.8	160.7	154.2	157.4	2.446	0.772	0.911
Carcass yield (%)	65.05	65.09	65.98	66.86	66.44	0.823	0.085	0.758
Drumstick	4.30	4.51	5.22	4.18	4.28	0.431	0.790	0.232
Thigh	6.79	7.81	6.67	6.73	7.82	0.675	0.654	0.603
Wing	4.70	4.81	4.67	5.24	4.84	0.238	0.360	0.741
Breast	17.40	18.08	17.79	17.36	17.65	0.288	0.819	0.422
Drumstick (cm)	6.19	6.17	6.32	6.24	7.12	0.421	0.949	0.516
Wing (cm)	11.69	11.80	11.77	11.74	11.60	0.205	0.693	0.494
Thigh (cm)	5.74	5.16	5.95	6.15	5.19	0.553	0.949	0.516
Back (cm)	11.48	11.53	11.82	11.79	11.24	0.443	0.871	0.356
Liver	3.20	3.38	3.31	3.14	3.14	0.181	0.526	0.490
Proventriculus	0.62	0.62	0.60	0.59	0.62	0.028	0.872	0.548
Gizzard	2.29	2.34	2.32	2.31	2.31	0.064	0.982	0.708
Spleen	0.18	0.19	0.27	0.14	0.20	0.046	0.853	0.595
Large intestine	1.09	1.13	1.11	1.09	1.03	0.052	0.387	0.280
Large intestine (cm)	9.56	11.25	9.30	12.26	10.87	0.970	0.264	0.743
Small intestine	4.03	4.35	4.27	4.39	4.15	1.935	0.964	0.227
Small intestine (cm)	64.05	67.75	54.63	66.50	65.42	4.247	0.920	0.378

[a,b]Means in a row with different superscripts denote statistical differences ($P < 0.05$).
[a] Diets: SM0 = a commercial grower diet without SM; SM20 = a commercial grower diet with 20 g/kg SM; SM40 = a commercial grower diet with 40 g/kg SM; SM60 = a commercial grower diet with 60 g/kg SM; SM80 = a commercial grower diet with 80 g/kg SM.
[b] Parameters: CCW = cold carcass weight; HCW = hot carcass weight.
[c] SEM = standard error of the mean.

Table 6
Breast meat quality attributes of five-week-old Jumbo quail (n = 315) fed with different levels of seaweed meal containing diets.

[b]Parameters	[a]Diets					[c]SEM	P value	
	SM0	SM20	SM40	SM60	SM80		Linear	Quadratic
pH_1	5.91	5.98	5.95	5.93	5.91	0.042	0.715	0.318
$Temperature_1$ (°C)	27.08	26.98	26.50	26.78	26.62	0.729	0.6237	0.814
L^*_1	51.91	51.26	53.59	51.62	51.98	1.146	0.892	0.599
a^*_1	6.47	6.69	6.64	6.86	6.88	0.311	0.308	0.919
b^*_1	5.22	4.83	5.44	5.32	6.20	0.445	0.085	0.276
$Chroma_1$	8.43	8.29	8.66	8.81	9.29	0.271	0.112	0.313
Hue $angle_1$	0.68	0.63	0.69	0.66	0.73	0.055	0.440	0.461
pH_{24}	6.07	6.11	6.10	6.13	6.12	0.056	0.489	0.757
$Temperature_{24}$ (°C)	18.93	18.54	19.28	18.77	18.90	4.862	0.991	0.279
L^*_{24}	52.75	51.45	54.00	55.38	51.77	1.283	0.642	0.256
a^*_{24}	7.43	7.35	8.10	6.82	7.73	0.792	0.984	0.994
b^*_{24}	5.75	5.07	6.21	6.35	5.83	0.376	0.254	0.639
$Chroma_{24}$	9.51	8.99	10.40	9.40	9.75	0.667	0.674	0.790
Hue $angle_{24}$	0.66	0.61	0.70	0.75	0.64	0.057	0.613	0.447
Cooking loss (%)	25.07	22.39	24.62	25.47	27.38	3.082	0.423	0.492
WHC (%)	67.50	69.18	67.46	71.74	69.17	1.076	0.118	0.567

[a] Diets: SM0 = a commercial grower diet without SM; SM20 = a commercial grower diet with 20 g/kg SM; SM40 = a commercial grower diet with 40 g/kg SM; SM60 = a commercial grower diet with 60 g/kg SM; SM80 = a commercial grower diet with 80 g/kg SM.
[b] Parameters: WHC = water holding capacity; a^* = redness; b^* = yellowness; L^* = lightness.
[c] SEM = standard error of the mean.

week (bird age) interaction effect on feed intake. In weeks 3, 4, and 5, dietary effects were observed on feed intake, in which birds reared on the SM80 diet showed the highest feed intake, possibly indicating a nutrient dilution mechanism to cope with high dietary fibre and lignin levels in the diet. Birds reared on diet SM60 had lower overall weight gain than those on control group and SM20, which is indicative of poor feed utilisation efficiency, due to increased NDF (197.3 g/kg), ADF (60.1 g/kg) and ADL (13.5 g/kg) values on the SM60 group. Contrary to these findings, similar studies reported a lack of dietary effects on weight gain in chickens fed diets with 30 and 35 g/kg SM [7,28]. The linear decrease for overall G:F as dietary SM levels increased could be attributed to the presence of long chain β-glucans, pectin, cellulose, and arabinoxylans in seaweeds [29], which are reported to reduce the rate of digestive enzyme diffusion into the digesta by forming a highly viscous digesta and, ultimately, reduce nutrient utilisation in simple non-ruminants [30].

Indeed, the diets containing between 40 and 80 g/kg SM had higher levels of ADF and ADL, compared to the control diet without the SM. In a broiler chicken study, the incorporation of 35 g/kg green seaweed in the diets also reduced overall G:F of the birds [31]. The reduced G:F can be attributed to the seaweed non-starch polysaccharides [11,12], which are known to suppress nutrient digestibility [32]. The lower G:F values in the SM80 group further confirms that the high ADL values in the diet affected the birds' ability to convert the feed into body mass. Indeed, Jha and Misha [32] reported that there is a strong negative correlation between high dietary fibre levels and nutrient utilisation efficiency in poultry.

Blood serum enzymes are valuable diagnostic indicators to assess hepatic function and the extent of hepatocellular injuries, tissue damage, and organ malfunction in farm animals [33]. The extent of liver injuries can be detected by measuring plasma levels of alanine transaminase (ALT), aspartate transaminase, alkaline phosphatase (ALKP), and gamma-glutamyl transferase, which are the most critical biomarkers in clinical practice [34–36]. The absence of dietary effects on the liver enzymes (ALKP and ALT) indicates that the incorporation of SM did not affect the health status of the Jumbo quail. Similar studies indicated that adding 20 g/kg seaweed (*Chondrus crispus*) into basal layer diets had no effects on serum protein, and aspartate aminotransferase [37]. Likewise, the concentration of ALKP was not altered by the inclusion of 60 g/kg brown algae in laying hens [26]. Similar studies [31,38] have reported that the incorporation of seaweeds in layer and broiler diets do not alter their health status. The observed haematological values agree with those reported by Kang et al. [37], where feeding broiler chickens with diets supplemented with 10 g/kg seaweed (*Chlorella vulgaris*) had no impact on heterophils, lymphocytes, and monocytes. However, the haematocrit values in the current study were higher than the normal reference values reported for normal and healthy quail [3,39].

4.2. Carcass characteristics, internal organs, and meat quality

Seaweeds contain functionally active substances with growth-boosting, antioxidant, and antimicrobial activities that can improve carcass yield and meat quality parameters by promoting muscular development, eliminating free radicals, and thus prolong the keeping quality of the meat [40]. However, the supplementation of diets with SM up to 80 g/kg lowered slaughter weights, which could be due high dietary fibre and the possible interference of seaweed secondary metabolites that restrict muscular development. These results corroborate those of Subakir et al. [41] who observed poor body weights in broilers raised on a diet containing 100 g/kg brown seaweed (*Sargassum polycystum*). The presence of phlorotannins in the seaweed could have interfered with protein utilisation and, as a result, suppress muscle development in the birds. Nonetheless, no diet-induced effects were recorded on carcass yield, carcass cuts and visceral organ sizes of the Jumbo quail. Similarly, El-Deek and Brikaa [42] found that feeding a diet diluted with 150 g/kg red seaweed had no effect on relative dressing weight, thigh, breast muscles, liver, and gizzards in finisher ducks. This is further supported by the findings of Abu Hafsa et al. [43], who found no dietary effects on relative weights of internal organs in laying Japanese quail fed with diets containing 30 g/kg brown and 15 g/kg green seaweed. Contrarily, an increase in cecum weights in layer hens and slow-growing chickens reared on seaweed-containing diets was reported by Nhlane et al. [7] and Kulshreshtha et al. [38], which was explained to be an anatomical adaptation to high dietary fibre levels in SM. Abu Hafsa and Hassan [44] also reported heaviest small and large intestine weights as well as the longest small intestine and caecal length when Japanese quail were offered diets contain 20 g/kg of brown seaweed (*Sargassum siliquastrum*). Thus, the lack of dietary effect on the sizes of small and large intestines was surprising because the birds fed with the highest inclusion levels of SM were anticipated to have larger intestinal sizes as an anatomical adaptation to cope with high dietary fibre levels.

Meat quality attributes have a huge impact on consumers' decision to purchase meat or meat products [45]. Moreover, properties such as meat colour, pH, WHC, cook loss, and juiciness are essential for meat processors to manufacture value-added meat products of exceptional quality and profitability [46]. In this study, dietary SM levels had no linear and quadratic effects on all meat quality parameters, indicating that the inclusion of green SM does not improve quail meat quality. This is despite the fact that seaweeds contain amino acids, minerals, pigments, and natural antioxidants such as carotenoids, flavonoids, vitamins A, C and E [40], which have the potential to positively influence meat colour or pigmentation, shelf-life, abdominal fat, WHC and cooking loss, while also reducing lipid peroxidation [28,47,48]. In a similar study, Matshogo et al. [31] found that green seaweeds have no impact on meat pH, colour, temperature, cooking loss and WHC in Cobb broilers. Moreover, Bonos et al. [49] observed no improvement on meat oxidative stability from chickens fed diets containing up to 20 g/kg brown seaweed (*Ascophyllum nodusum*). Considering the colour classification guidelines and the meat pH range (5.3–6.5) reported by Hertanto et al. [50], the meat colour and pH values measured at 24 h post-mortem were within the normal range in the current study. This further indicates that dietary SM does not alter meat quality traits in Jumbo quail.

5. Conclusion

The inclusion of green seaweed meal up to 80 g/kg in diets of Jumbo quail compromised gain-to-feed ratio and slaughter weights but not serum biochemical and haematological parameters, internal organ sizes, and carcass and meat quality traits. Future studies can be conducted to enhance the utilisation of seaweed meal using either physical, chemical, or biological methods prior to its inclusion in Jumbo quail diets.

Author contribution statement

Mveleli Marareni; Godfrey Mhlongo: Performed the experiments; Analysed and interpreted the data; Wrote the paper.

Caven Mguvane Mnisi: Conceived and designed the experiments; Analysed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

Declaration of competing interest

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

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References

[1] A. Jeke, C. Phiri, K. Chitindingu, P. Taru, F. Yildiz, Ethnomedicinal use and pharmacological potential of Japanese quail (*Coturnix coturnix japonica*) birds' meat and eggs, and its potential implications on wild quail conservation in Zimbabwe: a review, Cogent Food Agric. 4 (2018), 1507305, https://doi.org/10.1080/23311932.2018.1507305.

[2] M. Marareni, C.M. Mnisi, Growth performance, serum biochemistry and meat quality traits of Jumbo quails fed with mopane worm (*Imbrasia belina*) meal-containing diets, Vet. Anim. Sci. 10 (2020), 100141, https://doi.org/10.1016/j.vas.2020.100141.

[3] T.I. Masenya, V. Mlambo, C.M. Mnisi, Complete replacement of maize grain with sorghum and pearl millet grains in Jumbo quail diets: feed intake, physiological parameters, and meat quality traits, PLoS One 16 (2021) 1–13, https://doi.org/10.1371/journal.pone.0249371.

[4] N. Nalluri, V.R. Karri, Grain legumes and their by-products: as a nutrient rich feed supplement in the sustainable intensification of commercial poultry industry, in: P. Guleria, V. Kumar, E. Lichtfouse (Eds.), Sustainable Agriculture Reviews 51. Sustain. Agric. Rev., vol. 51, 2021, pp. 51–96, https://doi.org/10.1007/978-3-030-68828-8_3.

[5] M.R. Rahman, I. Fliss, E. Biron, Insights in the development and uses of alternatives to antibiotic growth promoters in poultry and swine production, Antibiotics 11 (2022) 766, https://doi.org/10.3390/antibiotics11060766.

[6] P.C. Gorain, S. Sengupta, G.G. Satpati, I. Paul, S. Tripathi, R. Pal, Carbon sequestration in macroalgal mats of brackish-water habitats in Indian Sunderbans: potential as renewable organic resource, Sci. Total Environ. 626 (2018) 689–702, https://doi.org/10.1016/j.scitotenv.2018.01.106.

[7] L.T. Nhlane, C.M. Mnisi, V. Mlambo, M.J. Madibana, Effect of seaweed-containing diets on visceral organ sizes, carcass characteristics, and meat quality and stability of Boschveld indigenous hens, Poultry Sci. 100 (2021) 949–956, https://doi.org/10.1016/j.psj.2020.11.038.

[8] E. da Costa, F. Ricardo, T. Melo, R. Mamede, M.H. Abreu, P. Domingues, M.R. Domingues, R. Calado, Site-specific lipidomic signatures of sea lettuce (*Ulva* spp., chlorophyta) holds the potential to trace their geographic origin, Biomolecules 10 (2020) 489, https://doi.org/10.3390/biom10030489.

[9] A.G. Gutiérrez-Rodríguez, C. Juárez-Portilla, T. Olivares-Bañuelos, R.C. Zepeda, Anticancer activity of seaweeds, Drug Discov. Today 23 (2018) 434–447, https://doi.org/10.1016/j.drudis.2017.10.019.

[10] I. Michalak, K. Mahrose, Seaweeds, intact and processed, as a valuable component of poultry feeds, J. Mar. Sci. Eng. 8 (2020) 620, https://doi.org/10.3390/JMSE8080620.

[11] R. Peñalver, J.M. Lorenzo, G. Ros, R. Amarowicz, M. Pateiro, G. Nieto, Seaweeds as a functional ingredient for a healthy diet, Mar. Drugs 18 (2020) 1–27, https://doi.org/10.3390/md18060301.

[12] L.W. Lu, J.H. Chen, Seaweeds as ingredients to lower glycemic potency of cereal foods synergistically a perspective, Foods 11 (2022) 1–24, https://doi.org/10.3390/foods11050714.

[13] D. Resiere, H. Mehdaoui, J. Florentin, P. Gueye, T. Lebrun, A. Blateau, J. Viguier, R. Valentino, Y. Brouste, H. Kallel, B. Megarbane, A. Cabie, R. Banydeen, R. Neviere, Sargassum seaweed health menace in the Caribbean: clinical characteristics of a population exposed to hydrogen sulfide during the 2018 massive stranding, Clin. Toxicol. 59 (2020) 215–223, https://doi.org/10.1080/15563650.2020.1789162.

[14] S. Cofrades, J. Benedí, A. Garcimartin, F.J. Sánchez-Muniz, F. Jimenez-Colmenero, A comprehensive approach to formulation of seaweed-enriched meat products: from technological development to assessment of healthy properties, Food Res. Int. 99 (2017) 1084–1094, https://doi.org/10.1016/j.foodres.2016.06.029.

[15] S. Roohinejad, M. Koubaa, F.J. Barba, S. Saljoughian, M. Amid, R. Greiner, Application of seaweeds to develop new food products with enhanced shelf-life, quality and health-related beneficial properties, Food Res. Int. 99 (2017) 1066–1083, https://doi.org/10.1016/j.foodres.2016.08.016.

[16] AOAC, Official Methods of Analysis of AOAC International, sixteenth ed., Association of Official Analytical Chemists, Arlington, VA, USA, 2005.

[17] P.V. Van Soest, J.B. Robertson, B.A. Lewis, Methods for dietary fibre, neutral detergent fibre, and non-starch polysaccharides in relation to animal nutrition, J. Dairy Sci. 74 (1991) 3583–3597, https://doi.org/10.3168/jds.S0022-0302(91)78551-2.

[18] K.J. Carpenter, K.M. Clegg, The metabolizable energy of poultry feeding stuffs in relation to their chemical composition, J. Sci. Food Agric. 7 (1956) 45–51, https://doi.org/10.1002/jsfa.2740070109.

[19] National Research Council (NRC), Nutrient Requirements of Poultry, ninth ed., National Academy Press, Washington DC, USA, 1994.

[20] I.M. Washington, G. van Hoosier, Clinical Biochemistry and Haematology, University of Washington, Seattle, WA, USA, 2012, pp. 59–91.

[21] CIE, Recommendations on Uniform Colour Spaces-Colour Difference Equations, Psychometric Colour Terms. Commission Internationale de l'Eclairage, Paris, France, Supplement No. 2 to CIE Publication No. 15 (E-1.3.1.) 1978, 1971/(TC-1-3), 1976.

[22] A. Priolo, D. Micol, J. Agabriel, S. Prache, E. Dransfield, Effect of grass or concentrate feeding systems on lamb carcass and meat quality, Meat Sci. 62 (2002) 179–185, https://doi.org/10.1016/S0309-1740(01)00244-3.

[23] K.O. Honikel, Reference methods for the assessment of physical characteristics of meat, Meat Sci.. 49 (998) 447–470 https://doi.org/10.1016/S0309-1740(98)00034-5.

[24] A. Mulaudzi, C.M. Mnisi, V. Mlambo, Dietary *Moringa oleifera* leaf meal improves growth performance but not haemo-biochemical and meat quality parameters in female Japanese quails, Pakistan J. Nutr. 18 (2019) 953–960, https://doi.org/10.3923/pjn.2019.953.960.

[25] SAS, Statistical Analysis System Institute Inc. Users Guide, Carry, North California, USA, 2010.

[26] M.A. Al-Harthi, A.A. El-Deek, Effect of different dietary concentrations of brown marine algae (*Sargassum dentifebium*) prepared by different methods on plasma and yolk lipid profiles, yolk total carotene and lutein plus zeaxanthin of laying hens, Ital. J. Anim. Sci. 11 (2012) 347–353, https://doi.org/10.4081/ijas.2012.e64.

[27] Z. Zuprizal, F. Andri, N.D. Dono, H. Sasongko, The effects of dietary seaweed inclusion on growth performance of broiler chickens: A systematic review and meta-analysis, F1000Res. 9 (2020) 1–11, https://doi.org/10.12688/f1000research.25726.1.

[28] A.M. Abudabos, A.B. Okab, R.S. Aljumaah, E.M. Samara, K.A. Abdoun, A.A. Al-Haidary, Nutritional value of green seaweed (*Ulva lactuca*) for broiler chickens, Ital. J. Anim. Sci. 12 (2013) 177–181, https://doi.org/10.4081/ijas.2013.e28.

[29] B. Gullón, M. Gagaoua, F.J. Barba, P. Gullón, W. Zhang, J.M. Lorenzo, Seaweeds as promising resource of bioactive compounds: overview of novel extraction strategies and design of tailored meat products, Trends Food Sci. Technol. 100 (2020) 1–18, https://doi.org/10.1016/j.tifs.2020.03.039.

[30] O.J. Tejeda, W.K. Kim, Role of dietary fiber in poultry nutrition, Animals 11 (2021) 461, https://doi.org/10.3390/ani11020461.

[31] T.B. Matshogo, C.M. Mnisi, V. Mlambo, Dietary green seaweed compromises overall feed conversion efficiency but not blood parameters and meat quality and stability in broiler chickens, Agric. For. 10 (2020) 1–11, https://doi.org/10.3390/agriculture10110547.

[32] R. Jha, P. Mishra, Dietary fiber in poultry nutrition and their effects on nutrient utilization, performance, gut health, and on the environment: a review, J. Anim. Sci. Biotechnol. 12 (2021) 1–16, https://doi.org/10.1186/s40104-021-00576-0.

[33] S. Borzouie, B.M. Rathgeber, C.M. Stupart, J. Macisaac, L.A. Maclaren, Effects of dietary inclusion of seaweed, heat stress and genetic strain on performance, plasma biochemical and hematological parameters in laying hens, Animals 10 (2020) 1570, https://doi.org/10.3390/ani10091570.

[34] A.H.L. Wan, A. Soler-Vila, D. O'Keeffe, P. Casburn, R. Fitzgerald, M.P. Johnson, The inclusion of *Palmaria palmata* macroalgae in Atlantic salmon (*Salmo salar*) diets: effects on growth, haematology, immunity and liver function, J. Appl. Phycol. 28 (2016) 3091–3100, https://doi.org/10.1007/s10811-016-0821-8.

[35] L. Bona, N. van Staaveren, B.B. Pokharel, M. van Krimpen, A. Harlander-Matauschek, The effect of low protein energy-rich diets on plasma hepatic markers, hepatic damage, and discrimination reversal learning in young female chicks, Front. Vet. Sci. 5 (2018) 1–9, https://doi.org/10.3389/fvets.2018.00107.

[36] L. Meunier, D. Larrey, Drug-induced liver injury: biomarkers, requirements, candidates, and validation, Front. Pharmacol. 10 (2019) 1–8, https://doi.org/10.3389/fphar.2019.01482.

[37] H.K. Kang, H.M. Salim, N. Akter, D.W. Kim, J.H. Kim, H.T. Bang, M.J. Kim, J.C. Na, J. Hwangbo, H.C. Choi, O.S. Suh, Effect of various forms of dietary Chlorella supplementation on growth performance, immune characteristics, and intestinal microflora population of broiler chickens, J. Appl. Poultry Res. 22 (2013) 3–108, https://doi.org/10.3382/japr.2012-00622.

[38] G. Kulshreshtha, B. Rathgeber, G. Stratton, N. Thomas, F. Evans, A. Critchley, J. Hafting, B. Prithiviraj, Immunology, health, and disease: feed supplementation with red seaweeds, Chondrus crispus and Sarcodiotheca gaudichaudii, affects performance, egg quality, and gut microbiota of layer hens, Poultry Sci. 93 (2014) 2991–3001, https://doi.org/10.3382/ps.2014-04200.

[39] F.M. Reda, M.S. El-Kholy, M.E. Abd El-Hack, A.E. Taha, S.I. Othman, A.A. Allam, M. Alagawany, Does the use of different oil sources in quail diets impact their productive and reproductive performance, egg quality, and blood constituents? Poultry Sci. 99 (2020) 3511–3518, https://doi.org/10.1016/j.psj.2020.03.054.

[40] I. Michalak, R. Tiwari, M. Dhawan, M. Alagawany, M.R. Farag, K. Sharun, T. Bin Emran, K. Dhama, Antioxidant effects of seaweeds and their active compounds on animal health and production a review, Vet. Q. 42 (2022) 48–67, https://doi.org/10.1080/01652176.2022.2061744.

[41] F.N.M. Subakir, N.I. Ishak, A.N. Samah, K.A.A. Aziz, N. Zaharudin, The effects of seaweed-based pellet binders on growth performance, feed efficiency and carcass characteristics in broilers, Anim. Feed Sci. Technol. 272 (2021), 114786, https://doi.org/10.1016/j.anifeedsci.2020.114786.

[42] A.A. El-Deek, A.M. Brikaa, Effect of different levels of seaweed in starter and finisher diets in pellet and mash form on performance and carcass quality of ducks, Int. J. Poultry Sci. 8 (2009) 1014–1021, https://doi.org/10.3923/ijps.2009.1014.1021.

[43] S.H. Abu Hafsa, H.S. Zeweil, H.S. Zahran, M.H. Ahmed, W. Dosoky, N.A. Rwif, Effect of dietary supplementation with green and brown seaweeds on laying performance, egg quality, blood lipid profile and antioxidant capacity in Japanese quail, Egypt, Poultry Sci. J. 39 (2019) 45–59, https://doi.org/10.21608/epsj.2019.28828.

[44] S.H. Abu Hafsa, A.A. Hassan, The effect of *Sargassum siliquastrum* supplementation on growth performance, cecal fermentation, intestine histomorphology, and immune response of Japanese quails, Animals 12 (2022) 432, https://doi.org/10.3390/ani12040432.

[45] N.A. Mir, A. Rafiq, F. Kumar, V. Singh, V. Shukla, Determinants of broiler chicken meat quality and factors affecting them: a review, J. Food Sci. Technol. 54 (2017) 2997–3009, https://doi.org/10.1007/s13197-017-2789-z.

[46] E.O.S. Hussein, G.M. Suliman, A.N. Al-Owaimer, S.H. Ahmed, A.M. Abudabos, M.E. Abd El-Hack, A.E. Taha, I.M. Saadeldin, A.A. Swelum, Effects of stock, sex, and muscle type on carcass characteristics and meat quality attributes of parent broiler breeders and broiler chickens, Poultry Sci. 98 (2019) 6586–6592, https://doi.org/10.3382/ps/pez464.

[47] H. Tomida, T. Yasufuku, T. Fujii, Y. Kondo, T. Kai, M. Anraku, Polysaccharides as potential antioxidative compounds for extended-release matrix tablets, Carbohydr. Res. 345 (2010) 82–86, https://doi.org/10.1016/j.carres.2009.10.015.

[48] M. Costa, C. Cardoso, C. Afonso, N.M. Bandarra, J.A.M. Prates, Current knowledge and future perspectives of the use of seaweeds for livestock production and meat quality: a systematic review, J. Anim. Physiol. Anim. Nutr. 105 (2021) 1075–1102, https://doi.org/10.1111/jpn.13509.

[49] E. Bonos, A. Kargopoulos, I. Nikolakakis, P. Florou Paneri, E. Christaki, The seaweed *Ascophyllum nodosum* as a potential functional ingredient in chicken nutrition, J. Oceanogr. Mar. Res. 4 (2017) 1–5, https://doi.org/10.4172/2572-3103.1000140.

[50] B.S. Hertanto, C.D.A. Nurmalasari, A.M.P. Nuhriawangsa, M. Cahyadi, L.R. Kartikasari, The physical and microbiological quality of chicken meat in the different type of enterprise poultry slaughterhouse: a case study in Karanganyar District, IOP Conf. Ser. Earth Environ. Sci. 102 (2018), 012051.